

A Thesis Submitted for the Degree of PhD at the University of Warwick

Permanent WRAP URL:

<http://wrap.warwick.ac.uk/106784>

Copyright and reuse:

This thesis is made available online and is protected by original copyright.

Please scroll down to view the document itself.

Please refer to the repository record for this item for information to help you to cite it.

Our policy information is available from the repository home page.

For more information, please contact the WRAP Team at: wrap@warwick.ac.uk

**REPRODUCED
FROM THE
BEST
AVAILABLE
COPY**

THE MEMORY REPRESENTATION AND REHEARSAL
OF A PERCEPTUAL-MOTOR SKILL

Peter Johnson, B.Sc.

Submitted for the degree of Doctor of Philosophy to the University
of Warwick. This research was carried out in the Department of
Psychology between 1st October 1978 and 30th September 1981.

Date of submission, February 1982.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	xiv
SHORT ABSTRACT	xvi
LONG ABSTRACT	xvii

CHAPTER ONE

Memory Rehearsal and Perceptual Motor Skill: An Introduction	1
1.1 A Cognitive Approach	1
1.2 Linear Positioning Tasks	5
1.3 An Outline of the Present Research	9

CHAPTER TWO

Mental Practice	13
2.1 The Equivalence of MP and Actual Practice	14
2.1.1 Criteria of Acceptability	15
2.1.2 Comparisons not Studies	16
2.1.3 Types of Comparisons	17
2.1.4 Empirical Evidence for a Strong and a Weak Hypothesis	19
2.1.5 Summary of the Comparisons involving MP	21
2.2 Procedures and Applications of MP	22
2.2.1 Types of Cues used in MP	22
2.2.2 Amount and Type of Training	29
2.2.3 Types of Tasks in which MP has been used	34
2.2.4 Summary of Procedures and Applications	40

2.3	Theories and Hypotheses of Mental Practice	41
2.3.1	Motivational Hypothesis	42
2.3.2	Trace Consolidation Hypothesis	42
2.3.3	Symbolic Learning Hypothesis	43
2.3.4	The Symbolic Perceptual Hypothesis	44
2.3.5	The Psychoncuromuscular Hypothesis	45
2.3.6	The Spaced Practice Hypothesis	46
2.3.7	Selective Attention Hypothesis	47
2.3.8	Summary of Mental Practice Hypotheses	48

CHAPTER THREE

	Mental Imagery	50
3.1	Imagery before Behaviourism	53
3.2	Early Psychological Approaches	54
3.2.1	Subjective Questionnaire	55
3.2.2	Objective Assessment	56
3.3	Imagery and Behaviourism	59
3.4	Quantative and Subjective Investigations	60
3.5	Objoective Investigations	64
3.5.1	Interference Techniques	64
3.5.2	Chronometric Analysis	68
3.5.3	A Summary of the Investigation of Imagery after Behaviourism	75

3.6	Theories of Mental Imagery	78
3.6.1	Paivio's Dual Coding Model	78
3.6.2	Kosslyn's CRT Model	81
3.6.3	Neisser's Model of Mental Imagery	84
3.6.4	Motor Theories of Mental Imagery	88
3.6.5	Propositional Accounts of Mental Imagery	90
3.7	Mental Imagery - Some Conclusions	92

CHAPTER FOUR

The Functional Equivalence of Images of Movements and Movements

4.1	Experiment I	100
4.1.1	Method	101
4.1.2	Interpolated Activities	104
4.1.3	Results	106
4.1.4	Discussion	119
4.2	Movement Imagery and Movement Production	120

CHAPTER FIVE

	Images of Movement and the Motor Production System	124
5.1	An Interference Paradigm	126
5.2	Experiment II	128
5.2.1	Method	129
5.2.2	Interpolated Activities	131

5.2.3	Results	133
5.2.4	Discussion	145
5.3	Summary	151

CHAPTER SIX

A Further Test of the Psychoneuromuscular Hypothesis		153
6.1	Experiment III	155
6.1.1	Method	155
6.1.2	Interpolated Activities	158
6.1.3	Results	160
6.1.4	Discussion	172
6.2	Some Conclusions on Imagery and the Psychoneuromuscular Hypothesis	173

CHAPTER SEVEN

Subvocal Rehearsal and Processing Load		176
7.1	Experiment IV	177
7.1.1	Method	177
7.1.2	Interference Tasks	179
7.1.3	Results	180
7.1.4	Discussion	192
7.2	Summary and Conclusions	194

CHAPTER EIGHT

Distinctions between Visual and Spatial Processing 197

8.1 Experiment V 198

8.1.1 Method 199

8.1.2 Interference Tasks 201

8.1.3 Results 202

8.1.4 Discussion 213

8.2 Summary and Conclusions 213

CHAPTER NINE

Further Distinctions between Spatial and Non-Spatial Processes in Images of Linear Positioning Movements 216

9.1 Experiment VI 217

9.1.1 Method 218

9.1.2 Interference Tasks 220

9.1.3 Results 222

9.1.4 Discussion 238

9.2 Summary and Conclusions 239

CHAPTER TEN

Relationships between Imagery and Memory for Linear Positioning Movements 242

10.1 Experiment VII 243

10.1.1 Method 244

10.1.2	Results	245
10.1.3	Discussion	255
10.2	Summary and Conclusions	260

CHAPTER ELEVEN

	Imagery Effects in a Pressure Learning Task	263
11.1	Experiment VIII	264
11.1.1	Method	265
11.1.2	Intervening Tasks	267
11.1.3	Results	268
11.1.4	Discussion	278
11.2	Some Conclusions on Images and Motor Acts	280

CHAPTER TWELVE

	Memory, Rehearsal and Perceptual Motor Skill:	
	Conclusions, Positions and Directions	283
12.1	Conclusions from the Present Study	283
12.2	A Position for Imagery in Skill and Cognition	287
12.3	Future Directions	302
	BIBLIOGRAPHY	310
	APPENDIX A	324
	APPENDIX B	330

APPENDIX C	331
APPENDIX D	333
APPENDIX E	335
APPENDIX F	337
APPENDIX G	339
APPENDIX H	341
APPENDIX I	343
APPENDIX J	345

TABLES

2.1	Analysis of cues present during MP	24
2.2	Analysis of type and amount of prior training	30
2.3	Classification of tasks according to their major components	36
2.4	Analysis of type of task and the effects of MP	38
4.1	Experiment I. Mean CE and VE	108
4.2	Experiment I. ANOVA summary, VE	108
4.3	Experiment I. Contrasting means, VE	110
4.4	Experiment I. ANOVA summary, CE	112
4.5	Experiment I. Decomposition of the interaction effect, CE	113
4.6	Experiment I. Regression analysis	118
5.1	Experiment II. Mean CE and VE	134
5.2	Experiment II. ANOVA summary, CE	135
5.3	Experiment II. Contrasting means, CE	136
5.4	Experiment II. ANOVA summary, VE	139
5.5	Experiment II. Contrasting means, VE	140
5.6	Experiment II. Two-way ANOVA summary, CE	142
5.7	Experiment II. Decomposition of interaction effect, CE	143
5.8	Experiment II. Two-way ANOVA summary, VE	146
5.9	Experiment II. Regression analysis	148
6.1	Experiment III. Mean CE and VE	161
6.2	Experiment III. ANOVA summary, CE	162
6.3	Experiment III. Decomposition of interaction effect, CE	163
6.4	Experiment III. ANOVA summary, VE	166
6.5	Experiment III. Contrasting means, VE	167
6.6	Experiment III. Regression analysis	169
7.1	Experiment IV. Mean CE and VE	181

7.2	Experiment IV. ANOVA summary, CE	182
7.3	Experiment IV. Contrasting means, CE	183
7.4	Experiment IV. ANOVA summary, VE	186
7.5	Experiment IV. Decomposition of interaction effect, VE	187
7.6	Experiment IV. Regression analysis	189
8.1	Experiment V. Mean CE and VE	203
8.2	Experiment V. ANOVA summary, CE	205
8.3	Experiment V. ANOVA summary, VE	207
8.4	Experiment V. Decomposition of interaction effect, VE	208
8.5	Experiment V. Regression analysis	210
9.1	Experiment VI. Mean CE and VE	223
9.2	Experiment VI. ANOVA summary, CE	224
9.3	Experiment VI. ANOVA summary, VE	227
9.4	Experiment VI. Completion time and errors on maze	229
9.5	Experiment VI. ANOVA summary, errors on maze	230
9.6	Experiment VI. ANOVA summary, time on maze	233
9.7	Experiment VI. Regression analysis	235
10.1	Experiment VII. Mean CE and VE	246
10.2	Experiment VII. ANOVA summary, CE	247
10.3	Experiment VII. ANOVA summary, VE	250
10.4	Experiment VII. Completion time and errors on maze	252
10.5	Experiment VII. ANOVA summary, time on maze	253
10.6	Experiment VII. ANOVA summary, errors on maze	256
10.7	Experiment VII. Regression analysis	258
11.1	Experiment VIII. Mean CE and VE	269
11.2	Experiment VIII. ANOVA summary, CE	270
11.3	Experiment VIII. Contrasting means, CE	272
11.4	Experiment VIII. ANOVA summary, VE	274
11.5	Experiment VIII. Contrasting means, VE	275
12.1	A set of productions for fastening two plates together	297

7.2	Experiment IV. ANOVA summary, CE	182
7.3	Experiment IV. Contrasting means, CE	183
7.4	Experiment IV. ANOVA summary, VE	186
7.5	Experiment IV. Decomposition of interaction effect, VE	187
7.6	Experiment IV. Regression analysis	189
8.1	Experiment V. Mean CE and VE	203
8.2	Experiment V. ANOVA summary, CE	205
8.3	Experiment V. ANOVA summary, VE	207
8.4	Experiment V. Decomposition of interaction effect, VE	208
8.5	Experiment V. Regression analysis	210
9.1	Experiment VI. Mean CE and VE	223
9.2	Experiment VI. ANOVA summary, CE	224
9.3	Experiment VI. ANOVA summary, VE	227
9.4	Experiment VI. Completion time and errors on maze	229
9.5	Experiment VI. ANOVA summary, errors on maze	230
9.6	Experiment VI. ANOVA summary, time on maze	233
9.7	Experiment VI. Regression analysis	235
10.1	Experiment VII. Mean CE and VE	246
10.2	Experiment VII. ANOVA summary, CE	247
10.3	Experiment VII. ANOVA summary, VE	250
10.4	Experiment VII. Completion time and errors on maze	252
10.5	Experiment VII. ANOVA summary, time on maze	253
10.6	Experiment VII. ANOVA summary, errors on maze	256
10.7	Experiment VII. Regression analysis	258
11.1	Experiment VIII. Mean CE and VE	269
11.2	Experiment VIII. ANOVA summary, CE	270
11.3	Experiment VIII. Contrasting means, CE	272
11.4	Experiment VIII. ANOVA summary, VE	274
11.5	Experiment VIII. Contrasting means, VE	275
12.1	A set of productions for fastening two plates together	297

FIGURES

3.1	Brooks' 'F' test	65
3.2	Paivio's dual coding model	80
3.3	Neisser's perceptual cycle	86
4.1	Basic apparatus	103
4.2	Experiment I. Mean VE	111
4.3	Experiment I. Mean CE	114
4.4	Experiment I. Mean error over recall trials (30 cms)	116
4.5	Experiment I. Mean error over recall trials (60 cms)	117
5.1	Experiment II. Mean CE	137
5.2	Experiment II. Mean VE	141
5.3	Experiment II. Visual and motor interference, CE	144
5.4	Experiment II. Visual and motor interference, VE	147
6.1	Experiment III. Apparatus used in Experiment III and subsequent experiments	157
6.2	Experiment III. Mean CE	164
6.3	Experiment III. Mean VE	168
6.4	Experiment III. Mean error over recall trials (60 cms)	170
6.5	Experiment III. Mean error over recall trials (30 cms)	171
7.1	Experiment IV. Mean CE	184
7.2	Experiment IV. Mean VE	188
7.3	Experiment IV. Mean error over recall trials (response)	190
7.4	Experiment IV. Mean error over recall trials (no response)	191
8.1	Experiment V. Additional apparatus used for Experiment V	200
8.2	Experiment V. Mean CE	206
8.3	Experiment V. Mean VE	209
8.4	Experiment V. Mean error over recall trials (spatial)	211
8.5	Experiment V. Mean error over recall trials (non-spatial)	213

9.1	Maze used in Experiment VI and VII	221
9.2	Experiment VI. Mean CE	225
9.3	Experiment VI. Mean VE	228
9.4	Experiment VI. Mean error on maze	231
9.5	Experiment VI. Mean time on maze	234
9.6	Experiment VI. Mean error over recall trials (spatial)	236
9.7	Experiment VI. Mean error over recall trials (non-spatial)	237
10.1	Experiment VII. Mean CE	248
10.2	Experiment VII. Mean VE	251
10.3	Experiment VII. Mean time on maze	254
10.4	Experiment VII. Mean error on maze	257
11.1	Experiment VIII. Pressure recording apparatus used in Experiment VIII.	266
11.2	Experiment VIII. Mean CE	273
11.3	Experiment VIII. Mean VE	276
11.4	Experiment VIII. Mean error over recall trials	277
12.1	Turvey's coalition model	291
12.2	Schmidt's recall and recognition schema	295

ABBREVIATIONS

AMP	-	Actual followed by Mental Practice
ANOVA	-	Analysis of Variance
ANS	-	Auditory non-Spatial
AP	-	Actual Practice
AS	-	Auditory Spatial
CB	-	Counting Backwards
CE	-	Constant Error
cm	-	Centimetre
df	-	degrees of freedom
E.M.G.	-	Electro-Myographic
I	-	Imagery
Kg	-	Kilogram
KR	-	Knowledge of Results
M	-	Motor
MAP	-	Mental followed by Actual Practice
MNR	-	Motor No Response
MNS	-	Motor non-Spatial
MP	-	Mental Practice
MR	-	Motor Response
MS	-	Motor Spatial
Ms	-	Mean Square
NAM	-	Novel Actual Movement
NIM	-	Novel Imaginary Movement
NIMM	-	Novel Imaginary Movement with Motor Interference
NIMV	-	Novel Imaginary Movement with Visual Interference
NP	-	No Practice
NR	-	No Response

NS	-	Not Significant
OBS	-	Observational Learning
P	-	Produce
Pr	-	Probability
R	-	Response
RT	-	Reaction Time
So	-	Standard error
Sec	-	Second
SIM	-	Imagery of Movement of the same extent
SS	-	Sum of Squares
V	-	Visual
VCI	-	Vivid Controllable Imagery
VE	-	Variable Error
Verb	-	Verbal
Verb NR	-	Verbal No Response
Verb R	-	Verbal Response
VNR	-	Visual No Response
VNS	-	Visual non-Spatial
VR	-	Visual Response
VS	-	Visual Spatial
VUI	-	Vivid Uncontrollable Imagery
WCI	-	Weak Controllable Imagery
WUI	-	Weak Uncontrollable Imagery
χ	-	Intercept Coefficient
β	-	Slope Coefficient
\bar{x}	-	Mean

ACKNOWLEDGEMENTS

The ideas and work contained within this thesis have been affected by my interactions with a wide number of people. I gratefully acknowledge their help and absolve them of any responsibility for the final product. I should like to thank the S.S.R.C. for their support in providing me with a linked studentship to carry out my research. The guidance and understanding provided by my supervisor, Professor John Annett, has been greatly appreciated. His readiness to listen to my ideas never faltered and the encouragement and support he has given me were warmly welcomed.

The staff of the Psychology Department at Warwick University were often responsible for provoking my thoughts in many directions. The stimulating environment created by them was a constant source of interest for me. The skills research group and June Fotheringham in particular provided me with a critical but appreciative audience on numerous occasions. Much of this work would have been impossible without the technical staff who assisted in the construction of the experimental apparatus.

My postgraduate colleagues often provided arguments, ideas and coffee, all of which was needed and welcomed.

The mammoth task of typing this thesis was painstakingly carried out by Joyce Beasley and the skilful artwork was provided by Les Prince.

Finally, my greatest debt is owed to Hilary, who is not only

my most severe critic, but also a constant support, often putting my work before her own.

Declaration

The work contained within this thesis contains no material which has been used before and is the sole work of the author.

SHORT ABSTRACT - SUMMARY

This thesis presents an investigation of cognitive aspects of a perceptual motor skill. In particular the relationship between covert rehearsal (mental practice), imagery and memory is considered. An analysis of past studies of mental practice suggested that some form of imagery is used by subjects to mentally rehearse certain aspects of various tasks. It appears that mental practice produces relatively consistent performance improvements in tasks which are predominantly perceptual or motor in nature, rather than symbolic. Two different types of imagery have been suggested; one based on the visual/perceptual system, the other based on the motor system. A review of the mental imagery literature considered the various methods of investigating imagery and outlined several hypothetical models of mental imagery. It was concluded that selective interference techniques offered the greatest potential for investigating mental imagery, as might be employed in mental practice procedures.

A technique for investigating mental imagery was derived from a recent study by Finke (1979) in which the functional equivalence between images and actions was inferred from the presence or absence of imagery induced biasing or after-effects. The present research used a linear positioning task, with novel movements interpolated between the learning and recall of a standard movement as the basic perceptual-motor task to be investigated. In past research such tasks have been shown to be biased by characteristics of the interpolated movement. It was hypothesised that if imagery of movements and movements were functionally equivalent, then biasing errors produced by making a novel interpolated movement should also be present with instructions to imagine but not execute such a movement. The results showed that instructions to execute or imagine linear movements produced similar effects on subjects' memory for other linear movements. A series of five further experiments then investigated the nature of imagery used in this task, by means of a selective interference paradigm, used to suppress any imagery effects. The results of these experiments suggested that this type of imagery primarily involved a spatial information processing system. The seventh experiment investigated the relationship between images of linear movements and subjects' memory for such movements. It was found that tasks which suppressed images also interfered with subjects' memory for linear movements. It was concluded from this that subjects' images of linear movements and their memory for that class of movement primarily involved the representation of spatial information. The final experiment investigated the effects of instructions to form images of a non-spatial task on subjects' memory for a similar non-spatial task. Instructions to imagine a novel pressure, interpolated between the learning and recall of a standard pressure, failed to produce a predicted biasing effect. However, it appeared, from subjective reports, that subjects were generating spatial images which had little or no significant effect on how the task had been remembered.

This research shows that imagery of linear movements involves a spatial information processing system and that even in a task with little spatial informational content it is the spatial aspects of the tasks which are reported in subjects' imagery. It is suggested that this may reflect the importance of spatial information in action control. Mental practice appears to be a procedure in which subjects use images consisting largely of spatial information to represent the environmental conditions for and consequences of action.

LONG ABSTRACT

Briefly this research has focused on the cognitive processes involved in learning a simple perceptual motor skill. These cognitive processes are highlighted in the relationship between memory and rehearsal. Rehearsal can be thought of as a continuum of procedures with overt rehearsal, in the form of actual practice at one end and covert rehearsal, in the form of mental practice at the other. Actual practice procedures are well covered in the psychological literature on training, while mental practice (MP) has not attracted much interest from psychologists. If one can assume that the effects of rehearsal occur within memory, then it is impossible to distinguish the effects of rehearsal procedures without identifying memory representations. A full explanation of the rehearsal of motor acts must include an understanding of how those acts are represented in memory.

A review of the mental practice literature revealed improvements in performance, in terms of reduced errors and increased speed which occur in a variety of tasks following MP instructions. When comparisons are made between MP, actual practice and no practice groups, it seems that MP consistently produces more improvements than no practice groups, but only occasionally are those improvements greater than actual practice groups. Further analysis of this literature revealed that MP has been applied to a variety of tasks under a variety of conditions.

An early hypothesis of MP, Norrisott (1956), suggested that MP would be best suited to "symbolic" tasks, or those which were sequential and highly verbalised. The current review included a

classification of tasks based on Morrisett's definitions, in terms of their "symbolic", "perceptual" and motor components. It appears that, contrary to earlier claims, MP produces improvements in performance most consistently with motor and perceptual tasks rather than symbolic tasks.

Another dimension of this review considered the amount and type of prior training which subjects had prior to the MP condition, compared with no practice and actual practice conditions. The set of types and amounts of practice included no prior training, 14 trials or less on the task itself, 15 or more trials on the task itself or prior training on some other task. Of these, 14 trials or less on the task itself resulted in the most consistent improvements in performance with MP. While MP still produced a high proportion of improvements following more than 15 trials of prior training, the increased amounts of prior training had no additional benefits for MP.

Possibly the most important finding to emerge from this review was the inclusion of "cues" to aid MP. It seems that when subjects are told to "think about" or "imagine" performing the task they are rarely left with no "cues" to aid this procedure. In fact the MP sessions were most often structured in specific ways, with particular cues being provided by the experimenter. These cues were either visual, such as the apparatus; verbal instructions presented either as written or spoken lists of procedures; action cues, in which the subject is required to produce certain movements which are schematic of those required in the actual task; or no cues at all. Mental practice consistently produces a higher proportion of improvements when visual cues are provided during the practice session.

The existing hypotheses of MP are vague and in some cases untestable but there is some consensus within the literature that a form of "imagery" is used by subjects to aid their MP. It seems that mental imagery is a fundamental process in mental practice and that this imagery process has important consequences for skill acquisition. What is not clear from the existing literature is the nature of mental imagery in perceptual motor skills.

A review of the mental imagery literature showed that very little attention had been given to imagery as an aspect of MP. The main focus of this literature is towards "visual" imagery. However, there has been a sufficient variety of investigations to allow some evaluation of the various experimental techniques to be made. These techniques include, introspective analysis, questionnaires, reaction times or chronometric analysis and selective interference. It was felt that selective interference techniques offered the most "power" in terms of identifying psychological processes. The main assumption of interference techniques being that tasks which interfere with performance compete for some common resource. Of course it could be argued that interference is caused by a general capacity loading. Therefore one of the aims of this research was to show that selective interference techniques can be successfully employed to identify underlying cognitive processes.

With the benefits of those reviews of MP and mental imagery, a series of experiments was designed to explore the nature of imagery in MP on a perceptual motor task. The foremost problem for this research was to find a suitable task which would give evidence of a subject's use of mental imagery. A series of experiments by Finke (1979)

had previously shown that instructions to imagine pointing and the effects of pointing at a target while wearing goggles fitted with displacing prisms and pointing at a target produced systematic biasing of subsequent pointing.

Biasing effects have also been found with linear positioning tasks in which subjects are required to learn a movement along a track by sliding a cursor to a predetermined stop. If the subject is required to first learn one movement, and then, during a retention interval, to produce a movement of a different extent to a different location along the track, their recall of the learned movement is biased towards the interpolated movement; this is known as the "interpolation effect". Assuming that images of movements can produce performance effects then one might expect similar biasing or interpolation effects when the interpolated movement is imagined. This research made use of this technique to investigate mental imagery and what follows is a brief summary of the eight experiments carried out.

Experiment I was designed to investigate the equivalence of linear positioning movements and instructions to imagine linear positioning movements. By comparing the biasing effects produced by imagining novel interpolated movements and the actual production of interpolated movements it was possible to investigate their equivalence. Controls in which subjects either counted backwards in threes, or imagined the same movement they had previously learned were also included during the retention interval. It was found that imagery of linear positioning movements is functionally equivalent, in terms of its biasing effect to producing linear positioning movements. Imagery is different from producing linear movements though, in that the sub-

sequent recall contained less variability. Furthermore imagining the same movement further reduces the variability in motor memory. Thus imagery operates on the memory trace of a linear positioning movement. In the case of imagining a novel movement this can have a biasing effect on motor performance. When subjects are instructed to imagine the same movement then a consolidation of the memory trace occurs. This suggests that the imagery process involves manipulation of perceptual representations in memory rather than activation of the motor production systems.

Experiment II was aimed at investigating the nature of mental imagery by using a selective interference paradigm to suppress the previously observed imagery produced biasing effect. This experiment used the previously established interpolation effect for imagery instructions, with the addition of various interference stimuli which occurred while subjects were attempting to carry out imagery instructions. The interference stimuli were either visual or motor; visual interference consisted of inspecting an XY display monitor and motor interference required subjects to squeeze a hand held dynamometer. The results were that the visual/spatial interference stimulus suppresses the imagery produced bias while the motor stimulus did not affect imagery. This suggests that imagery of linear positioning movements involves some cognitive resource which is taxed by a concurrent visual/spatial task. Therefore it seems that this type of imagery involves visual/spatial processing.

Experiment III sought to replicate Experiment II but with a less complex visual interference stimulus and a more complex motor task, in term of its involvement of the motor system. The visual

interference stimulus was now two flashing lights positioned above the track in non-relevant locations. The subject's task was to report which of the two lights appeared brighter (in fact they were of equal brightness) and how many times a particular light flashed on. The motor task now required the subject to push, with their outstretched arm, against a pressure plate, mounted at shoulder height. The results of this experiment confirmed those of Experiment II in that a visual/spatial task suppressed any imagery produced bias while the motor task appeared not to affect imagery. Manipulating the level of visual and motor interference stimuli did not appear to alter their effect on mental imagery. It seems that imagery of linear positioning movements utilises a visual/spatial processing resource rather than a motor resource.

The fourth experiment investigated the assumption that interference tasks compete for a specific resource. It was intended to see if separate effects could be found for the specific resource taxed by the interference stimulus and its response demands on a general response capacity. A further manipulation of this experiment was the inclusion of a verbal interference task, to test an hypothesis that subjects might rehearse or "imagine" movements by counting, perhaps subvocally. The results showed that a concurrent verbal task had no effects on imagery. It was also found that increasing the response demand of the interference stimulus had no effect on the bias produced by imagery, but it decreased the variability in the subject's recall. This suggests that the response demand of a particular interference stimulus affects the output or response production component of variable error (VE) while the specific nature of the stimulus affects the memory resource used by imagery.

The fifth experiment sought to distinguish between the visual and spatial components of an interference stimulus. The previous experiments have shown that imagery of a linear positioning movement is suppressed by a visual/spatial task. In the present experiment visual, kinaesthetic and auditory tasks were either of a spatial or non-spatial nature. The results showed that non-spatial tasks, including a visual non-spatial task, did not suppress imagery of a linear positioning task. All spatial interference tasks regardless of their source, suppressed imagery. Therefore it is the spatial rather than visual nature of the interference tasks which suppresses imagery of linear positioning movements. This suggests that the processes involved in mental imagery involve spatial processing, and that this processing is independent of the modality of sensory input.

The sixth experiment employed a different spatial task as an interference stimulus. It had previously been reported that simple Y mazes were capable of being learned from three different methods of instructions; visual, verbal or motoric. In this experiment subjects were instructed to imagine a novel interpolated linear movement while attempting to learn the correct path through a Y maze, from either a visual, verbal or motoric source of information. Other subjects were required to imagine the same novel interpolated movement while responding to one of the visual, verbal or motor, non-spatial interference tasks. The results showed that only spatial tasks suppressed imagery of linear positioning movements. This confirms the previous experimental finding that imagery involves the processing of spatial information, or at least involves some or all of those parts of the cognitive system which are normally used to process spatial information. It seems then that images of linear positioning movements are primarily manipulations

of spatial representations.

The seventh experiment was designed to test a hypothesis that images and movements, in the case of a linear positioning task, are equivalent at a level of memory representation. If images are primarily spatial and the memory representation for the linear positioning task is of spatial information then those tasks which suppress imagery should also interfere with the memory representations for a linear positioning task. Therefore in this experiment the same manipulations of spatial and non-spatial stimuli were used, but without instructions to imagine a novel movement. It was found that, as predicted spatial tasks interfered with subsequent recall of a linear positioning movement, while non-spatial tasks had no effects on subjects' memory. This suggests that linear positioning movements are represented by their spatial component. Furthermore images of linear positioning movements manipulate the representation for the movement itself. Thus images and movements, with respect to a linear positioning task, are functionally equivalent in their effects on memory for movements.

The eighth and final experiment investigated the generality of previous findings to non-spatial motor tasks. Previous results have consistently shown that imagery of a linear positioning task involves spatial information. This is hardly surprising since linear positioning tasks are primarily spatial in nature. It is not clear whether other forms of imagery operate when the task itself is of a non spatial nature. One such task involves learning a force, in which subjects are required to push a lever which has very little linear movement with it. Past research has shown that similar biasing effects occur with interpolated pressures as occurs with interpolated linear positioning movements.

Therefore if subjects are able to imagine applying a pressure or force, then instructions to imagine applying a novel pressure interpolated between the learning and recall of criterion pressure should produce biasing effects which are similar to those produced by applying such a pressure. The results showed that subjects instructed to imagine applying a pressure did not produce any more bias at recall than counting backwards in threes did, while applying a novel pressure produced a significant bias at recall.

It seems that images do not share an equivalence with the memory representation for applied pressures. In a debriefing session all subjects reported that they had formed an image of pressing but the image featured their own hand on the lever, being moved in a downward direction but by a "magnified" amount. Thus it appears that in this experiment the main feature of the subjects' images was still spatial.

The findings from this series of experiments are summarised below.

(1) Instructions to imagine linear movements have an effect on subsequent linear movements. This effect can either have positive or negative transfer effects to the subsequent recall of a learned linear movement depending on the type of movement imagined. If subjects are instructed to imagine a novel linear movement then their recall of a learned criterion linear movement is biased towards the imagined movement. Alternatively if the imagined movement and the criterion movement are the same then recall performance improves compared to a control group who simply count backwards during the retention interval.

(2) Imagery of linear movements does not appear to involve the motor

production system, since the variability in a subject's recall performance score is much lower in conditions involving imagery instructions, compared with equivalent motor production conditions.

(3) Interference tasks which occur at the same time as an imagery instruction only suppress imagery effects when they have a spatial component to them.

(4) This spatial component is independent of the sensory modality in which it is presented. Indeed, spatial information presented either visually, motorically, auditorally or verbally suppress imagery effects, while non spatial tasks in any of these presentation modes has no effects on imagery.

(5) Separate interference effects were found for attentional load, as reflected by response demand of the task, and resource demand.

(6) Similar interference effects of spatial tasks were found for imagery and movements. Those tasks which had suppressed imagery effects also interfered with subjects' memory for linear movements when no imagery instructions were given.

(7) No evidence for imagery effects was found with a non-spatial motor task. It seems that imagery of motor acts only exerts a memory effect on the spatial properties of a perceptual motor task.

These are the main findings from the experiments carried out during this research project. It seems that mental practice of linear movement involves the generation of an image which is not simply visual

nor motoric in nature but which is in some sense spatial, or at least contains spatial information within it. The process by which this image generation improves performance seems to involve the reduction of output noise from the motor production system and the enhancement of the spatial characteristics of the memory for the movement. It remains to be seen by further research if other non-spatial tasks can be enhanced by imagery instructions.

This research has made some contribution to our understanding of the cognitive processes involved in skill acquisition and retention in that it has highlighted the coding of a perceptual motor skill and ways in which different cognitive processes might function.

While this particular research was based on a simple laboratory task, there are some practical implications which might be of use. In particular the benefit to training gained from a breakdown of the effects of mental practice is worthwhile. It should be possible to identify which situations will be best suited to MP procedures. Perceptual motor tasks which have a spatial component (and most real world tasks do) can be rehearsed by means of imagining those spatial aspects. This can be aided by a visual cue, such as a video tape of the environment in which the action is to be performed. One possibility is that imagery of movements might be used in conjunction with other motor acts. If, as it seems, motor acts of a non spatial nature are not affected by images, then subjects might actually practice the non-spatial parts while imagining the spatial parts of the skill.

While the present research project has reached a convenient and logical end-point it has only begun to explore the cognitive elements

of skill. In many ways the present research has raised more questions than it has answered, but these questions are now more clearly defined and address specific applications of the present research findings. Perhaps the foremost question to be asked is whether motor acts are primarily represented in terms of their spatial characteristics or if different tasks have say a force or temporal representation. Furthermore what kind of cognitive processes are capable of operating on these representations if imagery is confined to a spatial representation?

On a more practical note, the implementation of new training procedures encompassing covert and overt rehearsal needs to be carefully considered with respect to the cost/benefit analysis of various training methods. While training is very much event driven, that is to say, in practice one trains people to do particular known tasks, the future training needs are very much unknown. Consequently research on training should now be aimed at evaluating all possible types of training and rehearsal procedures with a view to their optimisation. Perhaps, if one might attempt to predict the future training needs, there will be a shift from manual skills to cognitive skills in which covert rehearsal procedures will be even more useful.

CHAPTER ONE

MEMORY REHEARSAL AND PERCEPTUAL-MOTOR-SKILL; AN INTRODUCTION

1.1 A Cognitive Approach

In his monograph supplement Woodworth (1899) complains that psychology has neglected motor skill. Motor acts were not included within the psychological study of consciousness. In defence of the role of consciousness in motor acts Woodworth makes the following claim:

"Movement enters consciousness not only as perceived but as intended. And the relation of the movement executed to the movement intended is just as important to the study of conscious life as is the relation of the perception to the stimulus perceived."

Woodworth (1899) p.2.

There has been little change in the attitude of psychologists towards motor acts since this time. With a few exceptions, psychological researchers have not investigated motor acts within cognitive psychology. Recent years have seen an upsurge of interest, particularly from physical education, in motor control. The majority of current research on the psychological aspects of motor control is being carried out by members of physical education departments. It seems that either cognitive psychologists do not consider motor acts to have a cognitive component, or else they find the investigation of motor acts more complex than other more heavily populated areas of interest. The first of these reasons is ill-founded, many cognitive psychology texts are now including chapters on skills and motor skills in particular (Harvey and Greer in Claxton (1980), and Anderson (1980) are but two examples). Fitts (1964) recognised that motor skills passed through a cognitive phase in which the symbolic components of the motor act were perceived and represented in memory. More recently Gentile (1972) suggests that motor skills have

a cognitive element which is present at all times not simply during their acquisition. An example of the cognitive aspect of motor acts is the planning and covert rehearsal of the movement. In a recent review of memory for motor acts Laabs and Simmons (1981) claim that such things as location and distance information are rehearsable while force information is not.

If it is the case that motor acts are difficult to investigate then they deserve greater attention since it is the purpose of science to explain not to ignore. The investigation of cognitive aspects of motor skills ought to be the concern of cognitive psychology, or cognitive science as it now wishes to be called.

The cognitive basis of motor skills is highlighted in the relationship between memory and rehearsal of movements. Rehearsal can be thought of as a continuum of procedures with overt rehearsal at one end and covert rehearsal at the other. Overt rehearsal of motor skills has been widely studied by psychologists in the past. This research, reviewed by Holding (1965) and Annett (1969), has been concerned with the frequency of rehearsal and amount of actual practice. Considering the quantity of research carried out on the various forms of overt rehearsal there has been little advancement in our understanding of how motor skills are controlled.

At the other end of this continuum is covert rehearsal. Most of the research on covert rehearsal has been in the area of verbal learning. Tulving and Donaldson (1975) suggest two forms of rehearsal, maintenance and elaborative. Maintenance rehearsal enables items to be

kept in memory, its only function being to delay any decaying process. Elaborative rehearsal extends a memory trace by activating an associated network which integrates a piece of knowledge with existing stored memory items and so embellishes the memory trace. The covert rehearsal of motor acts has been studied, mainly by physical education researchers, under the guise of mental practice. Reviews of mental practice have been provided by Richardson (1967a, b) and Corbin (1972). Unfortunately the accounts of mental practice presented are vague. There appears to have been no theoretical guidance to any of the experimental studies. Covert rehearsal or mental practice of a motor act may simply prevent any memory decay through constantly re-activating the memory trace, as in maintenance rehearsal. Alternatively mental practice may facilitate the development of a new, more elaborated memory trace.

It has been suggested that some form of elaborative rehearsal may account for the improvements in performance following "rest-periods" (reminiscence effects). In a recent study Frith and Lang (1979) suggest that improvements in performance of a tracking task, following rest periods were due to subjects actively formulating new motor programmes and re-organising the memory representation for the skill during the rest period. One function of this elaborative rehearsal and re-programming is to automatise new components of the skill.

Because the main effects of rehearsal occur within memory it is impossible to distinguish the effects of rehearsal processes without identifying memory representations. A full explanation of covert rehearsal of motor acts must include an understanding of how these acts are represented in memory.

It is the aim of this thesis to investigate and explain how a perceptual motor-task is represented in memory and how that representation is involved in the covert rehearsal of the task. This problem is indeed a cognitive one. Motor acts cannot be fully explained without an understanding of the cognitive processes involved. Furthermore cognitive psychology cannot ignore the production of motor acts. Neisser (1976) states that actions are clearly within the framework of cognition. Neisser's perceptual cycle captures the dynamic nature of cognition and actions. Motor acts are, at one and the same time, the consequences of previous perceptual activity and the initiation for new perceptual processing.

A prominent, but controversial, topic within cognitive psychology is imagery. According to Neisser images occur when the cognitive system is prepared to receive a particular input but the external stimulus does not occur. This is very similar to the notion of perceptual set described by Woodworth (1938). The relationship between rehearsal and imagery is quite strong. The use of imagery as a mnemonic technique has been recognised by psychologists (e.g. Bugolski (1971), Morris and Reid (1970), Morris and Stevens (1974), Richardson (1980)) at least within verbal learning. The role of imagery within motor learning is less clear. Mental practice has frequently been described as a process of image generation, but definitions of imagery within motor learning are vague and scarce. Kelso and Wallace (1978) suggest that movement production is based upon an image. They relate "plans" and "pre-selection" effects showing improved retention characteristics for subject defined movements as opposed to experimenter defined movements, to the subject's activation of an image. They define an image as "the environmental consequences of a movement". The role of this image

being "to generate anticipatory signals that prepare the actor to accept certain kinds of information" p.105. This is very much in the vein of Neisser's (1976) definition of imagery and adds little to his original ideas.

Imagery has been mentioned in connection with motor acts in the past. William James (1890) identified

"an anticipatory image of the sensorial consequences of movement which is the only psychic state which introspection lets us discern of the forerunner of our voluntary acts" p.501

Unfortunately the definition of an image seems to have been vague throughout psychology, consequently many of the arguments about imagery have concentrated upon what we mean by an image.

1.2 Linear Positioning Tasks

A central feature of the research presented in this thesis is the linear positioning task. This simple perceptual motor task requires subjects to learn movements by sliding a cursor along a fixed linear track. This task had its beginnings in Woodworth's (1899) research on line drawing. His monograph supplement is a report of his studies on the control of voluntary movements and his basic task involved producing linear movements. To record those movements Woodworth used pencil and paper. With this basic experimental procedure Woodworth was able to show that our memory for movements enables us to reproduce the same movement with relative accuracy. A similar study was also carried out by Thorndike.

In later years Bilodeau and Bilodeau (1969) enhanced the

basic line drawing task by introducing lever positioning. This enabled more rigid control to be made over the type of movements subjects were able to make. Further work was carried out by Annett. Annett (1969) began to draw people's attention to what we would now call the underlying cognitive processes involved in learning simple lever positioning movements. This was particularly true with respect to the role of knowledge of results (KR) and feedback in such tasks.

Shortly after Annett's work on linear positioning Adams and Dijkstra (1966) started what was to lead Adams to a model of motor learning, based on the role of KR in linear positioning tasks. From about 1966 onwards Adams with various associates began to systematically investigate the role of KR and visual versus kinaesthetic feedback in motor learning on a linear positioning task. By controlling the conditions under which subjects learned and recalled linear movements Adams was able to show that subjects rely heavily on KR during learning which was normally provided by the experimenter. For Adams, skill acquisition, on this task, lead to the establishment of a "perceptual trace" which allowed the subject to produce particular movements in the absence of external KR. It further appeared that visual information picked up by the subject during learning was important for the development of this perceptual trace. In recent years Adams has argued for the dominance of visual over other sensory inputs for the control of movements.

In the early 1970's researchers in physical education began to take an interest in the experimental investigation of motor control and in particular the linear positioning task. Various forms of manipulation were derived focusing on the learning, retention or recall

phase of the linear positioning task. In its standard form the linear positioning task requires subjects to move a slide to a fixed stop for a number of learning trials. This may then be followed by a short unfilled retention interval and a number of recall trials in which the subject has to return the slide to the original position with the stop removed. This has been termed "constrained movements". Adams varied the form of learning so that instead of moving to a stop subjects were given verbal feedback of their error from an experimenter determined position, for example the experimenter might report -11 cm or +11 cm depending on whether the subject had undershot or overshot the criterion position. Adams, Gopher and Lintern (1977) had subjects learn a movement in this way while blindfolded and then compared a "visual" recall group with a "kinaesthetic" recall group. It was found that the visual recall group had lower errors scores (i.e. closer to target position) at recall than the kinaesthetic recall group. This superiority of recall with visual monitoring of movements lead Adams et al to propose a visual dominance of the "perceptual trace" for motor control. Further experiments by Chew (1976) in which three different types of KR were compared, visual, verbal and motor showed no differences in subsequent recall performance, which suggests that the perceptual trace is in fact amodal. However, Johnson (1980) varied the form of feedback available to subjects both during learning and at recall. It was found that subjects who had learned a linear positioning movement with visual feedback and were then required to recall the same movement without visual feedback had greater errors at recall than a group of subjects who learned the movement blindfolded and recalled it blindfolded. Furthermore the blindfolded learning and recall group had less error than a group which learned the movement

blind then recalled it with vision, but this group continued to show learning during recall. Therefore subjects prefer to recall movements in the conditions under which they were learned; however, there is superiority for visual over non visual information. This suggests that the linear positioning task is primarily a spatial task which involves learning a position and distance along a track and that the visual modality is most suited to processing information.

Arguments have been raised as to whether it is position or distance that is learned during a linear positioning task. Recently Walsh, Russell and Crassini (1981) have shown that subjects rely on both distance and location information. The two types of information interact such that the subjects who are told to ignore the distance and learn the location are affected by moving the starting point of the movement, while subjects who are instructed to ignore the location and learn the distance are biased towards a particular end location which was pertinent during learning.

A further development has been the use of the subject's own pre-selected movements rather than experimenter determined movements. In standard linear positioning tasks in which subjects are allowed to pre-select where their movement will terminate it seems that their movement errors at recall are much lower than when preceded by moving to a stop, Kelso and Fokany (1978).

In experiments of this type it is the cognitive processing prior to movement which is being investigated. Therefore while the linear positioning task is a simple perceptual motor task it offers

a range of experimental manipulations which can be used to investigate the underlying processes of motor control.

Finally one part of the linear positioning task paradigm which can be experimentally manipulated is the retention interval. It is possible to vary the length and/or the subject's activities during the retention interval. It appears that varying the length of the retention interval differentially affects recall of preselected and constrained movements, in that preselected movements are retained better over longer intervals. There appears to be a distinction between the affects of filled and unfilled retention intervals on subsequent recall only when the activity during the retention interval involves movements of a similar kind to the to be recalled movement. No systematic investigation of the affects of various interpolated activities has been made, although Pepper and Herman (1970) and others have shown that specific biasing affects can be caused by interpolating particular motor tasks between learning and recall of standard movements.

1.3. An Outline of the Present Research

The following chapters first present a review of the literature of covert rehearsal (or mental practice) in motor skills. This work has been carried out mainly by researchers in physical education, consequently the psychological implications of their studies are not always clear. First criteria of acceptability were established for the inclusion of reports within the review. This was necessary since many of the experiments were without any controls and some escape statistical analysis. An analysis of acceptable experiments was performed to identify

the underlying processes of mental practice. Finally suggested theories of mental practice were evaluated against existing empirical evidence. The third chapter presents a review of mental imagery. Because much of this work has been carried out within the main area of cognitive psychology it is mainly concerned with visual and perceptual processes in imagery. This review includes an examination of the experimental techniques, such as introspection, questionnaires, chronometric analysis and interference techniques. Theories of mental imagery are reviewed and some arguments about the existence of images as a cognitive process within a memory recall system are presented.

The next eight chapters present a series of experiments which investigate the nature of mental imagery in the covert rehearsal of movements. By using a variety of interference stimuli presented concurrent with imagery instructions the underlying properties of movement images are investigated. Some arguments are presented which relate images and linear movements to an abstract form of memory representation.

A linear positioning task, which consists of learning to move a slide along a track to a required stop and then being able to reproduce the same movement along the track but with the stop removed, was the main experimental task. Past experiments on such a task have shown that one of the things which can be manipulated is the retention interval. If subjects are required to produce a novel movement to a different point along the track during the retention interval then their subsequent recall of the original movement is biased towards this new point. Such affects are well documented in the motor learning literature.

The experiments which follow make use of this biasing effect with linear positioning movements in a rather subtle way. Certain groups of subjects are instructed to imagine, rather than produce, a movement to a novel point along the track during the retention interval. By comparison with other groups of subjects who either produce novel movements or else perform some other activity such as counting backwards during the retention interval, it is possible to investigate the functional equivalence of images of movement and movement itself.

It was found that in many ways images of movements and movements themselves are functionally equivalent and evidence is presented in Chapter IV which shows that instructions to imagine movements has a profound effect on the memory for a linear positioning movement, which can either enhance or bias the subject's memory for the correct position. Imagery is shown to produce both negative and positive interference effects on subjects' performance in a linear positioning task depending upon the type of movement subjects are instructed to imagine.

Further investigations of mental imagery and movements were made possible by using an additional interference task to suppress the effects of mental imagery in a linear positioning task. This, of course, assumes that there is some relationship between the cognitive processes required to produce images and the specific resources taxed by the supressant. The strength of this assumption is justified in later experiments when separate effects are found for task complexity and resource demand. The general capacity loading of the supressant appears to produce a separate effect on motor performance than that of

The experiments which follow make use of this biasing effect with linear positioning movements in a rather subtle way. Certain groups of subjects are instructed to imagine, rather than produce, a movement to a novel point along the track during the retention interval. By comparison with other groups of subjects who either produce novel movements or else perform some other activity such as counting backwards during the retention interval, it is possible to investigate the functional equivalence of images of movement and movement itself.

It was found that in many ways images of movements and movements themselves are functionally equivalent and evidence is presented in Chapter IV which shows that instructions to imagine movements has a profound effect on the memory for a linear positioning movement, which can either enhance or bias the subject's memory for the correct position. Imagery is shown to produce both negative and positive interference effects on subjects' performance in a linear positioning task depending upon the type of movement subjects are instructed to imagine.

Further investigations of mental imagery and movements were made possible by using an additional interference task to suppress the effects of mental imagery in a linear positioning task. This, of course, assumes that there is some relationship between the cognitive processes required to produce images and the specific resources taxed by the supressant. The strength of this assumption is justified in later experiments when separate affects are found for task complexity and resource demand. The general capacity loading of the supressant appears to produce a separate effect on motor performance than that of

the specific resource demands.

The final chapter draws together the intricate relationships between memory, imagery and motor acts. Suggestions are made for the application of imagery in motor learning situations and about future research in applied and theoretical settings.

CHAPTER TWO

MENTAL PRACTICE



The process by which performance improves following a period of imagining some aspects of the task has been called mental practice (MP). There have been a number of studies over the past fifty years which seem to show that performance does indeed improve following MP. Unfortunately little of this research has been aimed at a theoretical explanation of the underlying processes. Instead the main concern has been with the amount and situations under which MP is effective. The state of this field of research is rather unsatisfactory for various reasons. First there is no way in which the experimenter can independently check that the instruction to practice mentally has been carried out. This means that the experimenter does not know what the subject is doing when improvements in performance do or do not occur as the case may be. Second the literature contains a high proportion of studies in which essential controls are lacking such as actual practice and no practice conditions as well as an MP condition. In his review Corbin (1972) described a "typical" experiment in which there is a no practice group, an MP group, a physical practice group and a combined MP/physical practice group. This is far from being a typical study,

it is almost an ideal, although one would want a combined MP/no practice group as well.

There have been two reviews of MP, one by Richardson (1967a, b) and more recently Corbin (1972). Both of these provide a reasonably coherent account of the findings from the various studies, but neither of them sufficiently analyse these studies in terms of underlying processes. Again their main force is to provide evidence for the existence of MP effects. Each of these reviews does, however, provide some vague theoretical suggestions as to why MP should improve performance but this is devoid of any empirical evidence. The present review is fundamentally different from past work in that an analytical approach to the procedures involved in MP are considered.

2.1. The Equivalence Of MP And Actual Practice

A review of the literature produced a corpus of over 70 published reports on MP and even more if such vague notions as "The inner game" method of training are considered. The inner game technique attempts to use such things as relaxation, imagery and consciousness to improve the subject's performance. Its main aim appears to be to focus the subject's attention on some external part of the task, such as the flight of the ball in tennis, and to leave the control and organisation free of interference from conscious monitoring. The psychological processes which this procedure makes use of are varied but it has some relationship with Ornstein's (1977) view of consciousness. In essence the inner game technique is assumed to permit the "shift" of control from the left or verbal hemisphere to the right-spatial hemisphere, such broad generalisations about hemispheric functioning

are, to say the least, tenuous. Only a relatively small number of MP studies escape serious criticisms, such as inadequate or non-existent control conditions against which the experimental condition(s) can be compared, e.g. Start (1960), (1964) and Powell (1973). Other reports fail to give sufficient detail about the procedures used in the experiment to be of use. The comparisons made between different types of practice methods do not always take into account the initial level of performance achieved in the learning phase of the experiment. In some cases, no statistical significance is attached to the difference between conditions.

These deficiencies within the corpus of experimental evidence are more serious than deviations in the type or length of practice, instructions to subjects or type of task used which past reviewers have considered. The discrepancies brought about through lack of controls, poor statistical analysis or sloppy reporting make any such reports and any review of those reports, of little value in explaining the underlying processes which produce the improvements observed in performance following MP.

In order to be able to disclose some reliable and interpretable effects of MP which might then be used to produce hypotheses capable of explaining the underlying psychological processes, certain criteria for including a report in this review have been established.

2.1.1. Criteria of Acceptability

As stated earlier, in order to make comparisons of MP adequate control conditions should be included with both a no practice and an actual practice condition with which to compare MP. At the very least

MP should be accompanied by one other control of either no practice or actual practice.

A full report of the procedures used mentioning the type and amount of prior training is necessary. The situations under which MP is carried out with details of instructions to subjects and any additional cues such as visual displays or written procedures which are available to subjects should be given. Finally the type of measures taken such as speed, accuracy, or number of trials, savings scores or percentage increase in performance should be clearly stated. Where a pre-test - post-test design is used comparisons made between the various conditions of the experiment must take into account the level of performance reached in the pre-test. Finally only statistical differences at the .05 probability level or below are taken as significant.

2.1.2. Comparisons not Studies

Rather than take individual reports as the unit of analysis comparisons made between MP and other methods of practice are used. The distinction between reports and comparisons is made clearer by an example; Perry (1939) and Ulich (1967) each published one report on MP. Within each report there are many comparisons made between MP and other practice procedures and between various tasks.

The benefits of selecting the comparisons made rather than the report as the unit of analysis are threefold. In the first case the number of units in the data base upon which the analysis is performed is increased. Second, the large discrepancies between the reports in terms of the tasks used, the type of practice and the amount

of prior training makes it impossible to identify similarities or differences in the effects of MP. When a smaller unit of analysis is used specific similarities and differences are more apparent. Third, it follows from the previous point that if the number of dimensions along which comparisons differ is reduced or separated, then interpretation of the corpus of experimental evidence is easier.

The choice of comparisons rather than studies as the unit of analysis provides a larger, more homogenous data-base and enables any review to produce a clear analysis and synthesis of the research on MP to date. From such a review some theoretical basis for the effects of MP procedures can be suggested. A full table of the studies reviewed here is shown in appendix A.

2.1.3. Types of Comparisons

The effectiveness of MP can be compared with a variety of other types of training/practice procedures. For example Ulich (1967) compared MP with actual practice, observational learning and no practice on a variety of tasks. The simplest comparisons are between MP and no practice or MP and actual practice. Depending upon which comparison is chosen different assumptions about MP are made. Contrasting MP with actual practice, a result which showed no significant difference between the two practice methods suggests that MP is as good (effective) as actual practice. The experimenter need not show that MP is better than actual practice, but must show that actual practice is better than MP.

However, when MP is contrasted with no practice a significant difference in favour of MP is sought. A non-significant result

here is treated as a refutation of a hypothesis supporting MP. In comparisons with actual practice non-significant results are taken as support for the effectiveness of MP. The two different types of comparisons signify two different strengths of an MP hypothesis.

(1) A strong hypothesis

When MP is contrasted to actual practice a strong version of the effectiveness of MP hypothesis is taken. The experimenter who adopts this hypothesis attempts to show that actual practice produces more improvements in performance than MP. Most often, a non-significant result is used as the basis for an assumption that MP and actual practice are equal. Thus a null hypothesis is taken as support for a strong version of the MP hypothesis.

(2) A weak hypothesis

Contrasting an MP group with a no practice group a weaker version of the MP hypothesis is taken. In studies which follow a weak hypothesis the experimenter is interested in whether MP is better than no practice. Here there is no temptation to take a non-significant result as support for MP effects.

The terms "better" and "effective" when used in connection with MP have specific meanings. When a group of subjects improve their performance, in terms of reduced errors or time on task, following a particular practice period, the improvement relative to their original performance level is noted. If the improvement produced following MP is greater than that following a no practice period, then MP is said to be "better", alternatively if actual practice produces greater improvements than MP then actual practice is "better". It should be

pointed out that by taking relative improvement scores any differences between groups prior to the type of practice/rehearsal procedure is equated, although it could be that particular practice procedures interact with the initial performance level. In which case one might find that with high-base level performance scores MP produces greater improvements than actual practice.

However, there is little a priori evidence to suggest that this kind of interaction occurs. Moreover, in many studies comparisons are made of base-level performance scores between groups prior to practice which show that the performance levels of the various groups are equal prior to any experimental manipulation. Thus the relative and absolute improvement values are equal.

The "effectiveness" of MP refers to the consistency with which an MP procedure produces better improvements in performance than a non or actual practice group. If out of ten comparisons MP improves performance better than no practice seven times, while actual practice improves performance better than no practice in eight out of ten comparisons then MP is not as effective as actual practice in improving performance. The dependant variable in all comparisons is the performance level, rather than the number of trials or retention level of skill over time.

2.1.4. Empirical Evidence for a Strong and a Weak Hypothesis

(1) A strong hypothesis

From 112 comparisons of MP with any other form of practice 35 were between MP and actual practice (31.25%). From these 35 comparisons 22 (63%) showed MP to be either better than or no different from

actual practice. The majority of these comparisons found no difference between MP and actual practice. Only six out of 35 comparisons (17%) found MP to be significantly better than actual practice. Perry (1939), Twining (1949), Clark (1960), Smith and Harrison (1962), Stebbins (1968), Rawlings and Rawlings (1974), Minas (1978) and McBride and Rothstein (1979) all found MP to be either better or no different from actual practice.

(2) A weak hypothesis

Comparisons between MP and no practice represent 37% or 41 out of the total 112 comparisons reviewed. Thirty of those forty-one comparisons found MP to be significantly better than no practice (73%). None of the comparisons that were made showed no practice to be more effective than MP, although the remaining nine comparisons all show no significant differences between the effects of MP and no practice. Sackett (1934), (1935), Perry (1939), Twining (1949), Smith and Harrison (1962), Corbin (1967a), Ulich (1967), Surburg (1968), Rawlings et al (1972), Rawlings and Rawlings (1974), Smyth (1975) and Minas (1978) all found MP to be more effective than no practice.

From the analysis of these comparisons the weaker MP hypothesis, that MP is better than no practice, is well supported. The stronger version, that MP is as good as actual practice, is relatively well supported, but, much of this support is based on "no significant differences".

(3) Other comparisons

Beside comparisons between MP, no practice and actual practice, several studies have compared no practice, MP and actual

practice with combined mental and actual practice. In these studies subjects alternate between periods of actual practice and MP in the combined condition, Ulich (1967), Corbin (1967b), Stebbins (1968) and Smyth (1975) have all included such comparisons. The majority of these comparisons show combined MP to be as good as actual practice. Smyth (1975), however, points out that in order to achieve proper control combined MP and actual practice conditions should be compared with combined no practice and actual practice conditions. It is not clear, therefore, whether spaced practice or MP improves performance. Finally, when MP is compared with observational learning, Ulich (1967), MP is superior in improving subject's performance on a variety of tasks.

2.1.5. Summary Of The Comparisons Involving MP

Using the comparisons made in various studies as the unit of analysis it has been possible to separate the various results in terms of a strong or weak hypothesis of MP. Whilst some support for the strong hypothesis was found much of this is based on non-significant differences. The weaker hypothesis in which MP is compared with no practice has more convincing support. It seems that MP is better than no practice but not better than actual practice, although in some cases MP may be as good as actual practice.

Finally the effectiveness of MP is measured in terms of a reduction in errors or an increase in speed and overall performance. Appendix A contains a table of the complete schedule of studies and comparisons used in this analysis. In view of the lack of control in experiments using combined MP and actual practice mentioned by Smyth

(1975) the remaining analyses exclude all such comparisons. Only comparisons between MP, actual practice and no practice are considered, this reduces the total number of comparisons to fifty-five. Comparisons between different kinds of MP and between MP and observational learning have also been excluded.

MP then, is a procedure which has some benefits for skill acquisition. The common theme of past research of MP has been to broaden the spectrum of situations in which MP has been used. There has been little analysis of what MP involves. Ulich (1967) is one exception, his study attempted to assess the involvement of muscular activity during MP. More attention is given later to Ulich's and other speculative hypotheses of MP. First an analysis of the type of MP used in past research is presented. The following sections analyse the various procedures that have been adopted during an MP period. Their effectiveness in terms of the consistency of improvements in performance compared with actual or no practice periods are considered. Through this kind of analysis it is possible to disclose what MP involves and what cognitive processes are operating.

2.2. Procedures and Applications of MP

The first analysis is in terms of the types of cues provided during MP; visual, verbal/written or action cues have all been used. Each type of cue is analysed separately and the most effective cues are interpreted as having a close relation to the underlying processes of MP.

2.2.1. Types of Cues used in MP

The types of cues available to the subject following instructions

to engage in MP are important in that inferences can be made about possible cognitive processes which are used from the specific cues present and the effectiveness of MP in improving performance. As mentioned above, the types of cues range from none, where a subject sits in a quiet room with his/her eyes closed and is instructed to "imagine" or "think about" a particular action, as in Smyth's (1975) experiments. At the other end of this continuum subjects are required to carry out some activity which resembles the task but with some elements missing; Summer (1977) uses this kind of cue in his experiments. Table 2.1 summarises the analysis of cues present during MP in terms of the various comparisons between MP, no practice and actual practice.

(1) No Cues

When subjects are deprived of all external sources of information following an MP instruction sixteen out of the total of fifty-five comparisons fell into this category. Comparing MP with no practice, MP produces significantly greater improvements in performance in eight out of the ten comparisons, Sackett (1935), Smith and Harrison (1962), Ulich (1967), Rawlings et al (1972), Smyth (1975). When MP is compared to actual practice only one out of the six comparisons showed MP to improve performance as much as, or greater than actual practice, Smith and Harrison (1962).

Overall nine out of the sixteen comparisons in which no cues at all were present show MP to improve performance significantly more than no practice and occasionally equal to actual practice. Instructions to imagine performing a task, without cues to aid imagery, are relatively effective in improving the subjects' subsequent performance on the task.

Cues \ Compari- sons	MP/no practice		MP/actual practice		Total No. of compari- sons
	No. of compari- sons	MP effec- tive	No. of compari- sons	MP effec- tive	
None	10	8	6	1	16
Verbal	4	2	4	2	8
Visual	10	6	10	7	20
Action	6	4	5	3	11
Total	30	20	25	13	55

Table 2.1 Analysis of cues present during MP

(2) Verbal Cues

The classification of cues into "verbal cues" includes both spoken and written aids. In these situations the subject is normally given an instruction to imagine or think about the task in hand whilst the experimenter presents a spoken or written list of the procedures and goals of the task. The subjects have additional cues to a no-cue group, which describe and outline the salient points of the task. It should be noted that in these comparisons the subjects in the MP group are the only ones who receive verbal cues. This confounds any improvements which may occur as the subjects are being given additional information as well as engaging in MP.

The analysis presented in table 2.1 shows that there were only eight out of the fifty-five comparisons which used verbal cues. Of these eight comparisons four were between MP and no practice and four between MP and actual practice. In both cases, two out of the four comparisons showed MP to significantly improve performance either above a no practice group, Corbin (1967b) and Surburg (1968), or equal to or greater than an actual practice group, Clark (1960) and McBride and Rothstein (1979). Whilst the analysis shows that verbal cues with MP improve performance in 50% or four out of eight comparisons this only represents four out of fifty-five or 7% of the total number of comparisons.

Because of the low number of comparisons using verbal cues it is difficult to form a clear opinion of the contribution to MP made by verbal cues. It would appear that MP is not enhanced by the addition of verbal information.

(5) Visual Cues

Twenty out of the total of fifty-five comparisons analysed used some form of visual cue to augment MP. The type of visual cues varied from study to study. For instance Minas (1978) provided lights which flashed at bin locations in a prescribed sequence to indicate which bin subjects should be aiming at. Rawlings and Rawlings (1974) had the apparatus present during MP so that subjects could look at it while imagining performing the task. Other studies, Twining (1949) had the target used in the experiment present while subjects were instructed to imagine aiming and throwing rings at it. In all cases subjects were instructed to make use of those visual cues while imagining performing the task. Finally, Surburg (1968) and Stebbins (1968) required their MP groups to watch other groups perform the task while imagining a performance of the task. All these examples embellish the practice environment with visual cues.

When comparing MP with a no practice group six out of the ten comparisons favoured MP, in so much that MP with visual cues improved performance significantly more than that of a no practice group in 60% of the cases. Again it is unclear whether all comparisons differed only in the MP instruction. Minas (1978) only provided visual cues for the MP group but others such as Rawlings and Rawlings (1974) provided visual cues for both the no practice and the MP groups. Generally when the cues consisted of the apparatus being present both MP and no practice groups had the same visual cues. Of the ten comparisons between MP and no practice eight of those used the apparatus as a visual cue and all six of the improvements in performance favouring MP were with the apparatus present, Perry (1939), Twining (1949), Smith and Harrison (1962), Rawlings and Rawlings (1974) and Minas (1978).

When MP is compared with actual practice seven out of a further ten comparisons favoured MP in so much that performance improved following MP at least as much as and sometimes greater than the improvement following actual practice, Perry (1939), Twining (1949), Stebbins (1968), Rawlings and Rawlings (1974) and Minas (1978). Only one of the comparisons did not use visual cues that comprised the apparatus or target, thus both actual and MP groups had the same amount of information available in the environment. On the whole visual cues produced an increase in performance which was greater than no practice in thirteen out of twenty cases (65%).

(4) Action Cues

The final category of cues available following an MP instruction is when the subject has to physically do something at the same time as imagining performing the task in question. There are an assortment of examples of this class of MP, for instance Sackett (1934) had his subjects mentally practice a maze by drawing the maze from memory. Smith and Harrison (1962) had three groups of active MP, the first of which were instructed to move their eyes around a peg board in the correct order for the task; the second group moved their eyes around the board in the reverse order and the third group had their hand guided around the peg board by the experimenter. The results showed that moving your eyes around the board in the correct order during MP produced a greater improvement in performance than actual practice. The reverse ordered eye movement group equally improved their performance as much as the actual practice group. Whilst the hand guided MP group showed no more improvement than a no practice control group. Another study by Summer (1977) involved the MP group having to tap a key board in the same order as required in

the actual task, but at their own rate, and without any guiding lights (the lights appeared if the correct key was pressed - giving feedback to the MP group). This is rather like the maze practice experiments described by Sackett (1934) in that the subject is given an opportunity to mentally rehearse elements of the task with the aid of overt actions but without actually performing the task itself.

From table 2.1, there are eleven of the fifty-five cases which use some form of action cue with MP. The analysis showed that four of the six comparisons between MP and no practice produced more improvement in performance with MP, Sackett (1934), Smith and Harrison (1962). Comparing MP with actual practice, three out of the five comparisons show MP to improve performance at least as much as actual practice does.

On the whole augmenting MP with actions produces improvements in performance which are greater than no practice controls, and sometimes equal to or greater than actual practice controls in seven out of eleven cases (64%).

(5) Summary of Cues used in MP

The predominant trend in experiments using an MP condition is to provide some kind of cue along with instructions for subjects to imagine some performance of the task; thirty-nine out of the fifty-five cases analysed (71%) used some form of cue. On the whole visual and action cues produced more consistent improvements following MP than no cues at all. Visual cues improve the effectiveness of MP such that when this form of MP is compared with no practice 65% of the MP, with visual cues, comparisons produce significantly greater

improvements in performance over no practice. Similarly, MP with action cues result in 64% of the comparisons with no practice favouring MP. Whilst MP with no cues improves performance in only 56% of the comparisons with no practice groups.

Verbal cues seem less effective than visual or action cues in facilitating improvements following MP. The improvements in performance following MP with verbal cues, compared with a no practice group, show that this form of MP improves performance above the no practice group in only 50% of the comparisons.

Of the visual and action cues, visual cues have the highest percentage of success in improving performance above the level of a no practice control group. The conclusion to be drawn is that visual cues facilitate imagery and effective MP. This suggests that imagery may have a strong visual component. The next section considers the amount and type of training given prior to any instruction to imagine performing a task.

2.2.2. Amount and Type of Training

As well as varying the type of cues provided following an instruction to imagine a task, the extent of training received prior to a practice period also varies in the literature on MP. In order to be able to practice a task the subject must have some knowledge of what the task entails. When MP is used Corbin (1972) claims that its effects can only be realized when the subject has already received some basic training on the task in question. One can assume that if MP involves making use of whatever representations are encoded in memory, then until some form of experience has been gained no encoding

Compari- sons Training	MP/no practice		MP/actual practice		Total No. of compari- sons
	No. of compari- sons	MP effec- tive	No. of compari- sons	MP effec- tive	
Less than 15 trials on actual task	14	8	14	8	28
More than 15 trials on actual task	12	8	9	3	21
Trials on a different task	1	0	1	0	2
Prior instruc- tion Written/spoken	2	1	2	0	4
Total	29	17	26	11	55

Table 2.2 Analysis of type and amount of prior training

can have taken place. Within the sets of studies under review the amount of training has varied from no actual training on the task itself, Smyth (1975), to 150 trials on the same task, (Corbin 1967a). Training has also varied in its type, ranging from actual trials on the task itself, Corbin (1967a), to trials on a different task and written instructions Corbin (1967b). This analysis classifies training in terms of the amount and type of training (see table 2.2). All groups, MP, no practice and actual practice receive the same amount and type of prior training before the experimental manipulation.

(1) Less than 15 trials prior training

In deciding upon 15 trials as the boundary for this class some consideration was made as to the type of task in question. Fifteen trials at a basket ball net might not be as beneficial as fifteen trials at a peg board task. Upon further analysis it seems that when tasks are of the more complex basket ball or tennis type the subjects were far from beginners at that particular skill. In view of this it was felt that the boundary of fifteen trials is adequate for all tasks.

When the number of comparisons between MP and no practice are considered eight out of fourteen (57%) of those comparisons with less than fifteen trials prior experience showed MP to improve performance more than the no practice control group, Sackett (1934), (1935), Perry (1939), Smith and Harrison (1962) and Minas (1978).

When MP is compared with actual practice, following less than fifteen trials prior training, again eight out of fourteen such comparisons show MP to be at least as effective as actual practice in improving performance, Perry (1939), Smith and Harrison (1962),

Minas (1978) and McBride and Rothstein (1979). The overall effect of having less than fifteen trials prior training is that in sixteen out of twenty-eight comparisons (57%) between MP and any other practice, MP improves performance above the level of a no practice group. This suggests that the ability to effectively imagine performing a task is quite good after a small amount of prior training.

(2) 15 or more trials prior training

When the amount of prior training comprises fifteen or more trials on the task itself there are twelve comparisons (75%) between no practice and MP. In eight of these twelve comparisons MP improves the subjects' performance significantly more than no practice, Twining (1949), Ulich (1967), Corbin (1967a), Surburg (1968), Rawlings et al (1972) and Rawlings and Rawlings (1974).

In this category there are nine cases comparing MP with actual practice. MP improved performance at least as much as actual practice in only three out of the nine comparisons (33.3%) following fifteen or more trials of prior training on the task itself, Twining (1949), Stebbins (1968) and Rawlings and Rawlings (1974).

Overall, more than fifteen trials of prior training on the actual task produces improvements in performance with MP that are at least greater than no practice control groups in eleven out of twenty-one comparisons (52%). This suggests that a relatively large amount of prior training produces more improvement when it is followed by further mental practice trials. Although MP is still effectively facilitating and improving performance above no practice levels, the benefits to be gained from longer prior training are not significant.

(3) Different task and written/spoken prior training

The remaining two categories of training have been merged into one as there are only two comparisons that used a different task and four that used written or spoken training procedures prior to an experimental condition.

Comparing MP with no practice one out of the three comparisons made resulted in MP improving performance above the improvement attained by a no practice group. When MP is compared with actual practice none of the three comparisons showed MP to produce as much improvement as actual practice, Smyth (1975).

Generally prior training on a different task or with written or spoken instructions is not effective in facilitating imagery in an MP procedure to the same extent as it facilitates improvement following actual practice. As there were only six out of a total of fifty-five comparisons which used this form of prior training, these conclusions are limited.

(4) Summary of prior training effects on MP

In summary, MP is most effective following a small amount of prior training on the task itself rather than a large amount of prior training on the same task. MP is still capable of effectively improving performance after a large number of prior training trials but there is no apparent benefit from having such large amounts of pre-training. The effects of presenting written or spoken pre-training with MP appears to be limited; they may even inhibit MP being carried out. The next section analyses the effects of different tasks on MP.

2.2.3. Types of Tasks in which MP has been used

A classification of tasks in psychology has been attempted by several authors, each with some degree of failure, Miller (1962), Knapp (1967) and Fleishmann (1967), (1978) provide good examples. The aim of this section is not to provide a task taxonomy, which in view of the infinite number of tasks that could exist is probably impossible, but to point out that different tasks may be affected differently by MP procedures. Indeed, Perry (1939) suggested that tasks with a high amount of symbolic content best suited MP. Perry defined symbolic content as verbal, this implies that it is those elements of a task which are capable of being verbalised that are used in MP and that tasks which are capable of being highly verbalised should benefit most from MP.

Morrisett (1956) extended Perry's classification to include perceptual and motor, as well as symbolic task content. Morrisett tested the hypothesis that MP would facilitate improvements in performance to the extent that perceptual and/or symbolic task components were involved. Tasks with a high motor component would show little or no improvement following MP. The implicit assumption behind this hypothesis is that MP involves the manipulation of symbolic and/or perceptual information. Motor tasks were defined as those which required skeletal-muscular activity, perceptual tasks involved discrimination between stimuli, while symbolic tasks were those that placed importance upon an "intervening associative process between reception of stimulation and the making of overt responses". While Morrisett makes three distinctions he only tests between two of them, namely motor and symbolic/perceptual. His results supported his hypothesis using various card sorting tasks to differentiate the level of motor

and symbolic/perceptual component of the task.

The types of tasks used in the various studies of MP considered here are listed in table 2.3. There are eighteen different tasks which have been categorised according to Morrisett's original three groups, symbolic, perceptual or motor.

(1) Definition of categories

Symbolic Tasks:- tasks which contain a high amount of procedural information about discrete sequences of operations.

Perceptual Tasks:- tasks which involve discriminations and judgements based on sensory inputs.

Motor Tasks:- tasks where the performer has to make many movements and that it is the movements themselves which constitute the main part of the task.

(2) Classification of tasks

To allocate tasks to categories 3 judges were given the above definitions of tasks and asked to rate each task on a scale from 0 to 5, with 5 being a high score, in terms of its symbolic, perceptual and motor content. For example, basket ball was given a total of 8 for symbolic, 13 for perceptual and 10 for motor components out of a total of 15 in each of the classes. The relation between the 3 judges' markings was tested using Kendall's correlation. An average correlation of .713 was found which is significant at the 0.01 level of probability (see appendix B for ratings).

The classification shown in table 2.3 is the result of

Symbolic	Perceptual	Motor
Three hole tapping Maze learning Key tapping Symbol/Digit- Substitution	Basket ball Pursuit rotor Table tennis Tennis Mirror drawing Rivetting Card sorting	Ball throwing Ring toss Finger dexterity Typing Peg-board Sit-ups Juggling

Table 2.3 Classification of tasks according to their major component

this rating procedure. Out of the initial 18 tasks all have been separated and classified into the category in which their highest marks fell. In the example above basket ball has been classed as a perceptual task. This classification was used to analyse the effects of MP according to class of task. While only three judges have been used to classify these tasks it is based on Perry and Morrisett's original classification. Therefore the present classification should be seen as an extension of the earlier analysis rather than a new analysis. (See Table 2.4)

(3) Symbolic tasks

The analysis of MP in terms of tasks rated as having a high symbolic component shows that one out of the four comparisons between MP and no practice results in MP improving performance more than a no practice group, Sackett (1935). Comparing MP with actual practice shows that two out of three comparisons of this sort result in MP producing at least as much improvement in performance as an actual practice group, Perry (1939), Ulich (1967). On the whole MP produces improvements in performance which are at least greater than those produced by no practice and occasionally as good as those produced by actual practice in three out of seven comparisons (43%).

(4) Perceptual tasks

Considering tasks which are classified as being primarily perceptual, eight out of eleven comparisons (73%) between MP and no practice show MP to improve performance above the level of improvement attained by the no practice group, Perry (1939), Ulich (1967), Surburg (1968) and Smyth (1975). When MP is compared with actual practice four out of the eight comparisons made show MP to improve performance at

Tasks \ Compari- sons	MP/no practice		MP/actual practice		Total No. of compari- sons
	No. of compari- sons	MP effec- tive	No. of compari- sons	MP effec- tive	
Symbolic	4	1	3	2	7
Perceptual	11	8	9	4	20
Motor	13	9	15	9	28
Total	28	18	27	15	55

Table 2.4 Analysis of type of tasks and the effects of MP compared with actual and no practice

least as much as actual practice, Clark (1960), Rawlings and Rawlings (1974), McBride and Rothstein (1979). MP improves performance on perceptual tasks in twelve out of the twenty comparisons made (60%).

(5) Motor tasks

Tasks which have been identified as being primarily motor in nature constitute almost 51% of the comparisons made between MP, no practice and actual practice. Of these twenty-eight comparisons eighteen, or 64% found MP to improve performance at least above a no practice level.

Comparing MP with no practice, MP produces greater improvements than no practice in nine out of thirteen comparisons (69%), Perry (1939), Twining (1949), Smith and Harrison (1962), Corbin (1967a), Ulich (1967), Minas (1978). The comparisons between MP and actual practice showed that in nine out of the fifteen comparisons (60%) MP was at least as good as actual practice in improving performance, Perry (1939), Twining (1949), Smith and Harrison (1962), Stebbins (1968), Minas (1978).

(6) Summary of effects of MP on various classes of tasks

According to the classification of tasks presented in table 2.3, eighteen tasks are classified into three categories, symbolic, perceptual, motor. MP produces improvements in performance most often in tasks which have a high motor component. The overall comparisons between MP, no practice and actual practice show that MP improves performance in 64% of the motor tasks, 60% of the perceptual tasks and 43% of the symbolic tasks. This contradicts Perry's initial hypothesis in so far as symbolic tasks have the lowest improvement

rate following MP. Morrisett's experiments failed to distinguish between symbolic and perceptual tasks; on the basis of this review it seems that the success of Morrisett's symbolic/perceptual group may be due to the perceptual component rather than the symbolic component of the tasks.

2.2.4. Summary of Procedures and Applications

Having analysed the empirical evidence for and against MP in terms of the various agencies, cues, prior training and task type, which might affect its use and relate to underlying cognitive processes, a summary of these findings follows.

MP improves performance in the majority of cases above the level of a no practice control group who spend a similar amount of time without instructions to engage in MP. This form of practice is not as consistently efficient as actual practice.

Subjects who are instructed to engage in MP are often provided with additional cues to augment their practice period. Comparisons were made between the effects of MP, no practice and actual practice in terms of the various cues; no cues, verbal cues, visual cues and action cues. Visual cues produced the highest ratio of comparisons in which MP improved performance above a no practice group. MP is best suited to visual information which suggests that MP is a form of visual imagery.

The amount of training prior to MP was used to differentiate the amount of prior knowledge of the task. The effects of MP were most efficient when only a small amount (less than 15 trials) of prior

training had occurred. MP was still as effective following longer training periods but there is no added benefit to be gained from increasing the amount of prior training. It may well be that MP serves to elaborate a particular memory encoding in much the same way that Craik and Watkins (1973) found elaborative rehearsal of verbal material to improve recall performance.

The type of task which subjects were tested on was analysed for differences in effectiveness of MP. A classification of tasks in terms of their symbolic, perceptual or motor components was produced. Tasks categorised as having a high motor component were found to have the highest proportion of comparisons in which MP improved performance above no practice. This is in direct opposition to a hypothesis put forward by Perry and later tested by Morrisott that MP facilitates performance to the extent that tasks have a high symbolic component. The assumption behind this hypothesis was that MP involved the rehearsal of verbal material. This is little more than a rote rehearsal procedure. The results of the literature review show that MP is not rote rehearsal in a different guise. MP may well include a rote procedure, but there is evidence that some form of imagery of the actions serves to augment and elaborate the memory trace.

2.3. Theories and Hypotheses of Mental Practice

The remaining part of this chapter is concerned with suggested accounts of MP that have appeared in various reports. The processes by which MP is thought to affect performance have been widely speculated upon within the literature. There are some quite elaborate accounts such as the "psychoneuromuscular hypothesis" which closely aligns with

a motor theory of mind, whereas others such as the "attentional focusing hypothesis" are loosely formulated suggestions. Each of these accounts is considered on its theoretical merits and capability of explaining the empirical evidence presented earlier.

2.3.1. Motivational Hypothesis

One hypothesis of why MP is effective is that during an MP instruction the subjects are asked to think about the task and this helps to sustain their interest. It is suggested that this sustained interest functions to enhance performance at recall, Richardson (1967b). This process might be especially effective when MP groups meet together for a group practice session, Corbin (1972). If it can be assumed that increased arousal accompanies increased motivation and that arousal can be measured by E.M.G. responses, then Williams (1970) has shown that MP and control no practice groups did not differ in their E.M.G. responses. The relation between E.M.G. recordings and arousal/motivation is unclear. Hockey (1979) notes that the relationship between different measures of arousal and the performance effects of arousal is unknown. One generalisation made by Hockey is that there is relatively better performance on delayed recall tasks with higher levels of arousal, and that delayed recall is better for material learned during high arousal states. Immediate memory does not seem to depend on one single factor. The majority of the work on arousal and memory has been concerned with verbal learning and arousal is often operationally defined in terms of white noise levels.

2.3.2. Trace Consolidation Hypothesis

The hypothesis here is that each practice trial or session,

leaves a trace which will decay at some exponential rate. MP re-activates the trace slowing the effective rate of decay, Corbin (1972). This hypothesis suggests that memory is laid down gradually as a permanent trace by a process of consolidation. One assumption made in this hypothesis is that the strength of the trace would be a function of the amount of time spent performing or rehearsing the task. Given this assumption one would predict that MP following more than 15 trials of training would be more effective than MP following less than 15 prior training trials. This is not the case, MP has a more pronounced effect following only a few trials. One explanation of this is that MP does not simply re-activate or consolidate a memory trace but elaborates existing memory traces. Thus mental rehearsal of a task may have some optimum level of prior training past which further prior training does not produce any significant increase in performance, since further practice on the task has a compounding rather than elaborative effect on memory.

2.3.3. Symbolic Learning Hypothesis

Skills vary to the extent that they can be symbolically coded as a function of the symbolic task component, Perry (1939). The use of symbolic here is confined to language. Perry suggests that tasks which contain a high amount of procedural information about discrete operations are capable of being verbalised (linguistically coded) to a greater extent than other tasks. It is this capability of linguistic coding which makes Perry claim that a symbolic form of encoding is used. This rather restricted use of the term symbolic is unfortunate and does not fit in with a more general interpretation such as Kolers and Smythe (1979) who point out that a symbol is first and foremost something

which stands in the place of something else. To this end any form of mental representation is symbolic (images, motor programmes) but not necessarily linguistic.

One prediction from this hypothesis is that tasks which are classified as highly symbolic (by Perry's definition) should show the most consistent benefits from MP. The analyses performed earlier show that symbolic tasks do not have the highest success rate with MP but the lowest. Tasks classified as motor have the highest success rates with MP while perceptual tasks are close behind.

This suggests that Perry's original hypothesis is incorrect in that tasks with a high proportion of discrete procedural elements are not those in which MP most consistently improves performance. The hypothesis can be redefined if a different interpretation of symbolic is used, which refers to any form of representation, but this changes Perry's initial intention.

2.3.4. The Symbolic Perceptual Hypothesis

Mental practice enables one to examine a representation of performance and "gain insight" which can lead to a modification of performance, Sage (1977). Involvement in MP does not ensure improved performance but provides for a new perceptual organization through insight. Corbin (1972) suggests that

" Regardless of the skill to be learned, some mental imagining is necessary prior to and during the improvement of performance through insight." p.103

It is hypothesised that MP involves examining an image and improving performance by modifying the image and subsequent performance.

This loosely formulated hypothesis has some resemblance to Kosslyn's (1980) theory of mental imagery in which images are supposed to exist as a form of representation in memory and that although they may be generated from a more basic form of encoding they can be examined by perceptual mechanisms and produce specific functions in recall and problem solving tasks. The next chapter is concerned with Kosslyn's and other theories of mental imagery in much greater detail.

One prediction which stems from this hypothesis is that some prior experience is necessary for image formation. Furthermore there is a strong implicit assumption that the form of imagery is visual/spatial. This is explicitly stated in Kosslyn's model of mental imagery. The empirical evidence from the MP literature shows that when MP is accompanied by visual cues performance improves most consistently. This can be taken as support for some form of visual/spatial imagery hypothesis. Interestingly enough it also seems to be the case that action cues produce consistent improvements following MP. This suggests that visual images may not be the sole contributor to MP and some form of action or motor imagery may also be involved.

2.3.5. The Psychoneuromuscular Hypothesis

The psychoneuromuscular hypothesis is based on a belief that images of movements excite minimal movements (detected by E.M.G. recordings) and this produces kinaesthetic feedback resembling actual movement, Richardson (1967b). Ulich (1967) has shown that subjects who appear to benefit most from MP show a medium level of muscle activity. This report is not very clear though as to what controls, such as base-level E.M.G. recordings, were taken. One possible suggestion is that actions are represented in terms of motor activity.

Indeed Jacobson (1932) proposed a similar account of all mental activity which led Liberman and his associates to produce a motor theory of speech perception, Liberman, Cooper, Shankweiler and Studdert-Kennedy (1967). More recently Weimer (1977) has proposed that acting, perceiving and comprehending are intimately connected, in that they may be thought of as simply different aspects of the same fundamental process, and that a "motor theory of mind" has the greatest power of explanation. Exactly what would constitute a motor theory of mind is, wisely, omitted from Weimer's account but one possibility is that "motor programmes" or rules for acting are the fundamental units of a cognitive system. The psychoneuromuscular hypothesis is more specific than this since it is claimed that these "rules" result in the activation of the musculature and that imagery is this activation.

The evidence from past research concerning the effectiveness of action cues in MP would seem to support a notion that imagery involved the representation of actions which resembled the motor activity in the task, but this does not necessitate that the images are motor programmes, whatever a motor programme might be, nor that they involve the motor production system to the extent that specific muscle groups are activated as implied by the psychoneuromuscular hypothesis.

3.5.6. The Spaced Practice Hypothesis

One rather obvious hypothesis of MP is that MP is equivalent to having a rest. The role of MP as a rest period being that of essentially dissipating inhibition, Holding (1965). In which case a long MP/rest period is not necessarily more beneficial than a short

one. One prediction from this hypothesis might be that alternate action and mental practice periods should be most effective. There have been a number of studies which have compared MP with alternating mental and actual practice, Smyth (1975) for example. The results have largely shown that indeed this form of practice produces greater improvements than MP alone but not greater than actual practice. These results do not really support MP though as improvements in performance could have been brought about by actual practice alone. As Smyth points out, alternating MP and actual practice needs to be compared with alternating rests and actual practice, or alternating an interfering mental task with actual practice task.

The hypothesis of spaced practice can not be ruled out but it does seem that MP involves some kind of active participation on the subject's part. Powell (1973) showed that negative MP, in which subjects imagined throwing darts which widely missed a target, did not improve performance as much as a positive MP group who imagined their darts to hit the required target. Rawlings and Rawlings (1974) have also shown that MP reduces reminiscence for high imagers but increases performance, which suggests that a simple spaced practice explanation is incorrect, as reminiscence produces improvements in spaced practice.

2.3.7. Selective Attention Hypothesis

The final hypothesis suggests that MP enables one to attend to various aspects of the task in a way which is impossible with real practice because the overt activity required makes much greater demands on attention. Thus sometimes MP may be even better than actual practice.

Corbin (1972) suggests that MP benefits the learner by calling attention to important details of the desired movement and allowing the redundant information to be filtered out, as it were.

This explanation assumes that MP is simply the focusing of resources on to a particular part of the action. It is not clear whether a specific or general resource is implied, although it does seem that a general limited capacity model of attention is intended. There is no evidence to date which bears directly on this issue within the MP literature.

2.3.8. Summary of Mental Practice Hypotheses

Seven hypotheses, some of which are rather vague, have been extracted from the literature on mental practice. Each one has a different explanation of the observed improvement effects following MP. Of the seven hypotheses some can be dismissed on the basis of existing empirical evidence, namely, the motivational hypothesis, the symbolic learning hypothesis, and the spaced practice hypothesis. Each of these hypotheses have been directly contradicted by existing experimental evidence.

The remaining four explanations have not been put to test by any previous research. There is no reason why these hypotheses should be mutually exclusive since they offer different levels of explanation. The trace consolidation hypothesis offers an explanation in terms of a change in memory representation. Two hypotheses, symbolic perceptual and psychoneuromuscular, each relate to processes by which changes in memory representation can come about and both refer to an image process. The fourth hypothesises attention as a

process by which changes in memory can come about when it is used as an agent in an image or some other cognitive process. Attention can be considered as a possible necessary agent but not a sufficient procedure by which changes in memory representation may occur.

One strong implication throughout the MP literature has been that imagery is the fundamental process which accounts for MP effects. This is explicitly stated in the symbolic/perceptual and psychoneuromuscular hypotheses, although they disagree as to the nature of imagery, and implied in all past experiments. The most common instruction to subjects is "I want you to imagine that you are"

In view of the close link between MP and imagery the next chapter presents a review of some of the experimental and theoretical evidence for various kinds of image processes.

process by which changes in memory can come about when it is used as an agent in an image or some other cognitive process. Attention can be considered as a possible necessary agent but not a sufficient procedure by which changes in memory representation may occur.

One strong implication throughout the MP literature has been that imagery is the fundamental process which accounts for MP effects. This is explicitly stated in the symbolic/perceptual and psychoneuromuscular hypotheses, although they disagree as to the nature of imagery, and implied in all past experiments. The most common instruction to subjects is "I want you to imagine that you are"

In view of the close link between MP and imagery the next chapter presents a review of some of the experimental and theoretical evidence for various kinds of image processes.

CHAPTER THREE

MENTAL IMAGERY

There seems to be some confusion in the mental practice literature on the distinction between mental practice and mental imagery. Richardson (1969) treats mental practice as one application of mental imagery, while Corbin (1972) refers to mental imagery and mental practice as if the two terms were interchangeable. Similar confusions are apparent in most of the research on mental practice. It is not clear whether mental practice is a specific practice procedure which uses some form of mental imagery, or mental practice is another instance of mental imagery. This conceptual uncertainty is not surprising since both MP and mental imagery are seldom defined. From the previous chapter it now seems clear that MP is a form of practice which enables certain aspects of a task to be rehearsed. On the basis of the evidence from the analysis of the types of cues used during MP it might be suggested that it is the visual/spatial aspects of a task which are rehearsed by MP. The most convincing hypotheses of MP assume an imagery process as the psychological process underlying this form of practice. There is some evidence on the function of imagery in MP but there have been few investigations of mental imagery within the MP literature. Conversely, there has been a considerable amount of literature on mental imagery within cognitive psychology in recent years, but very little mention of MP. There is some consensus amongst cognitive psychologists that mental imagery is a visual/spatial process, although Pylyshyn (1973) and others disagree.

Frequently, in MP experiments subjects are instructed to "imagine performing x". Individual differences in the amount of improvements that have occurred following MP, have been accounted for in terms of imagery differences by Richardson (1969). Clark (1960) obtained subjective reports of the use of imagery during the MP of a basketball task. The results suggested that vividness and controllability of imagery were important individual difference variables. Further studies by Start and Richardson (1964) and Richardson and Start (1964) investigated the effects of four imagery subtypes on the level of skill in performing a gymnastic task (single leg up start on a high bar). The four different imagery subtypes were vivid controllable imagery (VCI), weak controllable imagery (WCI), vivid uncontrollable imagery (VUI) and finally, weak uncontrollable imagery (WUI). Four groups of subjects were assigned to the four different imagery conditions according to their scores on Gordon's (1949) and Sheehan's (1967) imagery questionnaires. Each group then had one five minute MP period per day for six days. None of the subjects had performed the task previously but all had attended one demonstration. After an MP period it was found that the (VCI) group had the highest performance rating on the task. The next highest performance rating was given to the (WCI) group, followed by the (WUI) group and finally the (VUI) group. Richardson (1972) concluded from these results that controllability of imagery is an important predictor of the effects of MP on performance. Unfortunately, there are a number of inadequacies in the experimental design. First, there were no control groups. In particular it would have been informative to have had "no practice" and also "actual practice" groups with which to compare the MP group. Second no base line performance score was taken. The effect of this is that it is not possible to assess the amount of

improvement due to MP. Third, the predictive validity of questionnaires of imagery is poor, since they often correlate with social desirability scores (Durndell and Wetherick, 1975). However, they do not correlate with performance tasks which are thought to align with imagery processes, e.g. concept formation or spatial thinking tasks (Durndell and Wetherick, 1976). Finally, the performance measures were judges' ratings rather than error rates or time on task.

The role of imagery in MP seems important, but unclear. It is a predominant feature in several of the previously discussed hypotheses of MP. Those explanations of MP which do refer to imagery as an explanatory construct pay little attention to the volumes of research which have been concerned with imagery as a cognitive process. One obvious reason for this is that a large amount of research on MP was carried out between 1930 and 1960. During this period imagery was omitted from mainstream psychology by more radical behaviourism. Since then there have been a number of reviews and experimental investigations of MP, which still disregard research in cognitive psychology in more recent years. Work was also conducted, before the behaviourist era by Galton, Titchener, Fechner, Wundt and others.

This chapter presents a review of research into imagery in psychology. The review initially follows a chronological progression through the introspectionist, behaviourist and information processing eras of psychology. A review of current imagery research paradigms within cognitive psychology follows in which the work of Paivio, Kosslyn and Shepard is considered. Theoretical arguments presented by Pylyshyn are discussed, which suggest that imagery has no importance

for psychological explanations of behaviour since it has no explanatory powers. Further theoretical discussions by a wider group of psychologists presenting a propositional or common code theory of memory representation are presented. The alternative theories of imagery representation put forward by Paivio, Kosslyn and Neisser are then outlined. Finally a connection is made between imagery and actions as suggested by motor control and MP literature.

3.1. Imagery Before Behaviourism

Imagery was a major topic of interest in psychology prior to the publication of J.B. Watson's book "Psychology as the Behaviourist sees it" in 1913. Interest in imagery dates back to Aristotle who regarded images as the "stuff of mind". The philosophical investigation of imagery had a strong influence on subsequent psychological investigations of imagery. The early introspective psychology of Wundt and his followers accepted Aristotle's belief that thought was impossible without images and that memory consisted of images. Berkeley disagreed with the notion of generalised or abstract images, believing that they must always be of concrete objects and could not represent abstract thought. Kant in his "Critique of Pure Reason" explicitly describes the way in which images can be connected with concepts only by means of a schema.

" Indeed it is schemata not images of objects which underlie our pure sensible concepts. No image could ever be equated to the concept of a triangle in general. It would never attain the universality of the concept which renders it valid of all triangles, whether right angled, obtuse angled or acute angled; it would always be limited to a part only of this sphere. The schema of the triangle can exist nowhere but in thought. It is a rule of synthesis of the imagination in respect to pure figures in space."

Kant (1797) A.141

Kant suggests that memory representations are not in the form of an image. Instead he suggests a more abstract form, such as schemata, which determine the referent of an image and also generate images. Images are still considered to play a role in memory and thought although it is necessary for them to have a schematised rule system. This rule system allows them to be universally applicable for concept representation. The trend away from images as the "stuff of mind" has recently been reflected in psychological theories of representation. In particular, Pylyshyn (1973) and Anderson (1978) do not wish to give images the status of a representational medium. (A detailed account of their position follows later).

3.2. Early Psychological Approaches

In the latter part of the 19th and early in the 20th century psychology emerged as a separate discipline. Imagery was one of the key issues studied by two kinds of psychological investigation. The first followed the Wundt school of trained introspectionists who analysed their own thoughts and psychological processes. Titchener (1909) reports,

" I can quite well get Locke's picture, the triangle that is no triangle and all triangles at one and the same time. It is a flashing thing come and gone from moment to moment; it hints two or three red angles, with the red lines deepening into black, seen on a dark green ground. It is not there long enough for me to say whether the angles joining to form the complete figure, or whether all three of the necessary angles are given. Nevertheless it means triangle

.....

I represent the meaning of affirmation, for instance, by the image of a little nick felt at the back of the neck" p.22

The extract might well be used as an argument against

Berkeley's attack and then later Kant's attack of imagery. Titchener who never appears to have had an imageless thought, claimed that subjects who reported imageless thought required further training in introspective analysis. This raises the question; are images a product of thought, or are they a product of training in introspection? The latter reduces images to a mere experimental artifact.

3.2.1. Subjective Questionnaire

Another form of psychological investigation which is closely related to introspection is the use of questionnaires. Unlike the Wundtian introspection techniques, questionnaires require no prior training, e.g. Galton (1883) and later Betts (1909). Galton administered a questionnaire to 100 subjects which asked them to recall such things as their breakfast table. He also asked questions about the strength and controllability of their imagery. The results indicated very little about the imagery process except for distinguishing between people who reported "good" or "weak" images. In excess of ten per cent of Galton's subjects claimed not to have images. This ten per cent consisted of scholars and scientists and consequently Galton surmised that imagery was a characteristic mode of thought for those of "lesser mental abilities".

Later Betts refined Galton's questionnaire by asking subjects to rate the vividness of their visual imagery and also to rate the vividness of their imagery in other sensory modalities, i.e. auditory, visual, olfactory, tactile etc. The results of Betts questionnaire were that auditory and visual images were reported as being more vivid than any other.

3.2.2. Objective Assessment

The second method of measuring mental images involved the use of objective rather than subjective tests. Woodworth (1938) describes a number of tests developed in the first decade of the twentieth century. A summary of these techniques follows with some of Woodworth's criticisms.

(1) Association

Subjects are given five minutes to recall objects having characteristic colours and then a further five minutes to recall objects with familiar sounds. Subjects are classed as "visualisers" if colour is a better cue and "audiles" if sound is a better cue. Woodworth observes that a violin may be recalled as a sounding object without the subject having any image of the sound the violin makes. Furthermore, properties of objects are a function of experience with those objects, regardless of how a subject uses a given modality in thought and/or imagery.

(2) Word type frequency

Here, the relative frequency of "sight words", "sound words" and "feel words" etc. is tabulated in a subject's prose and is then used to class the imagery or thought mode of that subject. Objections mentioned previously also apply to this type of test. In addition Woodworth also notes that there is nothing to prevent the non visualiser from seeing what is worth seeing, remembering it as "being seen" and reporting it as such in their prose.

(3) Learning by eye or ear

Subjects are classified according to their relative memory

for visually versus auditorially presented lists. According to Woodworth subjects could translate modalities internally immediately after a stimulus presentation. Therefore the modality of presentation does not dictate representation, for example, an audile who becomes deaf does not stop thinking.

(4) Method of distraction

This type of test rests on the assumption that internal processing will be disrupted more if subjects have to process multiple stimuli in the same modality than if they could process multiple stimuli in different modalities. Subjects are instructed to learn a list of words while being subjected to auditory, visual or kinaesthetic distractions. Those with poorer recall having had interference in a given modality are then assumed to be using that modality to represent the words. Woodworth considers that the processing loads of different stimuli may be more or less demanding. Consequently a stimulus may be more or less distracting or interfering for reasons other than the mode of internal representation, such as familiarity with or general processing load of the stimulus.

(5) Spelling

Words are read to a subject who is asked to spell them backwards. It is assumed that if subjects use a pictorial image the letters can be "read off" as easily in reverse as in the normal manner. Fernald (1912) found that nobody could read from images equally easy in reverse order. Woodworth observes that subjects reporting visual imagery tend to do better than other subjects in a test of this type. It is unclear whether or not the test is actually measuring imagery as such. It could be that subjects imagine the objects rather than the written

word. It is also possible that some words are more difficult to imagine than others for a number of reasons, e.g. familiarity, abstractness. The test could merely measure one's ability to chunk letters or measure memory capacity. Other factors such as word pronouncability or the sequential nature of auditory presented material could also influence a subject's performance.

(6) The letter square

This test is based upon similar reasoning as the spelling test. Subjects are read a series of letters or digits and asked to arrange them mentally into a matrix of n rows by k columns. They are then requested to recall them by rows, columns or along the diagonals. If "pictorial-images" are formed then recall in any direction should be possible. All the limitations of the spelling test apply equally here.

(7) Description of a picture

Subjects are asked to describe a picture from memory and then asked to what extent they used visual imagery. Fernald (1912) noted that, those subjects who gave more complex descriptions also reported use of imagery, although those who reported use of a verbal memory gave more accurate and less incorrect descriptions. Subjects could do well in the test by naming the objects in the picture and then recalling only the names.

Angell (1910) and Fernald (1912) examined the majority of these objective tests and found that they had only low validity. They did not correlate well with subjects' direct reports of imagery. Woodworth and Shlosberg (1955) noted that work had not continued on

this topic (mental imagery) because of the lack of adequate experimental methods.

3.3. Imagery and Behaviourism

A central tenet of behaviourism was the failure of introspective reports to provide common, objective evidence for investigating mental processes. Consequently, they believed that psychology should only be concerned with observable behaviour. Such things as consciousness, mental states, mind, will and imagery were openly denounced. Watson (1913) suggested that imagery was subsumed by "subvocal thought", which consisted of verbal memory with accompanying laryngeal movements which are potentially measurable.

Watson claims that any rehearsal of scenes, etc. is facilitated by verbal rather than imagery processes. He implies that things are represented in memory in the form of words.

Towards the 1960's psychology again began to enquire about thought, attention and imagery. The status of images and the like was not as empirical phenomenon as in the pre-behaviourist era, but as explanatory concepts or hypothetical constructs, MacCorquodale and Meehl (1948). Explanatory concepts are incorporated into theories of information processing in order to account for behavioural phenomenon. Imagery is a prime example of an explanatory concept.

The re-emergence of imagery as an area of interest to psychologists brought with it a new approach to experimental investigation. While experimenters became more subtle in their reasoning the

basic methods of investigation still closely resembled the pre-behaviouristic approach. Two classes of investigation are to be found; quantative, subjective assessments of mental imagery and objective studies of mental imagery. The former uses questionnaire methods, while the latter uses reaction times (or chronometric analysis) and interference techniques. Often the two approaches are incorporated so that experimenters both objectively measure such variables as reaction time to a particular stimulus and question subjects on their use of imagery.

Richardson (1980) points out that there has been no radical change in the way mental imagery is investigated in psychology. In recent years artificial intelligence (A.I.) and computer simulation have brought a new kind of experiment to psychology involving simulation and computational modelling. Sloman (1978) claims that computers have revolutionised the way we have been able to think about and investigate mental events, such as mental imagery. There has, as yet, been little development of A.I. techniques to the study of mental imagery, except in Kosslyn's (1980) approach. These sections present a review of the experimental investigation of mental imagery since the behaviourists. There appear to be only two major levels of analysis; quantative, subjective assessments and objective studies. The former relies on questionnaire data while the latter makes use of reaction time and selective interference.

3.4. Quantative and Subjective Investigations

This method of research extends Galton's methodology to detect differences between both individual subjects and particular stimuli in

their ability to generate images. Richardson (1980) outlines three procedures for this research.

a) Instructions to subjects to use mental imagery in learning and memory experiments. Typically, a list of stimulus words are displayed and subjects are instructed to learn the list by forming images of the semantic content of one word. These experiments normally involve using mnemonic strategies in a paired-associate-learning paradigm. Inferences are made about the learning curves and recall scores of various word lists. Word lists have been produced with ratings of imageability and concreteness (amongst other things) by Paivio, Yuille and Maddigan (1968) and Gilhooly and Logie (1980a,b).

b) Closely related to a) is the subject's report as to what extent a particular stimulus invoked an image. Correlations are then made between the subject-rated, image evoking potential of a particular stimulus, and the subsequent recall test performance of that subject with that stimulus. One example of this kind of test is the probability of recall of variously rated words or objects, Paivio (1978).

c) Finally, subjects are classified according to their controllability and vividness of imagery. Comparisons are then made between the differentially classified groups' performance on cognitive task thought to involve mental imagery, such as spatial manipulation. Durndell and Wetherick (1976) carried out a variety of such tests.

The results of this method of research, which emphasises introspective assessment of imagery are not very convincing. Durndell and Wetherick (1976) tested subjects with known controllability and vividness of imagery (as measured by Betts questionnaire, revised by Sheehan (1967) and Gordon's (1949) controllability of imagery questionnaire) on five cognitive tasks. These tasks fell into three

classes; divergent thinking, problem solving and concept formation. The results were that performance on the divergent thinking task by subjects rated as high controllable imagers, was better than a similarly rated low controllable imagery group. No differences were found between high and low vividness of visual imagery groups. No effect was found for the presence or absence of instructions to use imagery but subjects' own ratings of their use of imagery correlated significantly and positively with task performance.

Subjects' performance on the problem solving task showed no effects for vividness of visual imagery, controllability of visual imagery, or the presence of instructions to use imagery. The time taken by subjects to solve the problems showed a significant, but negative correlation with the subject rated use of mental imagery. Similarly, subjects' performance on the concept formation task did not differ with the rated vividness or controllability of subjects' visual imagery. No significant correlations were found between subjects' own ratings of imagery during the task and their performance scores.

These results suggest that either imagery has no beneficial effects on problem solving and concept formation tasks or the dimensions of imagery measured by the various questionnaires are not important to image processes.

Subjects may not be able to introspect on their use and type of imagery. Imagery questionnaires are heavily biased towards Galton's early intuitions as to what might be important factors in imagery. Despite more sophisticated techniques of questionnaire design involving

classes; divergent thinking, problem solving and concept formation. The results were that performance on the divergent thinking task by subjects rated as high controllable imagers, was better than a similarly rated low controllable imagery group. No differences were found between high and low vividness of visual imagery groups. No effect was found for the presence or absence of instructions to use imagery but subjects' own ratings of their use of imagery correlated significantly and positively with task performance.

Subjects' performance on the problem solving task showed no effects for vividness of visual imagery, controllability of visual imagery, or the presence of instructions to use imagery. The time taken by subjects to solve the problems showed a significant, but negative correlation with the subject rated use of mental imagery. Similarly, subjects' performance on the concept formation task did not differ with the rated vividness or controllability of subjects' visual imagery. No significant correlations were found between subjects' own ratings of imagery during the task and their performance scores.

These results suggest that either imagery has no beneficial effects on problem solving and concept formation tasks or the dimensions of imagery measured by the various questionnaires are not important to image processes.

Subjects may not be able to introspect on their use and type of imagery. Imagery questionnaires are heavily biased towards Galton's early intuitions as to what might be important factors in imagery. Despite more sophisticated techniques of questionnaire design involving

factor analysis, the initial selection of tests for the analysis can be biased towards particular factors. Thus current questionnaires may be artifacts of an earlier bias rather than sensitive quantifiers of important dimensions of mental imagery. There is no reason to expect that image processes are open to introspection. If imagery is a cognitive process then subjects may be completely unaware of what it involves, in much the same way as they are unaware of perceptual processes. Furthermore, any introspective analysis of cognitive processes may be incorrect in that the results of introspection may suggest particular processes but that these may be apparent rather than actual processes. Assuming questionnaires are unbiased quantifiers of important dimensions of imagery, and that subjects are able to openly and correctly interpret cognitive processes, there are still doubts as to how the questionnaire will be interpreted by different subjects. Subjects may differ in what they call an image, how they view controllability or in what they regard as a vivid image.

The post-behaviourist research on the subjective quantification of mental imagery faces serious methodological problems which limit the power of such approaches. This type of research has been concerned with identifying what correlations exist between mental imagery and other abilities, and under what situations the use of imagery has beneficial effects. This approach seems inappropriate at the present since the underlying psychological processes involved in mental imagery have not yet been identified. The descriptions of mental imagery provided by questionnaire analysis and correlation studies have not been particularly helpful in furthering our understanding of mental imagery. It may be of interest to know the extent of a subject's ability to consciously access their cognitive processes and the kind of

reports made about imagery at a purely qualitative level.

3.5. Objective Investigations

Rather than assessing the effects of imagery in various situations or quantifying subjective descriptions of mental imagery, this approach attempts to identify the cognitive processes that produce and operate on images within a more general model of cognition. This section reviews various techniques including selective interference, chronometric analysis and the symbolic distance effect which allow inferences to be made about image processes.

3.5.1. Interference Techniques

Interference techniques have been used to identify any overlap between imagery processes and other cognitive processes. The major assumption underlying these techniques is that any interference caused by concurrent tasks is due to competition for a common resource. Brooks' (1968) study is one of the most familiar examples of this approach. Brooks asked his subjects to imagine a block diagram of a letter "F" (as in figure 3.1), and from a proscribed starting point in a proscribed direction, to categorise each corner as being inward or outward facing, with a yes (Y) or no (N) response. The responses that subjects were required to make were either verbal, "yes" or "no"; motor, tap with left hand for "yes", right hand for "no"; or perceptual motor, pointing to successive Y's or N's on a sheet with randomly positioned Y's and N's. As a control subjects were required to classify words as nouns or not from sentences read out by the experimenter. The most important result was that subjects took longer to point to Y's or N's when imagining the F than when processing the sentences.

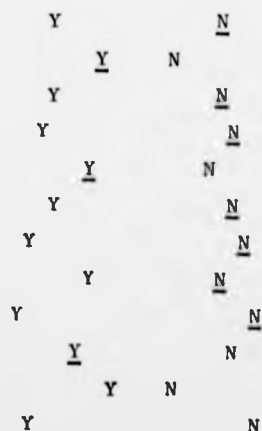
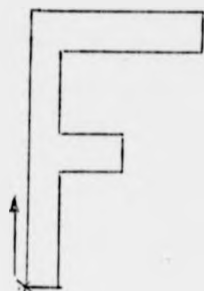


Fig 3.1 Brooks' "F" test. Subjects imagine a block diagram as above and then categorise each corner as being inward or outward facing. The perceptual motor task used "Y" and "N" in different locations as shown.

One explanation of this result is that a visual based pointing task interferes with visual imagery. Further experiments showed that the conflict is not visual but more abstract, arising from the different directions in which the subject had to monitor the physical array of Y's and N's and the imagined "F". When subjects had to respond by scanning a tactile array of Y's and N's with their eyes closed, similar differences between image and sentence processing occurred, suggesting a spatial rather than visual conflict.

Baddeley and Lieberman (reported in Baddeley, 1976) had subjects perform the F test while monitoring a particular type of concurrent stimulus. One group of subjects (visual, non-spatial) had to press a key whenever the brighter of two stimuli appeared. Another group of subjects (auditory, spatial) had to track a swinging pendulum by means of the sound it emitted. While blindfolded, the subjects were required to keep a light beam directed at a photo-electric cell on the pendulum. Whenever the light hit the cell the frequency of the sound emitted from the pendulum changed. The results showed that the auditory, spatial tracking impaired the performance on the "F" test, more than did the visual non-spatial task, supporting Brooks' spatial processing hypothesis.

One might attribute the differences in interference effects to the complexity of the response demanded of the subject, rather than the spatial content. In the Baddeley and Lieberman study auditory tracking is a more complex task which has a greater response demand than a brightness detection task with a key pressing response. This difference in task complexity and response demand could be responsible

for the observed performance differences in the "F" test.

Segal and Fusella (1970) asked subjects to form either visual or auditory images while performing a concurrent auditory or visual signal detection task. They found that reporting the presence of a faint blue dot on a screen was interfered with more by forming a visual image, than an auditory image. Forming an auditory image interfered with the detection of a faint tone embedded in white noise, more than forming a visual image did. Using signal detection theory they concluded that these findings were due to decrements in subjects' sensitivity (d') rather than changes in their criterion for responding, (β).

Recently, Schorr, Balzano and Smith (1978) extended Segal and Fusella's study in an attempt to identify whether interference caused by images was modality specific or relation specific. By relation specific they meant spatial or temporal. The experimenters varied the relation and modality of the imagery task. Subjects were instructed to form one of four types of images; visual spatial, visual temporal, auditory spatial or auditory temporal. While maintaining images of the type instructed, subjects had to perform a visual detection task which featured either a temporal or a spatial relation.

The temporal relation of the visual detection task required subjects to judge whether two dots of light appeared simultaneously or successively. The spatial relation comprised judging whether two dots of light were horizontally or vertically positioned.

The images that subjects were instructed to form were either

of two colours (visual) or two instrument sounds (auditory), a flute and a violin. The images were either to be of the two colours or sounds in different locations simultaneously (spatial), or of the two successively at the same location (temporal).

The experimenters found that there was more interference to the detection tasks with instructions to form visual images rather than auditory ones. No significant effects for the temporal or spatial nature of the image instructions were found. This was taken as supporting a visual/perceptual rather than a spatial/relational hypothesis of mental imagery. Only "skilled" imagers were used, which could have biased the results as there may have been a preference towards the visual modality. Generating an image with two "pieces" of information in it (two sounds or colours in different positions) might be more complex than generating two consecutive images each with one piece of information in it. The absence of an auditory detection task makes it difficult to compare different forms of imagery.

3.5.2. Chronometric Analysis

Chronometric analysis uses reaction times (RT's) to infer processing time in mental activities. Possibly the best known work on mental imagery using this technique is that of Shepard and his associates in the "transformations on representations of objects in space" experiments, Shepard and Metzler (1971), Cooper and Shepard (1973a,b), (1975) and (1978). Typically subjects are presented with two three-dimensional block diagrams, one of which is rotated either in the depth plane or the picture plane, or both. The subject's task is to identify the two diagrams as being same or different.

The results of these experiments were that the latency of a subject's response increases as a direct function of the angle of rotation. From these results Shepard infers that subjects actually rotate an analogue representation of the object, in their imagination. Further experiments by Cooper (1975) showed that giving subjects prior knowledge of the degree of rotation of the stimulus object reduced their RT's to a uniform level, regardless of the angle of rotation. By having subjects press a button when they were ready to receive the stimulus and then again when they made their decision, Cooper was able to record both preparation times and response times. When preparation time was analysed it was found to increase as a direct function of the angle of rotation. Consequently, giving subjects advance warning of the degree of rotation of an object allows them to prepare or anticipate the new configuration of the object before responding. This suggests that a similar process of mental rotation is carried out on already presented objects and expected objects.

In yet a further study Cooper (1976) had subjects imagine a familiar two-dimensional polygon, rotating in a circular field at a predetermined rate. Test shapes then appeared at both expected and unexpected orientations. Subjects were required to decide whether test shapes matched the original (except for angle of orientation) or not. The results showed that test shapes occurring at expected angles of rotation had uniform decision time, while test shapes in an unexpected orientation had decision times which increased as a direct function of the angle of departure from the expected orientation.

Finally, Cooper and Podgorny (1976) found that RT increased uniformly with the angle of rotation independent of the complexity of

the stimulus. Thus it seems that it is the act of mental rotation which affects RT, not amount of information contained in the stimulus. This distinction between complexity demands and specific resource or process demands suggests that spatial processing of images is a distinct cognitive process. By using the RT to decide the equivalence of two objects, Shepard and his associates have been able to conclude that images of objects are represented in an analogous way to the actual display and that this is closely linked to the perceptual inputs.

Another chronometric approach to the study of mental imagery has been that of Kosslyn and his associates. Kosslyn bases his work upon a model of mental imagery which resembles a computer controlled display on a cathode-ray-tube (C.R.T.). Images resemble displays on a CRT which can be "looked-over" by a "mind's-eye". Consequently his experiments have been directed at such topics as "scanning", "zooming in on", or "magnifying" visual images and analysing the time taken to perform these tasks.

Kosslyn (1973) gave four groups of subjects ten line drawings of real objects, (e.g. flower, aeroplane, clock-tower). Two groups were instructed to encode an image of the objects, while the remaining two groups were instructed to verbally describe the objects and encode their descriptions. An RT task then followed in which the name of a given drawing was presented and followed by a test probe which was a possible property of the object. Half the time the object drawing had included the property and half the time it had been absent. Subjects were required to respond if the property had been included by pressing a button. In addition one group of imagers was instructed to focus on one part of the image prior to the test probe, while the

other imagers were instructed to focus on the whole object. Similarly, the verbal group had to either verbally describe a given end of the drawing or describe the whole drawing prior to the test probe.

The results were that both the imagery groups had quicker RT's than the verbal encoding groups. The RT of the imagery group which had to focus upon one end of the drawing increased as a function of the distance of the probe property from the point of focus independently of direction. A similar increase in RT occurred in the equivalent verbal encoding group but this was not independent of direction.

In this experiment Kosslyn uses the time taken to scan images as a tape measure with which to assess the properties of mental images. He assumes that if distance regulates the time to scan between portions of the image then images can be thought of as containing spatial information, and preserving the relative internal distances among portions of objects.

However, since the amount of information and the distance between parts of the picture were highly correlated one cannot distinguish between increases in RT due to distance and increases due to information. Consequently, this experiment cannot distinguish between latencies in RT caused by scanning a visual image and those caused by searching an associated network as in Anderson's (1972) FRAN model.

More recently, Kosslyn, Ball and Reister (1978) separately manipulated the number of items in the display and the distance between parts. In a letter classifying experiment they found that the time to classify the probed letter increased linearly with distance between

letters, and independently of the number of interpolated letters. Similarly in a map experiment in which subjects imagined a map with various landmarks on it, RT to a test probe increased with distance between objects and independently of the number of objects. Finally in a series of experiments involving faces, subjects were presented with drawings of faces containing various coloured eyes and with various distances between the eyes and the mouth. When asked to imagine the face, then fixate on the mouth, and then report the colour of the eyes, RT increased as a function of the distance from eye to mouth. Other instructions to imagine the faces at either "half-size", "full-size" or "overflowed" until the mouth filled the image, produced similar differences in RT to identify eye colour. Overflow took longer than full-size and full-size took longer than half-size.

From these and other similar experiments reviewed in Kosslyn (1980), he concluded that images are "quasi-pictorial" representations depicting all the information normally contained in a picture. A fuller description of Kosslyn's model of mental imagery follows in the next section (3.5).

Kosslyn has amassed a great deal of experimental evidence to validate his assumptions about the relationship between image processing and RT. One cannot help wondering what it must feel like to be a subject in his experiments. The complicated nature of his instructions to form images, scan them, zoom in on parts, magnify or shrink the whole image, must leave some of his subjects in a state of bewilderment. It seems highly probable that the pressures brought about in such experiments may encourage experimenter effects and demand characteristics, as

described by Orne (1962) and Rosenthal (1967).

Other experiments have been performed by Posner and Mitchell (1967), Posner, Boies, Eichelman and Taylor (1969), Posner (1973), Paivio (1971) and (1977), Paivio and Begg (1974) and Moyer (1973) which also use RT's to infer imagery processes. As in Shepard's and Kosslyn's experiments subjects are asked to judge two stimuli as being similar or different. However, the match can be based upon a shared attribute such as a common verbal label or on some physical property. Consequently, inferences about the nature of a code used to store information in memory are dependent upon the relationship between the stimuli and the subject's RT.

Posner and Mitchell (1967) instructed subjects to indicate if pairs of letters were the same or not; same could have been in terms of physical identity (AA or aa), name identity (Aa or Bb) or rule identity (Au - vowels). They found that "same" responses were faster for physical matches and slower for rule matches. This can be taken as evidence for a separate image form of representation based on the visual/perceptual properties of a stimulus as Paivio (1978) suggests. Alternatively, the same results can be used as evidence for a levels of processing view of memory such as Crnik and Lockhart's (1972).

In later experiments, Posner et al (1969), subjects were presented with the first letter auditorily, the second visually and were given prior knowledge as to the upper or lower case nature of the second letter. Posner et al found that audio-visual matching was as efficient as visual-visual matching; while visual-name matching produced slower RT's. It seems that subjects could have generated visual images

of the auditorily presented letters with which to compare the second stimulus.

Paivio (1978) reports a study by Rosenfield (1967), which used Carmichael, Hogan and Walter's (1932) technique of presenting ambiguous figures with labels. Subjects were first presented with a visual or verbal stimulus, followed by a visual stimulus in one group and a verbal stimulus in another. The task for the subject was to judge the two stimuli as the same or not. It was predicted that if a common (amodal) coding was used the subject's RT should be unaffected by the type of comparison. If a pictorial code was used then RT's should be quicker if the second stimulus is a picture. If a verbal coding is adopted then RT should be quicker if the second stimulus is verbal. The results were that faster RT's occurred when the second stimulus was a picture. Furthermore, when the two stimuli were of the same type (visual or verbal) RT's were faster than if they were different. In a similar study Paivio and Beggs (1974) required subjects to search through arrays of pictures or words for a target item. Search times were consistently faster for picture targets with picture arrays than any other combination. When, in the same study subjects were presented with face and name pairs the face-face comparisons were faster than the name-face comparisons as predicted.

Another variation on the same-different theme is Moyer's (1973) experiment using the "symbolic distance effect" in which subjects are asked to identify the larger of two objects. An underlying assumption here, is that RT to choose between two stimuli varies inversely with the magnitude of the perceptual differences; Johnson (1939). Moyer presented names of animal pairs, such as "dog-mouse" and "rabbit-mouse" and asked

subjects to judge which of the two was the larger by a switch under the appropriate name. Reaction time increased as the magnitude of the actual size differences increased. This was taken to indicate that size information was stored in an analogous way and the comparisons were made in an image processing system. Paivio (1975 a,b) found similar results when judgements were made across conceptual categories, e.g. mouse-toaster produced faster decision times than cat-toaster. He also found that contrasting pictures of objects produced faster decision times than contrasting names, even when the pictures were scaled to give incorrect size information.

However, Banks and Flora (1977) instructed subjects to rate animals on a 1-10 scale of intelligence. A second group of subjects was then presented with pairs of these animals and asked which of the two animals were the more intelligent. They found that judgement time decreased as the rated intelligence of the two animals became more similar. Similar effects for judgements of ferocity were found by Kerst and Howard (1977). Paivio (1978) found that judgements between the pleasantness of words had a similar inverse relationship. Paivio, however, persists in believing that an imagery system must be involved in these judgements.

3.5.3. A Summary of the Investigation of Imagery after Behaviourism

Before moving on to assess theories of mental imagery, a summary and evaluation of the techniques used to investigate mental imagery is worthwhile. The quantitative, subjective assessment of mental imagery has been concerned with the identification of the properties of imagery, by questionnaire assessments and the correlation of these properties with other psychological tests. A good review of this area

is provided by Richardson (1980). The main characteristics to emerge add little to Galton's early intuitions. Factors such as vividness and concreteness of visual imagery, while being widely reported, may not be of any explanatory use. The experiments of Durndell and Wetherick (1976) cloud the usefulness of such approaches. One assumption is that imagery is a stimulus based potentiality as well as a subject based capability.

Imagery questionnaires, as they are currently used, have little predictive or explanatory power. It is possible, however, that questionnaires could provide us with some indication of the kind of things which people are able to report about their image experience. Furthermore, the ratings of concreteness and imageability of words seems a reliable indicator of their probability of recall. This approach does not give much insight into what kind of imagery processes might function within the cognitive system.

The objective assessment of mental imagery has tried to place image processes within a cognitive system. The techniques employed have fallen into two main categories; selective interference on the one hand and chronometric analysis on the other. The former has been less frequently used but has led to some apparently reliable conclusions about the relationship between images and spatial representations. The major weakness with this approach is the strength of the assumption that interference is caused by competition for some specific cognitive process. It has been pointed out that some experiments could have manipulated a general capacity response demand rather than a specific cognitive resource. The application of this technique permits some flexibility. Some experimenters have used imagery as an inter-

ference agent to other cognitive tasks, while others have used cognitive tasks to interfere with image processes.

Chronometric analysis assumes that mental processes can be inferred from reaction time data. Increases in reaction time are assumed to reflect increases in the amount of mental processing. Unfortunately subjects can and sometimes do, choose to make slower responses. Consequently reaction times may not be able to distinguish between processing demands and subject response strategies.

Three different types of reaction time studies have been identified; mental rotation, image scanning and mental comparisons, including the symbolic distance effect. Mental rotation of objects has been quite successful in reliably identifying spatial properties of visual images. Claims about analogue representations are not as well-founded, since discrete operations such as transformations of matrices could conceivably be performed to produce similar effects. No reference to images has been made in this type of experiment, therefore subjects are less likely to "co-operate" with the experimenter, although use of tacit knowledge cannot be ruled out.

Image scanning, and other similar procedures have been widely used to support a CRT model of mental imagery. The findings consistently follow this model, although there are a number of criticisms. The major reservations with this technique are that the complex instructions to subjects might enforce compliance by the subject to the experimenter's hypothesis. Frequent references are made to images and operations to images by the experimenter during the experiment. Finally, the evidence for spatial representations in images is strong but there is little

evidence for other pictorial properties. Mental comparisons have been used more widely than other RT techniques within mental imagery, though perhaps not as extensively. The assumptions are similar to other RT studies but the findings are open to alternative explanations. Experiments of this kind are, as yet incapable of isolating specific forms of representation in images. Paivio's dual coding model (to be described in full later) which depicts visual/perceptual and verbal processing systems reflects the inadequacy of this approach to distinguish between visual coding and other explanations of the same data.

3.6. Theories of Mental Imagery

The remaining sections of this chapter present a review of the major theories of mental imagery. The models of imagery put forward by Paivio (1978) and Kosslyn (1980) are contrasted with the propositionalist accounts favoured by Pylyshyn (1973) and Anderson (1978). An alternative model of imagery is suggested by Weimer (1977) in the framework of a "motor theory of mind". Finally, Neisser's (1976), (1978) schema theory presents imagery as an everyday cognitive event. The theme is one of images and representations.

3.6.1. Paivio's Dual Coding Model

Dual coding theories have been suggested which identify two distinct forms of representation for images and verbal information, Wallach and Averbach (1955), Brooks (1968), Tversky (1969), Paivio (1971), (1978) and Posner (1978). The most recent and well defined theory being that of Paivio's dual coding model. Paivio's model suggests that verbal and image systems constitute two distinct forms of representation, processing and organizing characteristics. The

relationship between the image system and the verbal system is shown in Figure 3(ii) which is taken from Paivio (1978).

Imagens are assumed to be perceptual isomorphs or analogues of objects and events, containing information such as size, shape and colour. Imagens are the representational units used to generate conscious images and to process pictorial information.

Logogens are taken from Morton's (1969) model of word recognition and are discrete representational units which correspond to the functional units of natural language. Unlike imagens these units are arbitrarily related to perceptual inputs.

According to this model the two systems function independently; for this reason we are able to simultaneously perform such tasks as watching a flow of traffic while answering crossword clues. When two tasks require simultaneous use of a particular system inhibition occurs, hence one cannot answer crossword clues while reading a book, unless the two are related and become one task. The inter-connections between the two systems permit objects and pictures to be named, and pictures to be drawn from the names of objects; although there could indeed be some items we cannot name or concepts we cannot imagine.

The most systematic evidence for distinct verbal and image codes comes from the studies of Posner and his associates, and Paivio mentioned earlier. These experiments use RT measures to detect differences between matching pictorial and verbal stimuli. The independence between the two forms of matching and the lower RT for pictorial matching leads Paivio to hypothesize a dual coding model of cognitive processing.

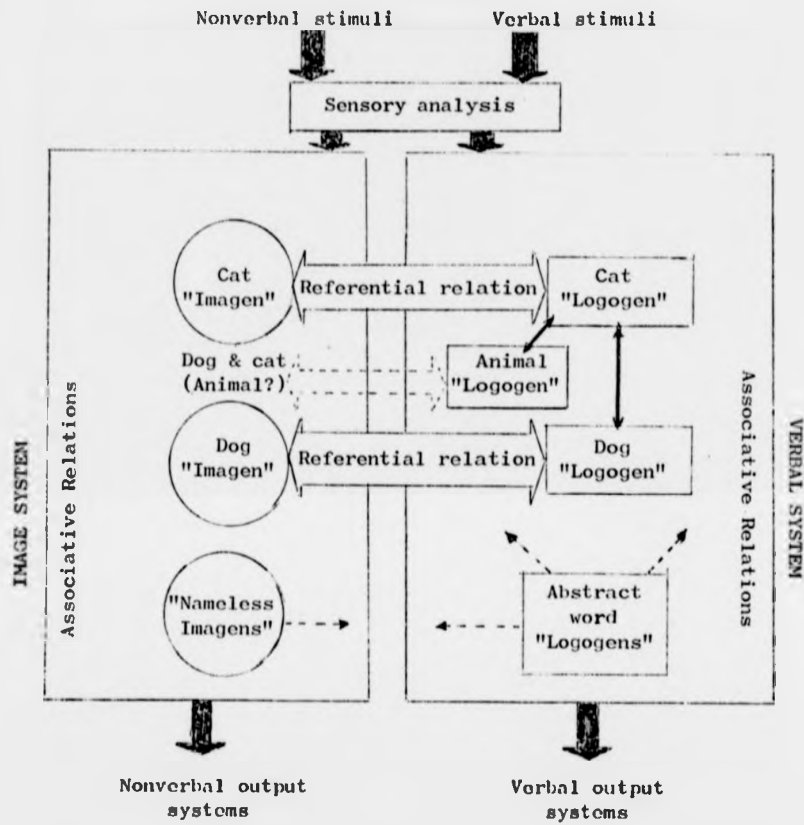


Fig 3.2 The verbal and image systems of Paivio's dual coding model showing the representational units ("imagens" and "logogens") and the interconnections between the image and verbal systems. (Paivio, 1978 p.381)

The ability of the verbal and image system to translate inputs into the opposite system suggests a common code exists between the two systems. The existence of an underlying common code makes further specific coding systems redundant. Anderson (1978) claims that any arguments made for specific coding systems can also be accommodated by a common coding system. If there is a translatory mechanism which can deal with information from multiple-codes then it is more parsimonious to represent information in a common code. The dual-coding model accommodates pictorial and verbal information but not motor, emotional or social information. Does this mean we must add an additional distinct representational system for each of these other cognitive processes?

A common coding system does not necessarily diminish the functionality of an image system. Imagery as a distinct process, acting on amodal representations, is suggested by Richardson (1980). In this conception, imagery functions as a method of recall and rehearsal which permits memory representations to be actively integrated and differentiated.

3.6.2. Kosslyn's CRT Model

Kosslyn (1980) proposes that images resemble displays produced on a cathode-ray-tube (CRT) by an executive computer programme. This model has been a prototype to enable Kosslyn to develop a computational simulation of image processes. He regards images as:-

" temporary spatial displays in active memory that are generated from more abstract representations in long term memory." Kosslyn, Pinker, Smith and Schwartz (1979) p.536

The main force of Kosslyn's model is not aimed at a description of images,

but at the process which can be performed on them:-

"Interpretive mechanisms (a mind's eye) work over (look at) these internal displays and classify them in terms of semantic categories as would be involved in realizing that a particular spatial configuration corresponds to a dog's ear, for example." Kosslyn et al (1979) p.536

He does, however, strongly claim that images are quasi-pictorial in that they "depict" rather than "describe" information in a spatial medium.

Images are thought to be based upon two sorts of data structures:-

- a) a surface representation/matrix or visual buffer, which is a quasi-pictorial entity in working memory;
- b) a deep representation in long term memory from which the surface representation is derived.

Kosslyn regards the surface representation as a "proper image". Images are represented here by a configuration of points in a matrix, which he calls a "visual buffer". This visual buffer is also involved in perception and functions as if it were a co-ordinate space. Images, (or in the case of direct perception, information) are represented in this space by selectively filling in cells of the matrix. The information which can be contained within this surface representation includes spatial extent, brightness, contrast and veridical correspondence between points on the object and points on the representation. Kosslyn suggests that some of the properties of this surface representation are that the rate of firing of a cell decreases with the distance of the cell from the centre of the matrix. Consequently images and percepts fade towards the periphery. The surface representation has only limited resolution, so that small objects become obscured and the spatial medium

in which the images occur has a limited extent, with a central region of high activation. Finally the matrix of the surface representation corresponds to a visual short term memory. Representations on this matrix decay with time but can be refreshed by rehearsal.

The second data-structure in Kosslyn's model of imagery is a deep representation from which the surface representation is generated in the case of images. Two sorts of deep representation are described; that used to store "literal" or "depictive appearance" data, and a factual store of "descriptive, conceptual" data. The literal (or perceptual) store depicts how information in the surface structure is arranged. The factual store is of a propositional nature and contains information about "parts" of images and procedures for identifying those parts. Other information in this store includes the name and address of a particular object representation, names of superordinate semantic categories to which the object belongs and a classification of the object's size.

Kosslyn's simulation model emphasises the processes which images undergo. This simulation model includes procedures, such as PICTURE, PUT and FIND which operate on "literal" data stores to produce and transform images on the surface representation. These hypothetical procedures are based upon subjects' actual performances in imagery experiments.

Kosslyn's research has been devoted to identifying the operations which can be performed on images and then incorporating these findings within his model. Unfortunately, no experiments to test the model itself have as yet been devised. This theory reflects a formal

simulation of a CRT proto-model rather than a simulation of mental imagery. The adequacy of such a proto-model to provide an explanation of mental imagery is limited. The model assumes, for example, that something resembling a "CRT display screen" exists within the cognitive processing system. There is some suggestion from Marr (1975) that perceptual processing utilizes a visual buffer to construct a "primal sketch" of objects, but this is supposed not to have any "screen-like" properties and to be inaccessible to conscious processing. While computer simulation is a useful aid to theorising, a simulation is purely a description of a system, and not a test of that system. Consequently, any procedures which function within the simulation need not be present in actual behaviour.

Kosslyn's model does not attempt to show how imagery might function in a cognitive system, his main concern is with how an image system itself might function. Kosslyn claims that images are distinct forms of representation, with separate propositional and image representational systems (i.e. "literal" and "factual" stores). These two systems interact to produce images and classify objects. Therefore, Kosslyn's CRT model seems to be an extension of Paivio's dual coding model of mental imagery in this respect.

3.6.3. Neisser's Model of Mental Imagery

Neisser (1976, 1978) presents an informal account of how images function within a "schema" theory of cognition. In this model images are "plans" for perceiving and acting. Cognition is seen as a dynamic process in opposition to the temporal flow-chart models of information processing.

"In an information processing model an image is treated as a train of processes that arise in the middle of the apparatus instead of at the left-hand-end and then proceeds along the sequence normally." Neisser (1978) p.80

Neisser claims that perception is most often veridical and always continuous. To achieve this continuous activity "looking" involves anticipating inputs as well as interpreting "picked-up" information. Schemata function as anticipations and plans which, together with the information in the environment, determine what is seen. Perception does not involve constructing an image for inspection by an "inner man" but produces plans for obtaining more information. In Figure 3.3 Neisser's "perceptual cycle" is outlined showing the dynamic nature of perception and action.

Neisser implicitly assumes a common code, since he notes that perceptual activity is not restricted to a single sensory system. Information from one modality produces explorations, which rely on plans or images in another. Schemata accept information from many sources simultaneously and direct explorations of many kinds.

Mental images are thought to be active but as yet unfilled expectations of anticipated information. They are not only able to operate as input processes, but are also able to anticipate actions, as in preparing to hit a cricket ball, the batsman imagines his strike before the ball hits the bat.

While an image represents stored information it is not used as stimulus information would be. We do not examine our images as we would a real object. It is not a picture but a plan for obtaining information. A verbal report of a visual image, therefore, is at most

"In an information processing model an image is treated as a train of processes that arise in the middle of the apparatus instead of at the left-hand-end and then proceeds along the sequence normally." Neisser (1978) p.80

Neisser claims that perception is most often veridical and always continuous. To achieve this continuous activity "looking" involves anticipating inputs as well as interpreting "picked-up" information. Schemata function as anticipations and plans which, together with the information in the environment, determine what is seen. Perception does not involve constructing an image for inspection by an "inner man" but produces plans for obtaining more information. In Figure 3.3 Neisser's "perceptual cycle" is outlined showing the dynamic nature of perception and action.

Neisser implicitly assumes a common code, since he notes that perceptual activity is not restricted to a single sensory system. Information from one modality produces explorations, which rely on plans or images in another. Schemata accept information from many sources simultaneously and direct explorations of many kinds.

Mental images are thought to be active but as yet unfilled expectations of anticipated information. They are not only able to operate as input processes, but are also able to anticipate actions, as in preparing to hit a cricket ball, the batsman imagines his strike before the ball hits the bat.

While an image represents stored information it is not used as stimulus information would be. We do not examine our images as we would a real object. It is not a picture but a plan for obtaining information. A verbal report of a visual image, therefore, is at most

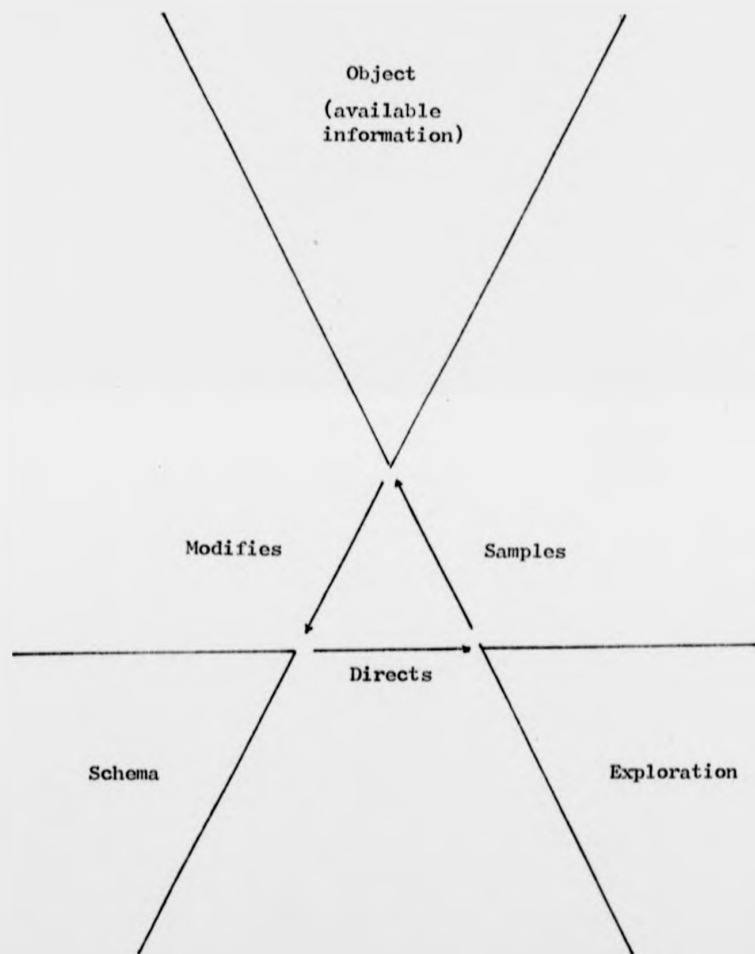


Fig. 3.3 Neisser's perceptual cycle, taken from "Cognition and Reality". 1976 p.21

a report of what you are prepared to see, not what you do see. Images can be modified, though, in order to match changes in the environment or our own desires.

Neisser appears to regard images as having primarily a spatial nature and to be part of a cognitive process which is familiar to all subjects.

"This account of imagery is not introspective. Any organism which anticipates the layout of objects in the environment and directs appropriate movements as a result may be said to have spatial imagery." 1978 p.99

Images are not exclusively visual, as anticipatory schemata can direct reaching, touching and listening as well as looking. It is the spatial arrangements of objects rather than the way they look which is contained within an image.

One prediction made by Neisser is that if images are anticipatory schemata then eye movements in looking and imagining should be similar. However, as we can look at things in many ways the predicted eye movements cannot be derived. It is possible that in a situation involving systematic motion, such as in tennis, some predictive eye movement patterns can be generated. Antrobus, Antrobus and Singer (1964) found similar eye movements in "imagers" and "lookers" in a tennis match situation. Hebb (1968) also suggested that eye movements might be an organising feature in imagery.

Much of Neisser's model is purely speculative and not explicit enough to generate more than a few testable predictions. This model is far less explicit than are those of Paivio and Kosslyn. Neisser does, however, present a functional model of how imagery is accommodated within a cognitive framework. Furthermore, this notion of imagery is

capable of describing all types of imagery in everyday situations. Finally, Neisser seems to use the terms anticipation, plan, image and schemata with a certain amount of flexibility and interchanging, making it difficult to interpret what each of these terms is being used to describe.

3.6.4. Motor Theories of Mental Imagery

Motor theories assume that representations are made in terms of motor acts; as distinct from motor imagery which relates to images of movements, which may be in some other form, such as "pictorial". The earliest motor theories of imagery can be found in Bain (1855) and Washburn (1916). More recently Weimer (1977) suggests that images are represented in terms of skilled actions. Weimer claims that the mind is intrinsically a motor system and that everything mental is a product of constructive motor skills. His arguments are aimed at showing the equivalence of perception and action but he seems to prefer an action representation system which is capable of interpreting perceptual stimuli. Perception and action are indeed intrinsically linked within a cognitive system, but to claim that this representation is motoric in nature is dubious. The present understanding of how motor acts are represented does not permit Weimer to make any claims about what that representation is. If one assumes that motor acts are represented as "motor programmes" then one must provide a definition of a motor programme. Perhaps he would agree with the current belief that a motor programme is a set of abstract rules which control the output of lower motor production centres. This definition is still sufficiently vague to be of little use.

However, assuming that some form of action representation

can be agreed upon there still remains the problem of explaining how it is that motor acts, and indeed other events, can often be perceived before they can be produced. For example one might be able to recognize a good dive from a diving board without being able to produce such a dive oneself. If imagery is to be based on an action production system then how do we form images of actions that we cannot produce? Furthermore any improvements in performance which occur as a result of imagining would be difficult to explain if imagery was the reactivation of our existing motor programme. Studies on second language learning and child language acquisition suggest that both adults learning a foreign language and children learning a first language can perceive and understand speech before they can produce it, (Glucksberg and Danks 1975). Therefore perceptual and production processes seem to have some functional independence. Weimer claims that all images and all mental acts are "motoric"; if by motoric he means part of a cognitive system which controls action then this is no different to Neisser's claim. It seems that what is lacking from this motor theory of mental imagery and of motor theories of mind is some specification of the mental representations involved.

The specific processes of images are not discussed in Weimer's account but it is assumed that there is no distinction between a sensation and an image. A similar pattern of excitation follows instructions to imagine an event as accompanies the actual event itself (or its direct sensory consequences).

This model of mental imagery does not specify how images are formed or what function they fulfill. Any suggestion that images (or thought) consist of motor programmes of skilled actions has diffi-

culty in explaining how novel images are generated. Furthermore, a motor theory of mind assumes that all "programmes" are prewired, otherwise perceptual recognition processes could not be accommodated since recognition precedes production in skill acquisition.

3.6.5. Propositional Accounts of Mental Imagery

The major figure on the propositionalists' view of mental imagery has been the research of Pylyshyn, (1973, 1978, 1980). He disagrees with claims that mental images are units of representation, or explanatory constructs for cognitive psychology. Pylyshyn does not question the existence of images, or the empirical results of imagery experiments. He believes, instead, that images are not explanatory constructs and that one cannot explain the cognitive processes involved in imagery without reducing "images" to a more primitive level. It is the representational status of images on which Pylyshyn has most to say. He believes that all explanations need to be at a representational level and adopts a reductionist, mechanistic approach. He claims that mental representations cannot be investigated by introspective techniques since subjects do not have conscious access to the functional representation (i.e. one that figures in human information processing).

One argument is that if subjects can translate between verbal and pictorial codes (as in Paivio's model) there must be some representation which is more abstract and not available to conscious experience. He suggests that this representation is amodal and of a propositional nature.

A proposition, according to Pylyshyn, is an assertion which

can be true or false. Both pictures and words must be interpreted before their conceptual contents can be represented. Propositions are found in the deep structure of language and pictures, but are not necessarily expressible by natural language or drawings. Thus the concepts and predicates in propositions may be perceptually well defined without having any explicit natural language level. Similarly motor acts might be represented as abstract mental concepts.

A propositional representation is one which does not correspond to a raw sensory pattern, but is highly abstracted and interpreted. It is not different, in principle, from the knowledge asserted by a sentence, or potentially asserted by some sentence. There is a dependence on the classification of sensory events into a finite set of concepts and relations. Consequently, what we know about some event or object is formally equivalent to a finite number of logically independent descriptive propositions.

Pylyshyn regards Baylор's (1972) programme of a block visualisation task as evidence for a propositional representation. This model hypothesises two closely related representational systems, the S-Space for symbolic factual information and the I-Space for imaginal information. These two systems closely resemble Kosslyn's model of mental imagery, but they make use of a propositional framework. This propositional account reduces imagery to a product of recall in working memory.

Pylyshyn (1978) believes that representations are structured descriptions and that early stages of perceptual processing are autonomous of higher cognitive processes. Any arguments for analogue representations, such as Shepard's mental rotation experiments, can be

accommodated by a propositional model. The increase in RT accompanying a mental rotation would still be produced if subjects had represented a rule system about what operations have to be performed on a particular structured description to arrive at a particular endstate. Pylyshyn suggests that such modelling, as that in production systems, support a propositional account of mental representation. "Production systems" have been used in artificial intelligence to represent procedures for achieving desired goals (Simon, 1973). (A production system for a simple motor skill is described in Chapter XII).

Anderson (1978) points out that we cannot distinguish between processes which act on representations and representations themselves. Therefore, any attempt to distinguish between a propositional and analogue representation is impossible. He notes that this is because we are looking for a behavioural distinction, whereas we ought to look for neurological and physiological constraints. These must be looked at, in addition to subjective criteria such as parsimony, efficiency, optimality and plausibility, in future evaluations of cognitive models.

5.7 Mental Imagery - Some Conclusions

The extent of any theoretical overlap between MP and mental imagery is not reflected within cognitive psychology. While cognitive psychology largely ignores MP, research workers in MP attribute its effects to cognitive processes of mental imagery. The main limitations to imagery research within cognitive psychology relate to the usefulness of imagery as an explanatory construct. From the early days of psychology

in which images were the "stuff of mind", mental imagery has been a controversial topic for investigation. The main reason for this appears to be the inability of psychologists to derive an acceptable paradigm for its investigation.

Theories of mental imagery have been concerned with the representation of visual images. There are those who argue that images are coded "raw" in memory, while the propositionalists argue that imagery has no explanatory powers at all in psychology. The functional properties of imagery are often used to distinguish between these two arguments. It is unfortunate that the functionality argument and the representation argument are often treated as one and the same. As a result it is often argued that images are not represented in memory and that they have no functional value to a cognitive system.

The way out of this problem seems, in the first instance, to be to show that arguments about the representation of images and the functionality of images are indeed two separate arguments. One can then address those questions about representations independently from those about the functions of images. It may be that images do indeed constitute an explanatory construct for psychology but that they are not distinct units of representation.

CHAPTER FOUR

THE FUNCTIONAL EQUIVALENCE OF IMAGES OF MOVEMENTS AND MOVEMENTS

The review of the mental practice literature revealed that improvements in performance following MP are most frequent when subjects have visual cues, relating to the task, to aid them. Of the seven hypotheses offered to explain the effects of MP four are capable of encompassing all the empirical evidence. These are:-

1. trace consolidation
2. symbolic/perceptual imagery
3. psychoneuromuscular imagery
4. selective attention

These four hypotheses are not mutually exclusive since they refer to three different levels of explanation. The first level of explanation is concerned with describing how knowledge is retained and to some extent organised in memory but not with how that knowledge is represented. Trace consolidation is an explanation of how MP might produce less forgetting by organising memory.

The second level of explanation is directed towards understanding how knowledge is represented and the process that might act on that representation. Two types of representation have been proposed; a) symbolic/perceptual which specifies a quasi-pictorial type of representation, and b) psychoneuromuscular which specifies a motor type of representation. Included within this level of explanation is a process which acts on these representations to produce performance improvements. This process is imagery. Imagery is conceived not as a form of repre-

sensation but as a specific process which enables the mental execution of an action.

The third level of explanation is not concerned with the retention of knowledge, the representation of knowledge nor a specific process enabling the mental execution of actions. The selective attention hypothesis offers an explanation at the level of resource allocation to an unspecified process. This level of explanation is concerned only with how any process might be put into operation within a finite system.

The level of explanation at which this research is aimed is the second, the type of representation and the specific process or processes which act upon that representation. Increased retention of knowledge by a process similar to trace consolidation may be a direct consequence of MP. MP may indeed necessitate selectively attending to a particular process. Neither of these levels of explanation captures the essence of MP though. They may be consequences or necessities of the second level of explanation but they are not specific enough to explain what MP is. Instead an explanation which permits the mental execution of an action by supposing a form of representation and a process which acts on that representation captures MP. It is this kind of explanation which cognitive psychology, as a whole, seeks for behavioural phenomena.

Recently, Byrne (1981) has shown that subjects who are asked to describe the ingredients and the procedure used to cook two dishes (lemon meringue pie and sherry trifle) have a high consistency in their ordering of ingredients and steps. Furthermore they put pauses and superfluous comments at the end of phases of cooking, e.g. pastry,

filling, topping, which correspond to actual phases in the cooking of these dishes. Byrne suggests that subjects mentally cook these dishes. He states that any explanation of mental cookery needs to be in terms of the mental execution of plans of action. He does not go very far in specifying what "mental cookery" is. What is needed is an explanation of how these plans are represented and what process acts upon these plans to produce their mental execution. Consequently any explanation of MP calls for the specification of a type of representation and a process to act on it. The most likely process candidate being mental imagery.

A review of the mental imagery literature, in the previous chapter, found very little literature pertaining to movements or actions. There is, however, a considerable amount of theoretical and empirical literature on visual imagery. There are two opposing theories of mental imagery, namely propositional versus analogue representations. Extremists such as Kosslyn (1980) and Anderson (1979) have modified their views on imagery. They regard imagery as a process which acts upon representations to produce functionally specific behavioural effects. This is a somewhat simplified account of their views, there still is disagreement about the type of information represented, the nature of this representation and the process of image generation. Pylyshyn (1980) still maintains that images have no function within cognition and that they are merely epiphenomena of some other cognitive process.

From these arguments several methods of exploring mental imagery have emerged, questionnaires/introspection, chronometric analysis and selective interference. Questionnaires and introspections

have been shown to have little predictive value or explanatory power, Durndell and Wetherick (1976). Chronometric analysis assumes that mental events can be accurately measured by reaction times (RT). Any increase in RT is assumed to be caused by an increase in mental processing. It is quite conceivable that an increase in RT may be due to a particular strategy of responding. An example of this is the speed accuracy trade-off, where some subjects actively choose to respond more slowly. Selective interference carries with it an assumption that stimuli which interfere with imagery (or any other cognitive process) involve similar cognitive processes. Nevertheless some experimental paradigms seem to be emerging from this turmoil which might be usefully employed to investigate mental imagery and in particular imagery of movements as might relate to mental practice.

Few studies of imagery have had any direct bearing on movements and actions. Sheehan's revised form of Betts' questionnaire includes questions about kinaesthetic imagery. There are two recent experiments by Kohl and Roenker (1980) and Hall (in press) which consider imagery and movements. Kohl and Roenker found that positive transfer from one limb to another occurred when subjects imagined tracking on a pursuit rotor with the opposite hand. Ammons (1958) amongst others, had previously shown that physical rehearsal with one limb produces positive transfer to the contralateral limb. Kohl and Roenker have shown that a similar positive transfer also occurs when subjects imagine tracking with one limb. The results of their experiment present problems for a psychoneuromuscular explanation or motor theory of mental imagery. The psychoneuromuscular explanation suggests that imagery of movements involves subliminal neuromuscular activity on the imagined limb, Jacobson (1932), Shick (1970) and Weimer (1977).

However, in this experiment subjects were instructed to imagine using one specific limb but were later tested for a transfer effect with the opposite limb. Imagery had facilitated an improvement in a non imagined limb, which would not have been subliminally activated according to the above theory. This suggests imagery of movement involves something other than the subliminal activation of a particular limb.

Hall has adapted Paivio's approach to investigating imagery by presenting subjects with patterns of movements and asking them to rate the imageability of those movement patterns. He then tested their ability to recognise particular movement patterns in a series of 25, two-choice, recognition tests. Finally he tested subjects' recognition for high and low imagery rated movement patterns. The results showed that movement patterns which had been highly rated for imageability also had higher recognition scores. From these results Hall concludes that instructions to use imagery can influence the learning and retention of movements. Furthermore he suggests that images of movements take the form of quasi-pictorial representations.

The experiments of Kohl and Roenker (1980) and Hall (in press) are encouraging. It is possible that subjects in the Kohl and Roenker experiments anticipated the bilateral transfer effect and imagined using either hand. Furthermore, the results could be accounted for by a motor theory of imagery if, as Fowler and Turvey (1978) suggest, motor activity is controlled by highly organised units. Imagery may involve motor commands and activation of motor production centres at a level which specifies collections of muscle groups which are normally activated together as one "co-ordinative structure". Co-ordinative structures need not be directly connected muscle groups, for example the two hands

of a drummer form one co-ordinative structure when drumming.

The Hall experiment relies on subjective introspective reports of imagery ratings. It is conceivable that subjects might have inferred for themselves that patterns of movements which resemble regular pictorial patterns ought to be recognised more readily than irregular ones.

One of Pylyshyn's main attacks on mental imagery is that images are epiphenomena of more abstract forms of cognitive representations. Images can be considered as real psychological phenomena only if they can be shown to have some functional properties which are not direct derivatives of some underlying propositional or more abstract representational code. Images must be shown to produce new or different conceptualisations or configurations of representations. This means that imagery must have some effect on what is stored in memory, which could not have come about without the formation of an image.

A series of experiments are reported by Finko (1979, 1980) in which he was able to show that perceptual motor biasing, which normally occurs as an after-effect of pointing at targets while viewing the target through goggles fitted with displacing prisms (Welch 1978) can occur when subjects imagine either pointing at targets, the visual feedback resulting from pointing, or both. Subjects were seated in front of a target which was positioned approximately at arm's length from the subject. The important contrasts made were between groups of subjects who pointed at the target wearing goggles fitted with prisms, and subjects who imagined pointing at the

target and also imagined producing the appropriate errors in pointing. All groups of subjects were then required to actually point at the target (with their arms hidden beneath a screen). The results showed that errors in pointing in both groups were equivalent. From this and other experiments Finke concludes that imagery and errors of movement are functionally equivalent.

The essence of Finke's approach to the experimental investigation of mental imagery is to show that biasing or after-effects which normally occur in reality can occur when subjects imagine the same conditions. This approach has two advantages, first it uses an experimental situation which has less predictable outcomes (from a subject's point of view). The second advantage is that the results of the experiments may be taken as evidence for the functional properties of imagery.

If it can be assumed that mental practice is comparable with actual practice, to the extent that similar cognitive processes are involved then it would follow that processes which interfere with, bias, inhibit or produce after-effects in actual practice would have a similar effect in mental practice.

4.1. Experiment I

In short-term memory experiments using a linear positioning task, it has been shown by Patrick (1971), Craft and Hendrichs (1971), Stelmach and Walsh (1973) and Laabs (1973) that a novel movement interpolated between acquisition and recall of a standard movement interferes with recall. This interference is produced by distorting

the location of the recalled movement in the direction of the location of the interpolated movement. If movements can be rehearsed by means of mental imagery then it should be possible to instruct subjects to imagine the interpolated movement. Furthermore, if movements and imagery are functionally equivalent then similar biasing after-effects should occur at recall when the interpolated movement is imagined.

The first experiment tests the hypothesis that an imagined movement can produce a bias in short-term memory for linear movements comparable to that produced by actual movement. This bias is contrasted with errors produced in memory for linear movements when the same retention interval is filled with counting backwards in threes. As counting does not, intuitively, involve any incompatible movement information, such as spatial locations, distances or velocities, it is hypothesised that this activity will have very little interfering effects upon a subject's memory for a linear movement.

In contrast to imagining or performing a different movement, imagery of the standard movement should consolidate the memory trace. The inclusion of a condition where subjects are asked to imagine the movement they have just performed should result in a lower error-at-recall than the backwards-counting control group.

4.1.1. Method

(1) Experimental Design

A two-factor independent groups design was used, type of interpolated activity having four levels and location/distance of movement having two levels. The types of interpolated activity were

counting backwards in threes, rehearsing by imagining the same movement, making a novel movement, and finally imagining a novel movement. The location/distance of movement was varied by altering the extent of the movement such that novel interpolated movements were either half or double the original movement.

(2) Subjects

48 right-handed subjects were randomly selected from a pool of 70 undergraduate volunteers, from the Psychology Department at the University of Warwick. The only constraint being equal numbers of each sex. Subjects were then randomly assigned to one of the eight experimental groups, six per group, three male and three female.

(3) Apparatus

The apparatus consisted of one linear slide comprising two 75 cm steel rods of 1 cm diameter mounted in parallel 2 cm above a plywood base. An alloy block 5 cm x 5 cm x 4 cm was free to slide along the two steel rods, the top of this block having a circular holding knob of 2 cm height and 1.5 cm diameter. Attached to one side face of the slide block was a pointer which aligned to a millimeter scale hidden from the subject's view. Along the track, on either side of the slide knob, were two adjustable stops which altered the useable track length. Parallel to the slide track was a third steel rod, 75 cm long and .25 cm diameter, upon which were mounted two adjustable light units, one red, one green. The whole apparatus was placed on a table 70 cm high. The lights were timed and powered to flash at regular intervals by two "Birkbeck timers" (see Fig. 4.1).

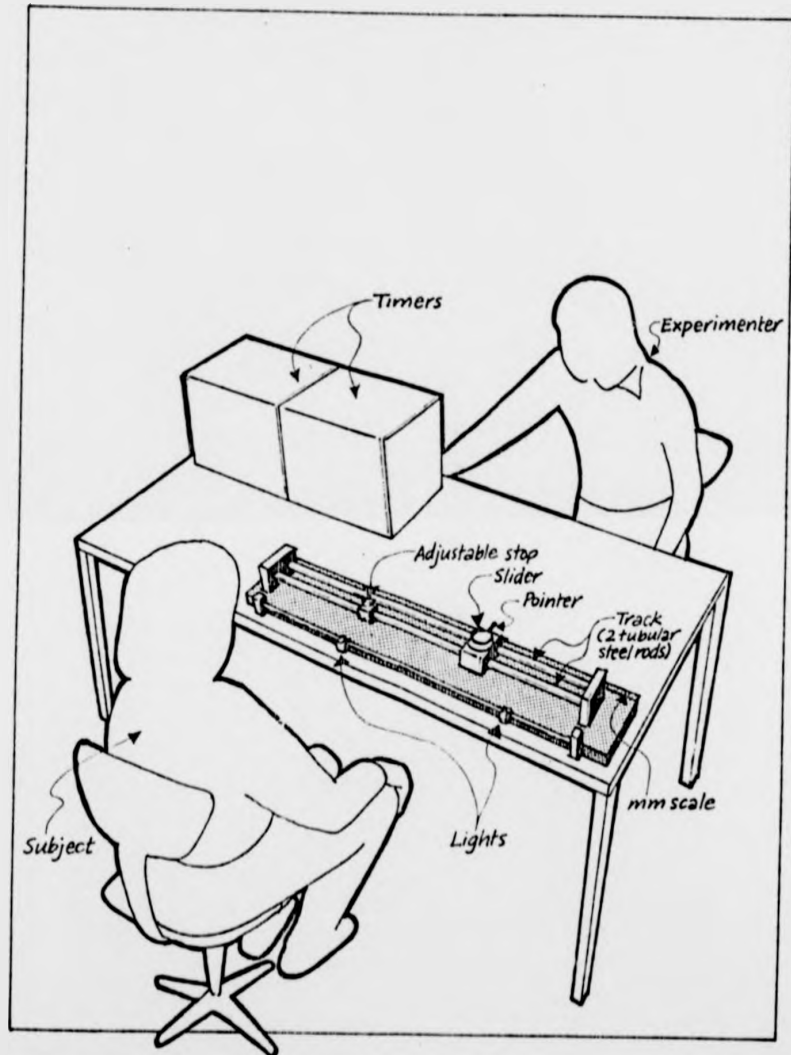


Fig 4.1 Basic apparatus

(4) Task and Procedure

The task was a standard linear positioning task in which subjects move a slide along a track until it reaches a stop. This is repeated fifteen times and then the subject has to recall the movement by moving the slide along the track with stop removed. Throughout the experiment subjects were able to see the whole of the slide track, except the mm scale measure. All subjects received 15 learning trials in which they took hold of the slide knob with their right hand and moved this to the stop position which had previously been set by the experimenter. Subjects were instructed to then release the knob momentarily before grasping it again and returning it to the start position. The end-stops were set to give a track length of either 30 cm or 60 cm. The green light was set at the start position and the red light at the stop. A two-second time interval between each trial was used. The red and green lights flashed alternately at two second intervals between each light. Subjects were instructed to time responses so that they arrived at the stop point as the red light appeared. Following the learning period there was a 40 second retention interval during which one of the prescribed interpolated activities was performed.

4.1.2. Interpolated Activities

(1) Counting backwards (CB 30), (CB 60)

Two groups of subjects were instructed to count backwards in threes aloud from 759 until they were told to stop by the experimenter. During this time the red light remained off and was removed to the start position as was the stop. One group having previously learned a 30 cm movement, the other group a 60 cm movement.

(2) Novel, actual movement (NAM 30), (NAM 60)

During the 40 second retention interval these two groups were required to move either half or twice as far as the original movement (i.e. if the original movement was of 30 cm the new movement was of 60 cm and vice versa). For these groups the red light was positioned at the new stop point. Subjects were instructed to move to the new stop point, momentarily release the slide, take hold again, and return the slide to the start position, timing their arrival at the stop point to coincide with the light appearing. In all, ten moves were made to the new position.

(3) Novel, imagery of movement (NIM 30), (NIM 60)

The two groups of subjects were required to sit with their arms at their sides and imagine moving to the new location of either half or twice the extent of the previous movement. Everything else was the same as in the actual movement group, except no movements were made. Subjects were told that they were to time each of their imaginary movements to arrive at the stop as the red light appeared and that they would be required to make 10 such imaginary movements.

(4) Imagery of movements of the same extent (SIM 30), (SIM 60)

Two groups of subjects were required to imagine making the same movement as they had been previously producing. In these conditions the apparatus was not altered from the previous learning trials. Instructions given to subjects were exactly the same as in the other imagery conditions. Ten imagery trials were given in the 40 second retention interval.

Immediately following the end of the 40 second retention interval

(2) Novel, actual movement (NAM 30), (NAM 60)

During the 40 second retention interval these two groups were required to move either half or twice as far as the original movement (i.e. if the original movement was of 30 cm the new movement was of 60 cm and vice versa). For those groups the red light was positioned at the new stop point. Subjects were instructed to move to the new stop point, momentarily release the slide, take hold again, and return the slide to the start position, timing their arrival at the stop point to coincide with the light appearing. In all, ten moves were made to the new position.

(3) Novel, imagery of movement (NIM 30), (NIM 60)

The two groups of subjects were required to sit with their arms at their sides and imagine moving to the new location of either half or twice the extent of the previous movement. Everything else was the same as in the actual movement group, except no movements were made. Subjects were told that they were to time each of their imaginary movements to arrive at the stop as the red light appeared and that they would be required to make 10 such imaginary movements.

(4) Imagery of movements of the same extent (SIM 30), (SIM 60)

Two groups of subjects were required to imagine making the same movement as they had been previously producing. In these conditions the apparatus was not altered from the previous learning trials. Instructions given to subjects were exactly the same as in the other imagery conditions. Ten imagery trials were given in the 40 second retention interval.

Immediately following the end of the 40 second retention interval

all groups were instructed to recall the movement they had been required to learn during the acquisition trials. During recall the stop and the red light were removed to the far end of the apparatus and no lights appeared. Subjects were instructed to move in their own time to where they thought the original movement to have been, release the slide, take hold again and return to the stop point. In all, ten such unpaced recall trials were given. The recall trials were scored for magnitude of error from the criterion position, taking note of the sign of the error to the nearest 0.5 cm.

Variable error and constant error.

The most widely used dependent variables in linear positioning studies are variable error (VE) and constant error (CE). Briefly VE is the standard deviation of the subjects' responses over trials, with respect to the criterion position. Constant error is simply the mean error with respect to the criterion position over trials. The two measures are relatively independent in that a particular subject's recall data may have a low mean or constant error but a high variance and therefore a high standard or variable error (VE). Conversely a subject may consistently reproduce the same incorrect movement, this would result in a high positive or negative CE but a low VE; of course, one might obtain a high VE and CE or low VE and CE. The former reflects widely fluctuating but consistent over or undershooting, while the latter reflects consistent accurate recall. To summarise, the two measures might be combined to reflect four different recall patterns:-

all groups were instructed to recall the movement they had been required to learn during the acquisition trials. During recall the stop and the red light were removed to the far end of the apparatus and no lights appeared. Subjects were instructed to move in their own time to where they thought the original movement to have been, release the slide, take hold again and return to the stop point. In all, ten such unpaced recall trials were given. The recall trials were scored for magnitude of error from the criterion position, taking note of the sign of the error to the nearest 0.5 cm.

Variable error and constant error.

The most widely used dependent variables in linear positioning studies are variable error (VE) and constant error (CE). Briefly VE is the standard deviation of the subjects' responses over trials, with respect to the criterion position. Constant error is simply the mean error with respect to the criterion position over trials. The two measures are relatively independent in that a particular subject's recall data may have a low mean or constant error but a high variance and therefore a high standard or variable error (VE). Conversely a subject may consistently reproduce the same incorrect movement, this would result in a high positive or negative CE but a low VE; of course, one might obtain a high VE and CE or low VE and CE. The former reflects widely fluctuating but consistent over or undershooting, while the latter reflects consistent accurate recall. To summarise, the two measures might be combined to reflect four different recall patterns:-

- (i) Low VE and low CE - consistent accurate recall of the to-be-remembered movement.
- (ii) Low VE and high CE - consistent inaccurate recall of the to-be-remembered movement, where positive CE represents overshooting and negative CE represents undershooting.
- (iii) High VE and low CE - inconsistent recall about the criterion position, e.g. large oscillations about the criterion position.
- (iv) High VE and high CE - inconsistent recall about an incorrect position, e.g. large oscillations about an irrelevant position.

These two measures have been taken (Laabs, 1973) to reflect perceptual and memory processes in linear positioning movements. CE might be taken as a measure of the amount of perceptual biasing in a subject's recall with high negative and positive values indicating under and overshooting respectively. VE might be taken as a measure of the relative strength of the memory trace, in which the value of the VE is inversely related to the strength of the memory trace. Furthermore, VE is thought to reflect the strength of the memory and any "noise" from the motor production system. Consequently, a weak memory trace will be swamped by low noise, alternatively, a rise in the noise level will swamp a previously strong memory trace. However at present no systematic investigation of the signal/noise ratio of VE has been carried out.

4.1.3 Results

From the raw error scores of each subject on the retention trials constant error (CE) and variable error (VE) were calculated. (Appendix C shows raw scores and computed CE, VE scores for each subject). CE is the most relevant measure in this experiment since it indicates the amount of directional bias in the recalled movement. Separate 2-way ANOVA's were carried out on each of the two dependent variables. A summary of the mean and standard errors for each condition and each dependent variable, CE and VE is shown in Table 4.1.

Interpolated- Standard move	CB 60	CB 30	NAM 60	NAM 30	NIM 60	NIM 30	SIM 60	SIM 30
CE \bar{X}	-0.1	-0.4	-4.5	4.8	-4.7	4.2	0	0
CE s.e.	1.62	2.18	0.82	1.25	1.72	1.71	0.17	0.23
VE \bar{X}	1.4	1.4	2.1	2.1	1.0	1.3	0.3	0.5
VE s.e.	0.75	0.41	0.94	0.5	0.33	0.26	0.12	0.1

Table 4.1 Experiment I: Summary of mean (\bar{X}) and standard error (s.e.) for CE and VE in each experimental condition. The value 60 or 30 refers to the magnitude of the to be recalled movement.

SOURCE	SS	df	Ms	F ratio	Pr
LOCATION/DISTANCE OF MOVEMENT	0.054	1	0.054	0.206	>0.05 NS
TYPE OF INTER- POLATED ACTIVITY	19.33	3	6.44	24.58	<0.001 ***
INTERACTION	0.106	3	0.035	0.134	>0.05 NS
ERROR	10.466	40	0.262		
TOTAL	29.956	47			

Table 4.2 Experiment I: ANOVA Summary 4 x 2 design using VE as the dependent variable

(1) Variable error

A 2-way ANOVA using VE as the dependent variable revealed no significant effects for location/distance of movement, $F(1,40)=0.206$ $p > .05$. A highly significant effect for type of interpolated activity was found, $F(3,40)=24.58$, $p < .001$. The interaction was not significant, $F(3,40)=.134$, $p > .05$. Further analysis of the main effect for interpolated activity using Tukey's HSD test shows that NIM and SIM have significantly less VE than NAM and that SIM has significantly less VE than CB. A matrix of the differences between each pair of means is shown in Table 4.3. The effects of type of interpolated activity on VE can be seen in figure 4.2 where the interesting feature is the relatively low levels of VE found in the two imagery conditions.

(2) Constant error

Analysis of CE by a 2-way ANOVA showed a highly significant effect for extent of movement, $F(1,40)=125.51$, $p < .001$ and for the interaction between location/distance of movement and type of interpolated activity $F(3,40)=43.95$ $p < .001$. No significant effect for interpolated activity alone was found, $F(3,40)=0.44$, $p > .05$. Decomposition of the interaction effect into simple effects using an F-test revealed a significant effect for location/distance of movement when a different movement was imagined, (NIM) $F(1,40)=123.58$ $p < .001$ and also for location/distance of movement when a different movement was actually made (NAM), $F(1,40)=133.72$, $p < .001$. In figure 4.3 one can see how the two types of interpolated activity which involved either forming an image of (NIM), or actually making (NAM) a different movement, produce remarkably similar biasing effects, in opposite directions, on the to-be-recalled movement. None of the differences between counting backwards (CB) and imagining rehearsal (SIM) of the same movement were significant, nor was the difference between forming an image and actually making a movement of a different extent to the to-be-recalled movement.

(3) Regression analysis

Finally a regression analysis was performed on each subject's error score over the ten trials. As shown in figures

(1) Variable error

A 2-way ANOVA using VE as the dependent variable revealed no significant effects for location/distance of movement, $F(1,40)=0.206$ $p > .05$. A highly significant effect for type of interpolated activity was found, $F(3,40)=24.58$, $p < .001$. The interaction was not significant, $F(3,40)=.134$, $p > .05$. Further analysis of the main effect for interpolated activity using Tukey's HSD test shows that NIM and SIM have significantly less VE than NAM and that SIM has significantly less VE than CB. A matrix of the differences between each pair of means is shown in Table 4.3. The effects of type of interpolated activity on VE can be seen in figure 4.2 where the interesting feature is the relatively low levels of VE found in the two imagery conditions.

(2) Constant error

Analysis of CE by a 2-way ANOVA showed a highly significant effect for extent of movement, $F(1,40)=125.51$, $p < .001$ and for the interaction between location/distance of movement and type of interpolated activity $F(3,40)=43.95$ $p < .001$. No significant effect for interpolated activity alone was found, $F(3,40)=0.44$, $p > .05$. Decomposition of the interaction effect into simple effects using an F-test revealed a significant effect for location/distance of movement when a different movement was imagined, (NIM) $F(1,40)=123.58$ $p < .001$ and also for location/distance of movement when a different movement was actually made (NAM), $F(1,40)=133.72$, $p < .001$. In figure 4.3 one can see how the two types of interpolated activity which involved either forming an image of (NIM), or actually making (NAM) a different movement, produce remarkably similar biasing effects, in opposite directions, on the to-be-recalled movement. None of the differences between counting backwards (CB) and imagining rehearsal (SIM) of the same movement were significant, nor was the difference between forming an image and actually making a movement of a different extent to the to-be-recalled movement.

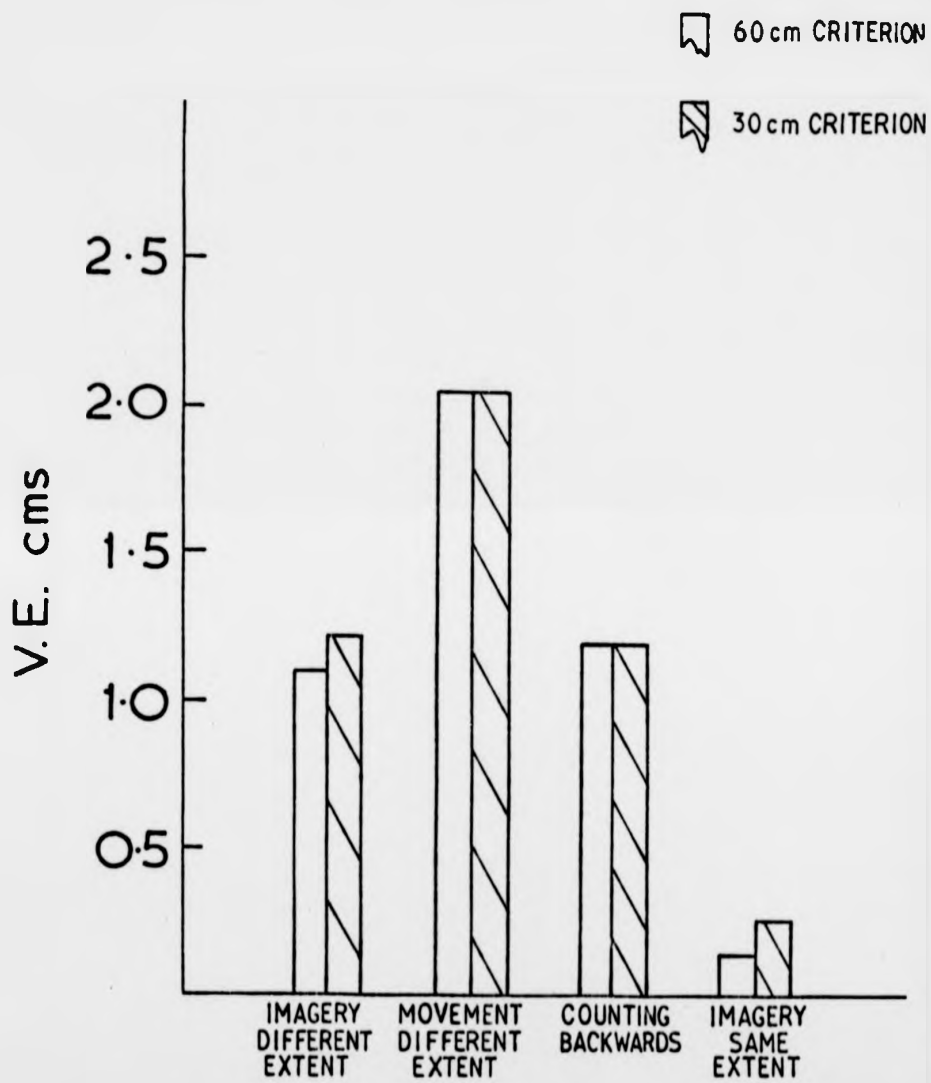
(3) Regression analysis

Finally a regression analysis was performed on each subject's error score over the ten trials. As shown in figures

	\bar{X}	NAM	CB	NIM	SIM
		2.14	1.42	1.06	0.39
NAM	2.14		0.72	1.08**	1.75**
CB	1.42			0.36	1.03**
NIM	1.06				0.67
SIM	0.39				

Table 4.3 Experiment 1: Contrasting means of type of interpolated activity. Differences between mean shown together with Pr level on Tukey's HSD test.

** = Pr ≤ 0.01 VE as the dependent Variable



INTERPOLATED ACTIVITY

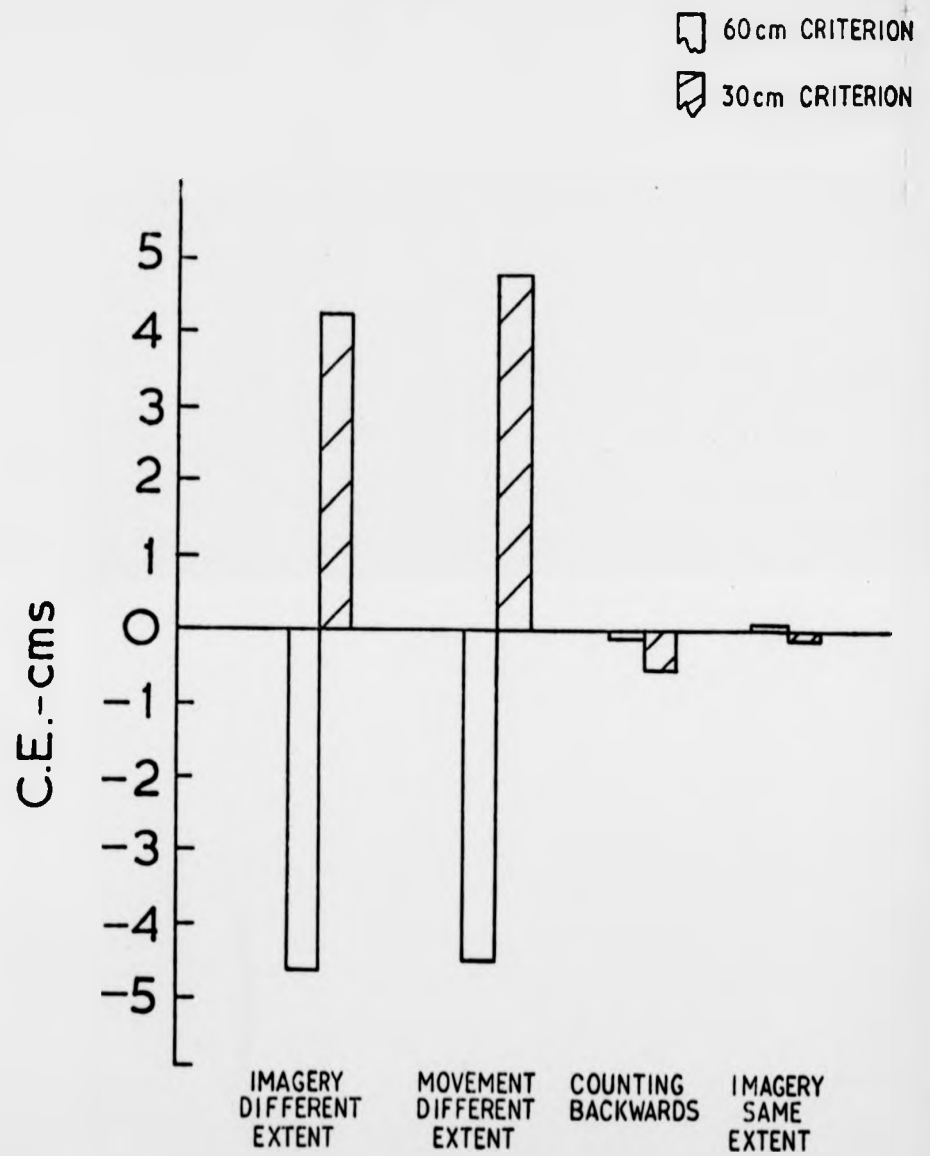
Fig. 4.2 Experiment 1: Mean VE

SOURCE	SS	df	Ms	F ratio	Pr
LOCATION/DISTANCE OF MOVEMENT	242.24	1	242.24	125.51	<.001 ***
TYPE OF INTER- POLATED ACTIVITY	2.57	3	0.86	0.44	>.05 NS
INTERACTION	254.45	3	84.82	43.95	<.001 ***
ERROR	77.12	40	1.93		
TOTAL	576.38	47			

Table 4.4 Experiment 11 ANOVA Summary 2 x 4 design using CE as the dependent variable

SOURCE	SS	df	Ms	F ratio	Pr
30, 60 -NIM	238.52	1	238.52	123.58	<.001 ***
30, 60 -NAM	258.08	1	258.08	133.72	<.001 ***
NIM, NAM -30	138.36	3	46.12	23.90	<.001 ***
NIM, NAM -60	118.66	3	39.55	20.49	<.001 ***
ERROR	77.12	40	1.93		

Table 4.5 Experiment I: Decomposition of interaction effect.
Scheffé F-test using CE as the dependent variable



INTERPOLATED ACTIVITY

Fig. 4.3 Experiment I: Mean CE

4.4 and 4.5 the mean errors over trials separate the NIM and NAM conditions from the SIM and CB conditions. There appear to be differences in the patterns of errors over trials between the imagery conditions NIM and SIM and the counting backwards and actual movement conditions, CB and NAM. These differences relate to the differences in VE previously described. Unfortunately VE collapses all the error scores for all of one subject's recall trials to one numerical value. If there is a tendency for error scores to increase with each recall trial then this would produce a high VE value. Similarly a fluctuating error pattern over recall trials would also produce a high VE value. These two recall patterns, however, are not equivalent and lead to different theoretical interpretations. By subjecting each subject's recall patterns to a linear regression analysis it is possible to distinguish between similar high and low VE values. Table 4.6 shows the slope coefficients β and the intercepts α for each subject in each condition when trials and error scores are regressed. If there is any tendency for errors to increase from trial to trial then a high positive β value should be found. As can be seen the highest positive value of the β coefficient is 0.39, and some are negative but none are significantly different from 0. (See Chatfield 1975 pp 174-177 for a test of significance of regression coefficients). Interestingly the intercept coefficients reflect the amount of bias introduced by a particular interpolated activity. In conditions NAM and NIM the value of α becomes positive or negative depending upon the extent of the interpolated movement. This mirrors the pattern of results found using CE as a dependent variable.

EXPERIMENT I

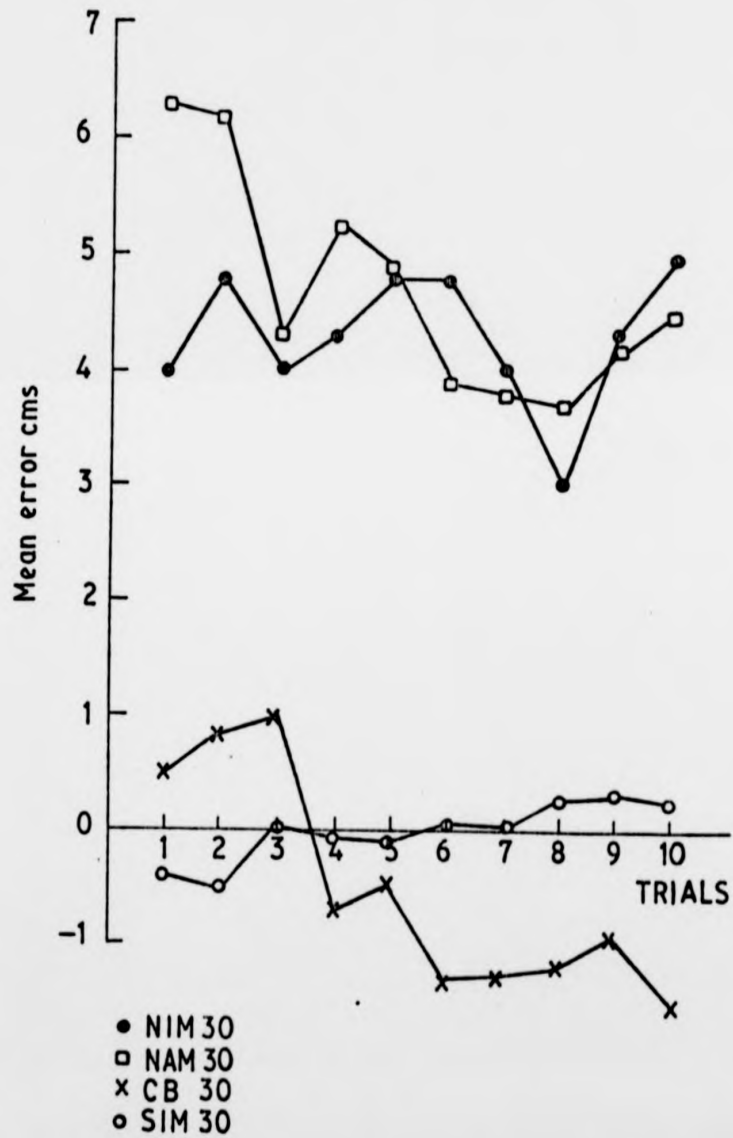


Fig. 4.4 Mean error recall trials for each condition with a 30 cm original movement.

EXPERIMENT I

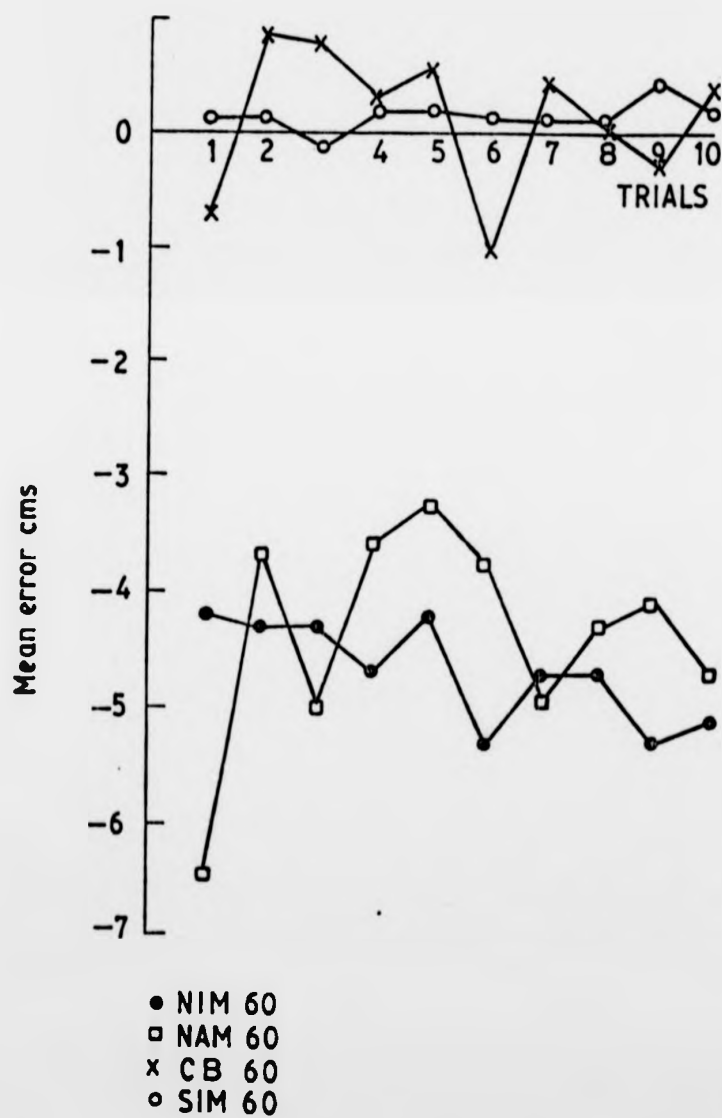


Fig. 4.5 Mean error recall trials for each condition with a 60 cm original movement

Condition		CB 60	CB 30	NAM 60	NAM 30	NIM 60	NIM 30	SIM 60	SIM 30
Subject 1	α	1.83	2.93	-4.4	6.53	-4.06	4.46	0.2	-0.2
	β	-0.21	-0.59	0.1	-0.39	-0.32	0.01	0.01	0.08
2	α	0.23	0.73	-4.13	7.97	-7.2	4.87	-0.17	-0.26
	β	-0.02	-0.22	0.12	-0.79	0.01	-0.30	0.04	0.03
3	α	-0.77	1.67	-5.13	3.6	-2.4	8.6	0.1	-1.00
	β	0.37	-0.30	0.19	0.26	-0.16	-0.25	0.01	0.12
4	α	1.76	5.26	-5.0	6.37	-2.13	1.6	0.3	-0.80
	β	-0.06	-0.38	0.04	-0.58	-0.16	0.15	-0.01	0.15
5	α	-0.63	-1.67	-3.86	8.60	-4.06	3.33	-0.03	0.20
	β	-0.12	-0.17	-0.16	-0.49	0.16	-0.02	0.03	-0.01
6	α	-0.17	-3.2	-6.2	2.81	-4.4	4.13	-0.03	-0.73
	β	-0.16	0.07	0.24	0.65	-0.22	0.10	0.02	0.12

Table 4.6 Experiment 1: Regression analysis. The slope coefficient (β) and the intercept value (α) are shown for each subject in each condition. Each subject's error score has been regressed against the recall trial number. (See Chatfield (1975) pp 174-177 for tests of significance of regression coefficients - following the student's t distribution)

4.1.4. Discussion

The results of this experiment clearly demonstrate that instructions to imagine interpolated movements of a given location/distance produce a biasing effect in subject's memory for linear positioning movements of the same direction and approximate magnitude as actual movements. Indeed in this respect real and imaginary movements appear to be functionally equivalent in much the same way that Finko (1979) has demonstrated real and imagined displacement of visual-motor-co-ordination are functionally equivalent.

The similarity between imagery produced biasing and movement produced biasing is so strong in terms of the direction and magnitude of the bias as measured by CE, that imagery of movements would seem to possess the same characteristics as producing movements. Imagining a movement and producing a movement do differ inasmuch as producing a movement has directly observable features of movement activity such as limb displacement, whilst imagining a movement has no such directly observable features. As well as finding aspects of imagery and movements that are functionally equivalent one should find some circumstances under which there are differences. When characteristics of the memory trace for the criterion movement are considered using VE, differences between imagery and production of a movement are found. Imagery of a different movement to the criterion movement produces bias (CE) but results in a significantly lower VE than production of a movement of a different extent to the criterion movement. Similarly imagining the criterion movement produces a similar amount of bias (CE) as counting backwards but has lower variability (VE) than counting backwards. If we take VE as a measure of the strength of the memory trace plus noise from other sources such as the motor or response

production systems then the fact that imagery has a lower VE than conditions where an output is required (as in counting backwards and producing a movement) can be interpreted as evidence for a restricted involvement of the response system in imagery.

Further support is given by the regression analysis. Those conditions with a high VE do not have a correspondingly high β regression coefficient. This suggests that the increased VE is not due to a compounding of error in memory, whereby each recall trial is constructed from the previous recall trial with the addition of a "noise" component at each trial.

4.2. Movement Imagery and Movement Production

An alternative explanation of high VE in the NAM conditions is that movement production and movement recognition are two separate cognitive systems. Imagery involves the movement recognition system but not the movement production system. Anderson (1980) points out that two different models are needed to explain recognition and production processes. Schemata or frame theory as outlined by Minsky (1975) are efficient recognition mechanisms. The schema or frame provides the necessary information to fill in missing details and to guide future perceptual searches by looking, listening, etc. "Production systems" as outlined by Simon (1973) are mechanisms for modelling procedures used in skilled activities. Briefly, "production systems" provide rules which allow desired goals to be achieved. Schmidt's (1975) schema theory of motor control sketches out two separate systems, one for the recognition of correct movement, the other for the production of movements. Schmidt's theory lacks any formal des-

cription of how these two separate systems might operate. Perhaps the more formal models of frames and production systems from cognitive psychology are the mechanisms operating in Schmidt's schema theory.

Schmidt's schema theory is an amalgamation of previous "closed loop" theories of motor control; such as Adams (1971) in which feedback is used to establish a "perceptual trace", and open-loop theories, Pew (1966), in which motor responses are "pre programmed" and executed without any reference to any feedback. The schema concept of motor control suggests that movements are initiated from a "response schema" which is a system of rules generated from past responses. The "recognition schema" is used to control the execution of a current movement and is based on past sensory consequences of movements. This model has provided a bridge between the more extreme views of the open and closed loop theorists but it is sufficiently vague to be virtually untestable. The suggestion of two separate but inter-related systems for movement production and movement recognition is not without support from other areas of psychology. In studies of memory it is widely accepted that recognition experiments produce a higher proportion of correct responses than recall experiments. If one can assume that different retention characteristics represent different processes then this supports a differentiation of the recognition and production systems. Of course there is some sense in which these two systems are related since in everyday life recognition and recall are often instantaneous. However, there are cases in which one cannot recall the correct action or word, but is able to recognize it as soon as it occurs.

Modelling by production systems provides a detailed set of

rules which require an existing state and a desired state, then given these two parameters a particular production rule will allow this action to be produced. A schema provides a framework which fills in missing details and enables expectations or plans to be generated. Schemata appear to be less well defined than production systems, since they are models for connecting knowledge structures and incoming information rather than procedures for producing actions (in a general sense). Both production systems and schemata are rule systems providing a structured model which may be appropriate to the different processes of recognising and producing actions.

If action production and action recognition do indeed constitute two different but inter-related processes then it is possible that images of movements could be either related to the action production or the action recognition system. The equivalence between images of linear positioning movements and actual linear positioning movements found in Experiment 1 suggests that images are related to one of these proposed systems. Given Laubs (1973) and others' suggestions for VE being a two component error term, then it seems that images of movements are not directly related to the motor production system.

The most important finding of the previous experiment is that a method of observing imagery effects has been established in which movements are the key focus. No other experiments have as yet been able to produce such consistent imagery effects where movements are concerned. The results cannot be explained by subjects' compliance with the experimental hypothesis nor the use of tacit knowledge since in a debriefing session no subjects were able to state what predictions had been made.

One possible alternative explanation might be in terms of adaptation theory as for example in Sekuler's (1974) account of spatial vision. The biasing effects of the novel interpolated activities could be due to subjects adapting to one particular location and hence having a lower threshold for that pathway. If this is so, then in the case of the imagery conditions subjects are adapting to an image. This does not explain the image but the bias. The focus of this thesis is towards the explanation of images of movements. Having established a procedure which permits imagery effects to be inferred without reliance upon introspective techniques further investigations of imagery are possible.

CHAPTER FIVE

IMAGES OF MOVEMENT AND THE MOTOR PRODUCTION SYSTEM

In the previous experiment it was concluded that imagery of movements appears to be based on a recognition system rather than a production system. This relates to two of the hypothetical explanations of mental practice, which postulate two forms of imagery. The more formal of these hypotheses is the psychoneuromuscular explanation of MP, Richardson (1967b) and Ulich (1967). MP involves images of movements and these images are minimal movements (detected by E.M.G. recording) which excite kinaesthetic feedback and hence produce a motor image of movement. This hypothesis assumes images are the result of some action production system. It has its roots in a motor theory of mind, Jacobson (1932), Weimer (1977), and a similar process to the motor theory of speech perception of Liberman et al (1967) is postulated. Recognition is based on template matching and the template is a motor-programme used for producing the particular event. Hence actions would be recognised by matching the perceptual input with a motor copy of producing the same action. In recognising visual stimuli the process seems to rely upon the matching of eye movements used to scan the object.

Certain logical flaws are apparent here. In the case of visual stimuli the motor theory of mind makes visual information almost redundant. An extreme consequence of this suggestion is that blind people ought to be able to recognise objects if they are made to make the appropriate eye movements. This makes the retina and visual cortex largely redundant

and the work of Hubel and Weisel mistaken. Of course this is taking the argument to an extreme. Neisser (1976) points out that the patterns of eye movements used to recognise objects is rarely consistent within subjects, furthermore in the case of familiar objects no eye movements are necessary. Mimicry might be used to support a motor theory of action recognition, as Piaget suggests that this is one of the ways that children can acquire knowledge. If one accepts a motor theory of action recognition then one is faced with the problem of explaining how the actions are recognised before they have been produced. Indeed there is a more general problem of how novel movements, or speech sounds, etc., are recognised without ever having been produced. The one possibility is that all productions are pre-programmed and are simply lying dormant awaiting activation, but this seems highly unlikely.

The second hypothesis, the perceptual symbolic explanation, is much less precise than the psychoneuromuscular hypothesis. As this hypothesis is stated in the MP literature it is not clear what processes imagery involves. The suggestion is that MP involves examining an image and forming a "new perceptual organisation of the task, Corbin (1972), Sage (1977). As this hypothesis stands it is too vague to be tested. The research on mental imagery within cognitive psychology, however, has produced more specific hypotheses. In particular Kosslyn (1975), (1976), (1980) has developed a model of mental imagery which explicitly states that visual images are quasi-pictorial, in so much as they contain similar information to that which would be found in a picture. Furthermore Kosslyn claims that images are inspected and examined by a "mind's-eye", which uses the same perceptual processes as are normally used in the interpretation of visual sensory stimulation. Thus images are examined by the perceptual system to produce novel organisations of the

information contained in the image. This model of mental imagery specifies in much more detail the kind of process hinted at in the MP literature.

Two predictions arise from the above hypotheses. The first prediction, derived from the psychoneuromuscular hypothesis, is that the biasing effect upon a subject's memory for a linear positioning movement caused by imagining a movement to a novel location will be suppressed when the subject has to perform a motor task whilst attempting to form an image. The second prediction derived from the perceptual/symbolic account of mental practice, relates to the visual/spatial aspects of imagery. If images are inspected using the perceptual system normally used in seeing, then a visual task during subjects' attempts at imagery will suppress the bias caused by imagery.

5.1. An Interference Paradigm

These two predictions introduce a novel interference paradigm, which might be characterised as a "second order interference", in which stimuli are presented concurrent with an instruction to imagine a linear movement. Following Brooks (1967, 1968) experiments involving competing perceptual and imagery tasks, it has been suggested by Bower (1970), Neisser (1970), Norman (1976) and Baddeley (1976), amongst others, that visual imagery and visual perception interfere with each other because they compete for limited special purpose resources. It is proposed that imagery is subject to stimulus specific interference rather than any general capacity loading. A series of experiments by Phillips and Christie (1977a, b), have tested this hypothesis and found that visualisation of a displayed pattern over a four second

retention interval is subject to interference from (what they class as) tasks which demand general purpose resources, such as mental arithmetic. They also found that visualisation is interfered with by visual perception and more so by certain kinds of perceptual tasks. Their results showed that visual perception interferes with visualisation specifically when it involves the "active formation of schematic representations of novel visual configurations". However, mental arithmetic may well involve the use of visual imagery for some subjects in certain situations. Steiner (1981) has found that visual imagery does indeed play a role in mental arithmetic with some subjects.

One problem with using an interfering concurrent task to explore the nature of mental imagery is to distinguish between competition for some general purpose resource and competition for some specific modality resource (Phillips and Christie, 1977a,b). Indeed, Kahneman (1973) suggested that distinguishing between and measuring the non-specific demand on general capacity made by a particular task is a basic problem for experimental psychology. Allport (1980) takes the view that interference tasks are unclear in their effect on central processing capacity and agrees with Neisser (1976) that experiments on attention and general purpose processing capacity have been of little use in extending our understanding of attention but have been useful in telling us about the specialised subsystems that are called on and may be competed for by the particular task chosen for investigation. Thus interference paradigms are suited to investigating specific resources that may be competed for by different cognitive processes.

5.2. Experiment 11

If it can be assumed that interference to some primary task is caused by the competition for a common resource by some secondary task then imagery processes may be inferred from the effects of such secondary interference tasks. It has previously been argued in the review of mental imagery (Chapter Three) that selective interference affords the most powerful experimental investigation of imagery, with the least assumptions.

As it is extremely unlikely that subjects will be able to guess the experimental hypotheses, any results should be unaffected by "demand characteristics". By incorporating a second order interference stimulus with the interpolated imagery instructions of the previous experiment the predictions from the psychoneuromuscular hypothesis and the symbolic/perceptual hypothesis can be tested. If a particular second order interference stimulus suppresses the biasing effects of instructions to imagine linear movements then inferences can be made regarding the processes involved in imagery of this kind. Suppression caused by a visual/spatial interference stimulus can be taken as suggesting a visual/spatial imagery process. Alternatively, if a motor interference stimulus suppresses the biasing effects of imagery, then this suggests a motoric imagery process.

In the present experiment certain experimental controls were used to deal with some of the problems in using interference techniques. Counting backwards in threes was used as a baseline with which to compare any bias in memory. To rule out any error or bias which might be induced by the 2nd order interference tasks themselves these were presented as

1st order and 2nd order interferences (i.e. with or without accompanying imagery instructions). This control also allows the effects of each interference task to be compared with each other. This is important as it enables distinctions to be made between interference produced by imagery instructions and interference produced by other tasks.

5.2.1. Method

(1) Experimental design

All seven of the treatments in the experiment were first combined in a one-way independent groups design. The seven treatments were all types of interpolated activities, namely counting backwards in threes, an actual movement of a different extent, an imaginary movement of a different extent, an imaginary movement with visual second order interference, an imaginary movement with motor second order interference, visual interference, motor interference. A subset of these seven conditions was then included in a two-way-independent groups design. The factors were interference stimulus and order of interference. Interference stimuli was either visual or motor, whilst order of interference was either 1st order, i.e. alone, or 2nd order, i.e. with an instruction to imagine a different movement.

(2) Subjects

A total of 42 subjects randomly selected from a group of 65 volunteer undergraduate psychology students at the University of Warwick who had not previously taken part in Experiment 1. Equal numbers of either sex were assigned to each of the seven experimental conditions giving a total of six subjects in each group.

(3) Apparatus

As in Experiment I with the addition of a Marconi Instruments X-Y display (model TF2213) connected to a variable frequency control box. This was centred 25 cm above the track at eye level to provide visual/spatial interference. A hand-held dynamometer was used for the motor interference condition.

(4) Task and procedure

As in Experiment I subjects were required to learn a movement of a given extent on a linear-positioning-task. This was then followed by one of the experimental interpolated activities prior to recall of the learned movement.

Subjects were required to first learn a 30 cm movement by moving the slide to the stop position fifteen times, as in Experiment I. Unlike the procedures of Experiment I the lights were on permanently during the learning phase as their flashing could have been a source of interference when combined with the interpolated movement of a different extent in Experiment I.

Subjects' instructions were to move the slide to the stop with their preferred hand, momentarily release the slide, take hold again, and return to the start for the next trial. Subjects were told to move at their own rate. The experimenter gave an instruction to start the next trial 2 seconds after the subject returned to the start point, the whole slide being visible throughout the experiment. Following the acquisition trials a 50 second retention interval followed in which one of the seven types of interpolated activities occurred. During this period the stop and lights were positioned at the ends of

the track unless otherwise stated below.

5.2.2. Interpolated Activities

(1) Counting backwards (CB)

Counting backwards in threes from 359 aloud for 40 seconds preceded by a 10 second instruction period.

(2) Novel Actual Movement (NAM)

Subjects had to move the slide to the 60 cm point 10 times with the stop and red light positioned at this new location. The light, together with an audible tone, occurred at $\frac{1}{4}$ second intervals for 40 seconds.

(3) Novel Imaginary Movement (NIM)

As in Experiment I subjects were instructed to imagine moving to the 60 cm point 10 times with the stop and red light positioned at this new location. Subjects were instructed to begin each new "move" as the light and tone occurred providing pacing for the ten imaginary moves during the 40 second period.

(4) Imagining a 60 cm move with visual interference (NIMV)

Subjects were presented with a Lissajou figure oscillating at a rate of 2 per second displayed on the X-Y monitor. At the same time subjects were instructed to imagine moving to the 60 cm position in time with the tone and red light. The end stop and red lights were positioned at the 60 cm mark as in the imagery alone and actual movement conditions. Again, 10 imaginary moves were required in a 40 second period.

(5) Imagining a 60 cm move with motor interference (NIMM)

This group of subjects were instructed to imagine the same 60 cm movement as above whilst maintaining a constant pressure of 15 lb on the dynamometer with the same hand they had moved the slide with for 40 seconds. Everything else was as in the previous imagery conditions. The experimenter gave verbal feedback whenever the pressure on the dynamometer deviated from the 15 lb load.

(6) Visual interference (V)

Subjects were presented a lissajou figure on the X-Y monitor as mentioned above without any instructions to imagine a movement. During this period the lights and end stops were removed to the end of the slide.

(7) Motor interference (M)

This consisted of squeezing the dynamometer at a constant pressure of 15 lb with the end stops and lights removed to the end of the track and no imagery instructions given. Subjects were required to squeeze the dynamometer with the same hand as used in moving the slide along the track.

All subjects who had to make or imagine a different move from the 30 cm extent were given two demonstrations by the experimenter of the new movement. This was to ensure that the groups had some knowledge of where the new movement was. This accounted for the first 10 seconds of the 50 second retention interval. Other groups who did not have to make or imagine a different movement had their tasks explained to them during this period.

Following the 50 second retention interval 10 recall trials were required, from all subjects, of the 30 cm movement without any end stop or lights to guide recall. Subjects were instructed to move in their own time to where they thought the original movement was in the same manner as subjects in Experiment I.

The recall trials were scored for magnitude of error from the criterion position, taking note of the sign of the error measured to the nearest 0.5 cm.

5.2.3. Results

The error scores for each subject are shown in Appendix (D) from which CE and VE were calculated as in Experiment I. Each of the above dependent variables was used to analyse the seven experimental conditions in a one-way ANOVA. The means and standard error for CE, VE are shown in Table 5.1.

(1) Constant error

A one-way ANOVA using CE revealed a significant effect for type of interpolated activity, $F(6,35) = 15.843$, $p < .001$. Further analysis using Tukey's HSD test showed differences between means as in Table 5.3. In figure 5.1 the mean CE for each type of interpolated activity is shown, the main point being the way in which imagery when combined with visual interference produces no more bias at recall than other activities which do not include a different extent in any form.

(2) Variable error

Using VE as the dependent variable for a one-way ANOVA involving all seven types of interpolated activity produced a significant F value of $F(6,35) = 8.176$, $p < .001$ (see Table 5.4). After further

	CB	NAM	NIM	NIMV	NIMM	V	M
\bar{X}	0.85	5.94	6.22	-1.03	5.02	-0.34	0.63
CE s.e.	1.63	1.45	2.45	2.51	1.59	1.72	1.84
\bar{X}	0.64	1.94	0.55	1.17	0.74	1.08	0.71
VE s.e.	0.43	0.58	0.11	0.32	0.28	0.37	0.98

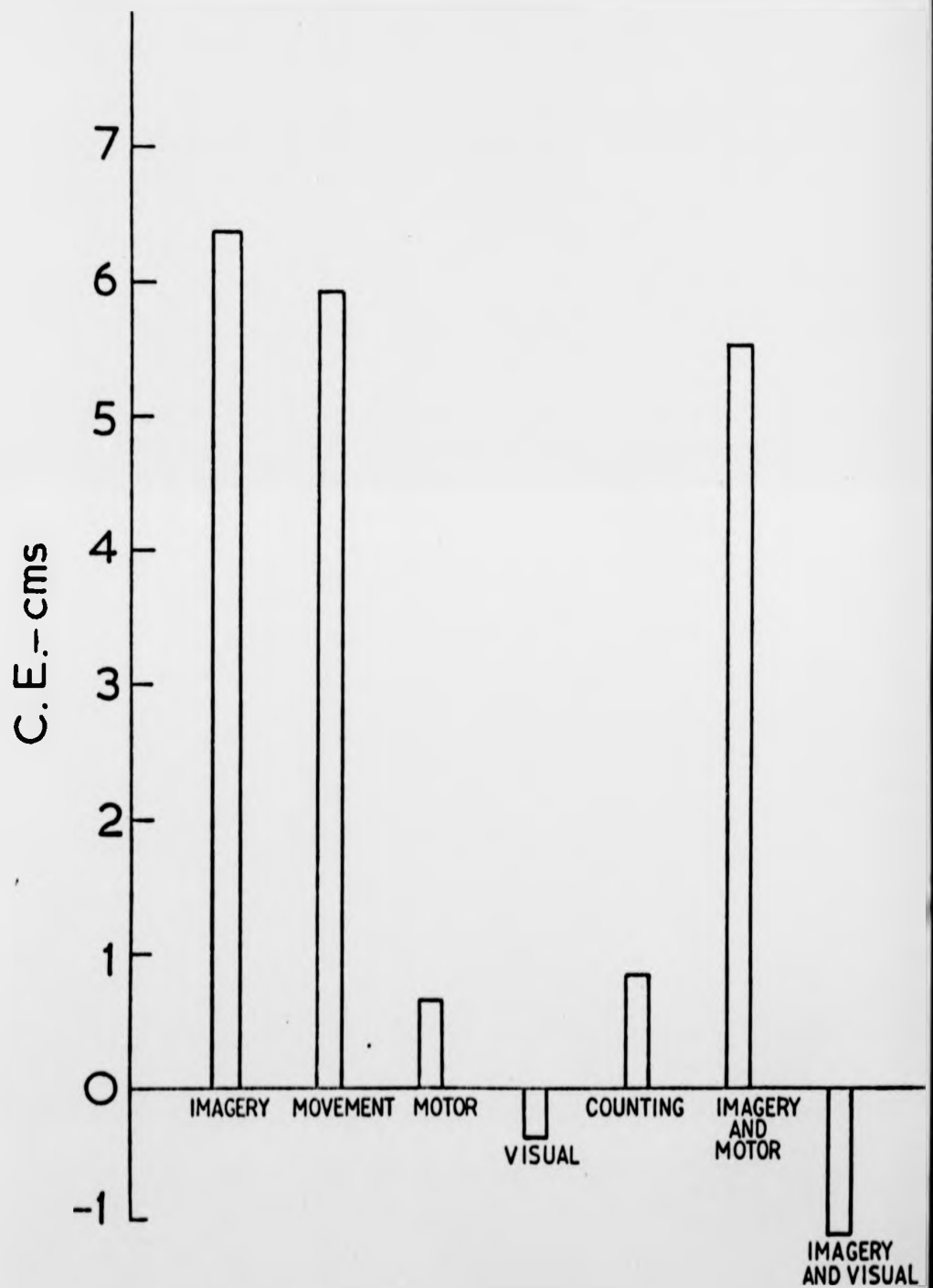
Table 5.1 Experiment II: Summary of mean (\bar{X}) and standard error (s.e.) of CE and VE for each experimental condition.

SOURCE	SS	df	Ms	F Ratio	Pr
TYPE OF INTER- POLATED ACTIVITY	350.035	6	58.339	15.834	<.001 ***
ERROR	128.939	35	3.684		
TOTAL	478.974	41			

Table 5.2 Experiment 11: ANOVA summary one-way design using CE as the dependent variable

	NIM $\bar{X}=6.22$	NAM $\bar{X}=5.9\frac{1}{2}$	NIMM $\bar{X}=5.02$	CB $\bar{X}=0.85$	M $\bar{X}=0.63$	V $\bar{X}=0.5\frac{1}{2}$	NIMV $\bar{X}=-1.03$
NIM $\bar{X}=6.22$		0.28	1.2	5.37**	5.59**	6.56**	7.25**
NAM $\bar{X}=5.9\frac{1}{2}$			0.92	5.09**	5.31**	6.28**	6.97**
NIMM $\bar{X}=5.02$				4.17**	4.39**	5.36**	6.05**
CB $\bar{X}=0.85$					0.22	1.19	1.88**
M $\bar{X}=0.63$						0.97	1.66*
V $\bar{X}=0.5\frac{1}{2}$							1.37
NIMV $\bar{X}=-1.03$							

Table 5.3 Experiment II: Contrasting means for type of interpolated activity. CB as the dependent variable with differences between means shown. (* indicates significant differences at .05 level on Tukey's HSD test). (** indicates significant differences at .01 level on Tukey's HSD test).



INTERPOLATED ACTIVITY

Fig. 5.1 Experiment II: Mean CE

analysis using Tukey's HSD(a) test (see Table 5.5) only moving a different extent produces a significantly higher VE, although when a less stringent test is used (Newman-Keuls) imagery and visual interference produce a significantly greater VE than imagery alone. In figure 5.2 the above means are shown graphically.

The following results take four of the above interpolated activities which together form two factors: interference stimuli and type of interference. The four conditions are motor interference, visual interference, motor interference with imagery and visual interference with imagery. Again each dependent variable (CE, VE) was subjected to a separate 2-way ANOVA.

(3) Constant error

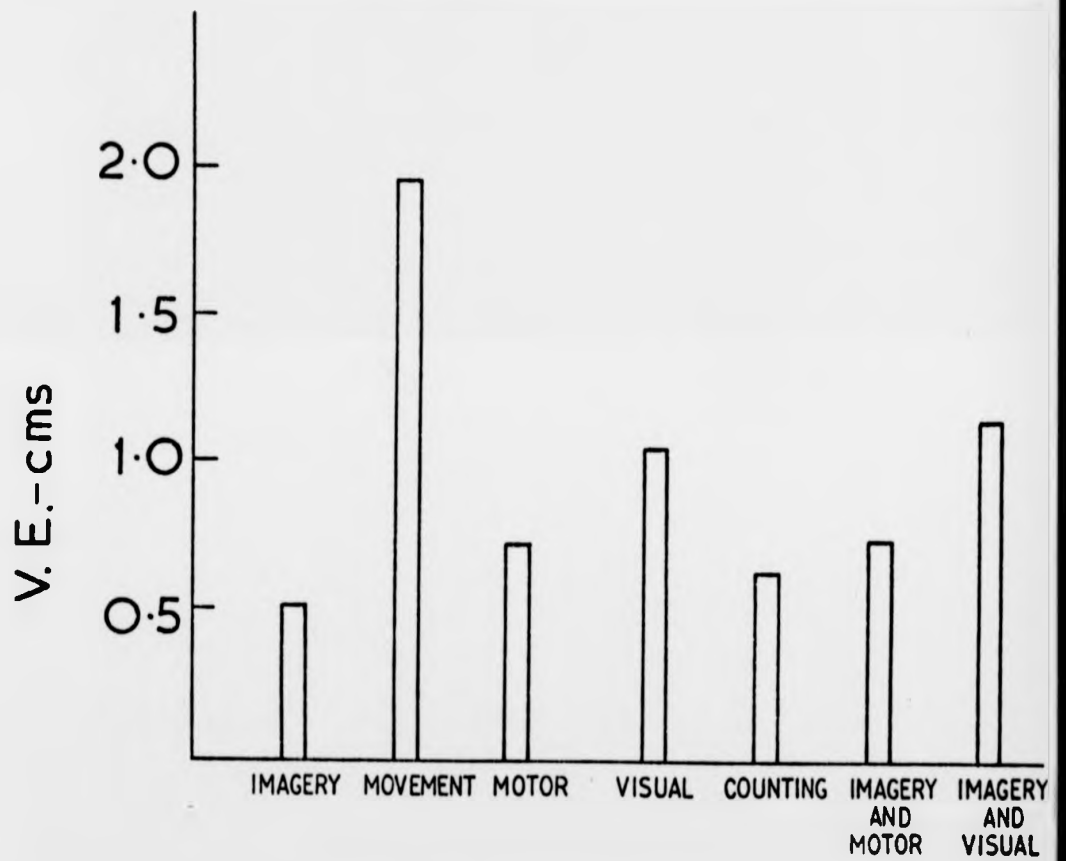
The results of a 2-way ANOVA using CE as the dependent variable gave a significant effect for interference stimulus $F_{(1,20)} = 16.067$, $p < .001$ and a significant interaction between interference stimulus and level of interference, $F_{(1,20)} = 12.833$, $p < .005$. Level of interference alone had no significant effect, $F_{(1,20)} = 3.29$, $p > .05$. Using an F test to look at the simple effects of the interaction revealed significant differences between level of interference with a motor stimulus $F_{(1,20)} = 14.59$, $p < .001$ and also between the two 2nd order interference stimuli (visual and motor) $F_{(1,20)} = 28.81$, $p < .001$. In figure 5.3 it can be seen that visual and motor interference alone produce no significantly different effects on recall. When imagery is included only motor interference with imagery produces a significant increase in the size of error of the to-be-recalled movement.

SOURCE	SS	df	Ms	F ratio	Pr
TYPE OF INTER- POLATED ACTIVITY	8.336	6	1.39	8.176	<.001 ***
ERROR	5.853	35	0.17		
TOTAL	14.189	41			

Table 5.4 Experiment II: ANOVA summary one-way design using VE as the dependent variable

	NAM $\bar{X}=1.9\frac{1}{2}$	NIMV $\bar{X}=1.17$	V $\bar{X}=1.08$	NIMM $\bar{X}=0.7\frac{1}{2}$	M $\bar{X}=0.71$	CB $\bar{X}=0.6\frac{1}{2}$	NIM $\bar{X}=0.55$
NAM $\bar{X}=1.9\frac{1}{2}$		0.77*	0.86*	1.20**	1.23**	1.30**	1.39**
NIMV $\bar{X}=1.17$			0.09	0.43	0.46	0.53	0.62
V $\bar{X}=1.08$				0.34	0.37	0.44	0.53
NIMM $\bar{X}=0.7\frac{1}{2}$					0.03	0.10	0.19
M $\bar{X}=0.71$						0.07	0.16
CB $\bar{X}=0.6\frac{1}{2}$							0.09
NIM $\bar{X}=0.55$							

Table 5.5 Experiment II: Contrasting means for type of interpolated activity with VI as the dependent variable. * .05 pr level of significance on Tukey's (a) test. ** .01 pr level of significance on Tukey's (a) test



INTERPOLATED ACTIVITY

Fig. 5.2. Experiment II: Mean VE

SOURCE	SS	df	MS	F ratio	Pr
LEVEL OF INTERFERENCE	12.5	1	12.5	3.29	>.05 NS
INTERFERENCE STIMULUS	61.038	1	61.038	16.067	<.001 ***
INTERACTION	48.751	1	48.751	12.835	<.005 ***
ERROR	75.985	20	3.799		
TOTAL	198.274	23			

Table 5.6 Experiment II: Two-way ANOVA using CE as the dependent variable

SOURCE	SS	df	Ms	F ratio	Pr
LEVEL OF INTERFERENCE V, NIMV VISUAL	0.02167	1	0.02167	0.057	>.05 NS
M, NIMM MOTOR	55.427	1	55.427	14.59	<.001 ***
INTERFERENCE STIMULUS V, M ALONE	0.3434	1	0.3434	0.090	>.05 NS
NIMV, NIMM WITH IMAGERY	109.443	1	109.443	28.801	<.001 ***
ERROR	75.985	20	3.799		

Table 5.7 Experiment II: Decomposition of interaction term for CE into its simple main effects using Scheffé F-test

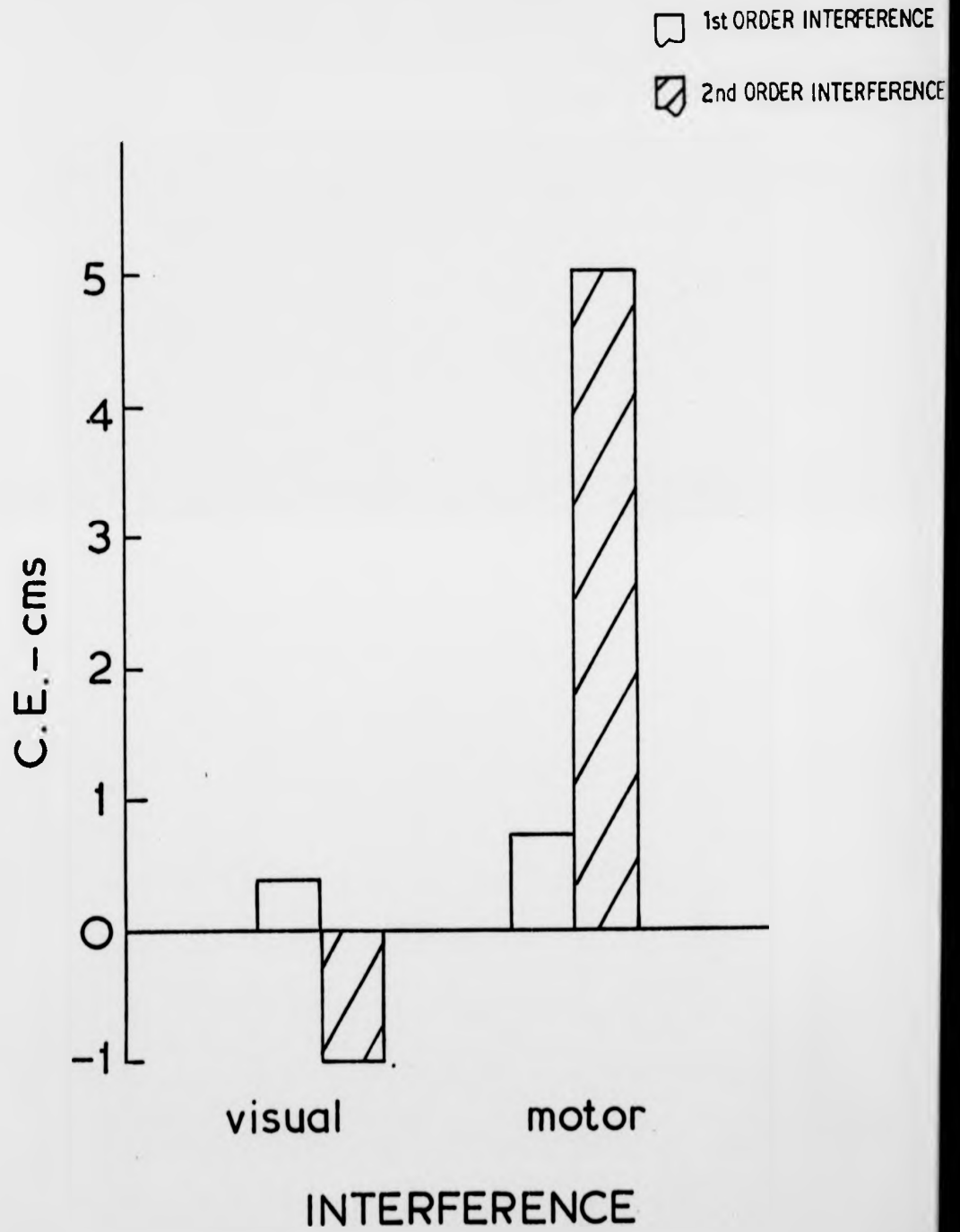


Fig. 5.3. Experiment II: Visual and Motor Interference, CE

(4) Variable error

Finally, using VE as the dependent variable, a significant effect was found for interference stimulus, $F_{1,20} = 5.68$, $p < 0.05$, whilst level of interference had a non-significant effect, $F_{1,20} = 0.99$, $p > 0.05$ as did the interaction effect, $F_{1,20} = 0.035$, $p > 0.05$ (see Table 5.8). The effect of source of interference was such that visual ($\bar{X} = 1.24$) produced a slightly higher amount of variability than did motor ($\bar{X} = 0.722$) interference (see Fig. 5.4).

(5) Regression Analysis

As in Experiment I a regression analysis was performed on the raw data for each subject and each condition. Table 5.9 shows the resulting intercept and slope (β) coefficients, none of the β 's are significantly greater than 0. It can be seen that the absence of any significant slope coefficient is similar to the findings of Experiment I. This suggests that in conditions such as NAM, and where the variability is relatively high this is not caused by an increase in the error score from trial to trial. Instead it seems that subjects in these conditions oscillate about a particular point but these oscillations are quite large. The intercept coefficient (α) is a reflection of the amount of bias in a subject's response. In the NAM, NIM and NIMM conditions the intercepts are all high positive values, whereas in all other conditions this value is either low negative or low positive.

5.2.4. Discussion

The results of this second experiment demonstrate that imagery produced biasing is suppressed by visual, secondary interference stimuli. Conversely imagery of a movement of a different extent is capable of

SOURCE	SS	df	Ms	F ratio	Pr
LEVEL OF INTERFERENCE	0.017	1	0.017	0.99	>.05 NS
INTERFERENCE STIMULUS	0.972	1	0.972	5.68	<.05 *
INTERACTION	0.006	1	0.006	0.035	>.05 NS
ERROR	3.411	20	0.171		
TOTAL	4.406	23			

Table 5.8 Experiment 11: ANOVA Summary, 2 x 2 design, using VE as the dependent variable

SOURCE	SS	df	Ms	F ratio	Pr
LEVEL OF INTERFERENCE	0.017	1	0.017	0.99	>.05 NS
INTERFERENCE STIMULUS	0.972	1	0.972	5.68	<.05 *
INTERACTION	0.006	1	0.006	0.035	>.05 NS
ERROR	3.411	20	0.171		
TOTAL	4.406	23			

Table 5.8 Experiment 11: ANOVA Summary, 2 x 2 design, using VE as the dependent variable

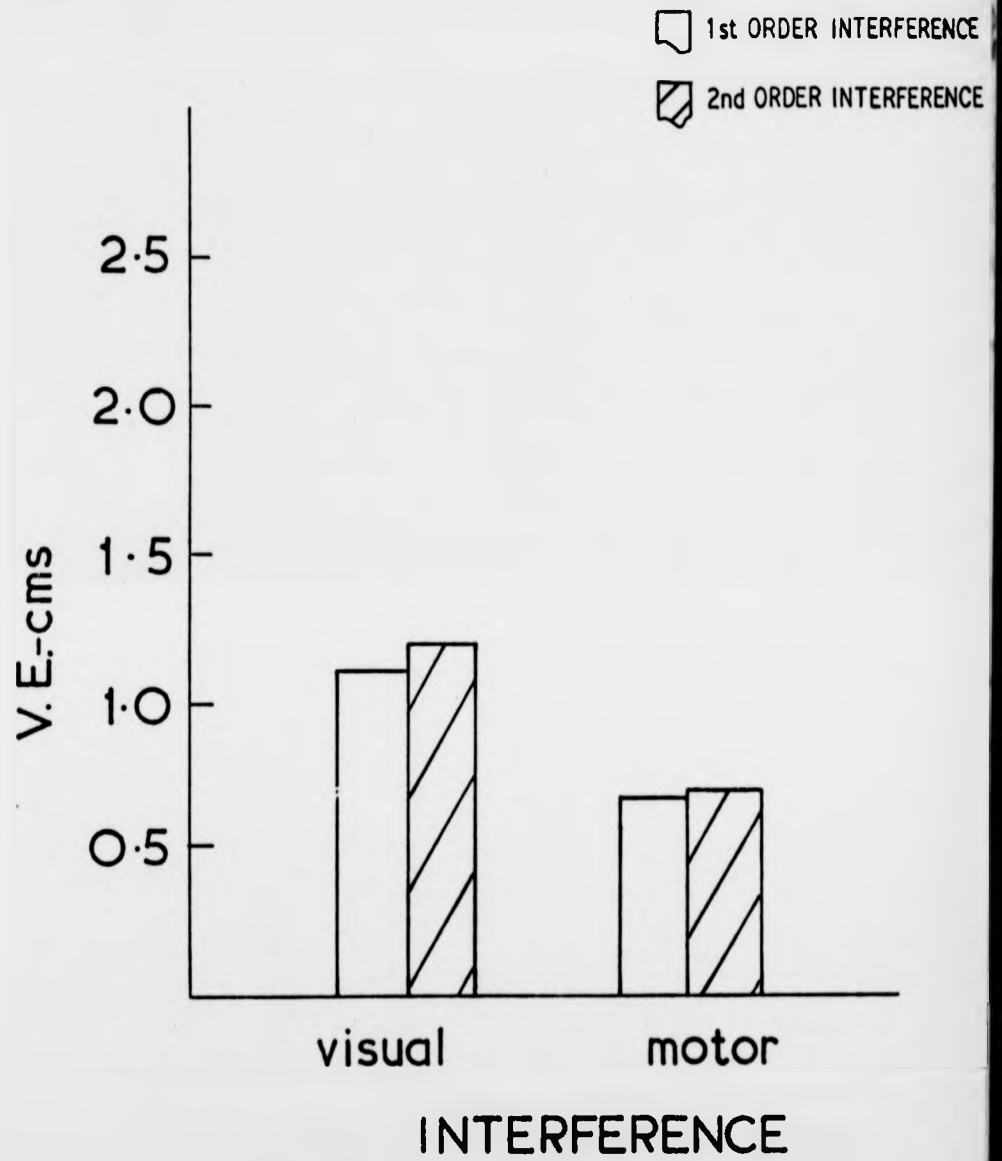


Fig. 5.4 Experiment II: Visual and Motor Interference, VE

Condition		CB	NAM	NIM	NIMV	NIMM	V	M
Subject 1	α	0.87	6.86	3.46	-4.27	2.47	1.33	2.40
	β	0.01	-0.18	-0.18	-0.03	0.01	0.07	0.00
2	α	2.00	6.46	6.40	1.00	5.27	-0.10	1.10
	β	-0.09	0.05	-0.16	-0.22	0.24	0.19	0.09
3	α	0.37	2.23	9.80	-2.47	6.80	-0.70	1.03
	β	-0.22	0.19	-0.07	0.07	-0.03	0.15	-0.37
4	α	0.93	8.23	9.27	1.97	5.07	1.27	0.07
	β	0.13	-0.27	-0.18	0.06	-0.10	0.06	-0.39
5	α	1.83	9.47	5.67	-2.93	6.13	-1.33	0.97
	β	0.09	-0.33	0.13	0.04	-0.10	-0.09	0.20
6	α	2.47	5.06	6.47	-2.13	3.60	-1.47	-0.87
	β	-0.08	0.16	-0.25	0.19	0.12	-0.09	0.01

Table 5.9 Experiment II: Regression analysis. The slope coefficient (β) and the intercept value (α) are shown for each subject in each condition. Each subject's error score has been regressed against the recall trial number.

biasing the recall of a to-be-remembered movement when imagery is accompanied by a motor stimuli. The two stimuli (visual and motor) do not, themselves, interfere with recall except when their VE is compared. The effect here is that the visual stimuli produced a higher VE than the motor task. Thus visual/spatial stimuli do not bias recall of a linear positioning movement. However, it seems that visual spatial stimuli do affect a subject's memory for a linear movement. This suggests that images of movements are equivalent to real movements at a memorial level. Furthermore, there appears to be some evidence that stimuli which suppress imagery of linear movements also interfere with a subject's memory for a linear movement. This is a further indication that images of linear movements manipulate memory representations and that these are interfered with by a visual/spatial stimuli.

The psychoneuromuscular theory suggested by Ulich (1967) and Richardson (1967b) which hypothesises a motor theory of mental imagery has not been supported by the present experiment. Support is found for the symbolic perceptual hypothesis of MP. Kosslyn (1980) hypothesised imagery to be of a quasi-pictorial nature. This conception of how an imagery representation system might operate is based on the notion that visual images might be like displays produced on a cathode-ray-tube by a computer program operating on stored data (Kosslyn, Pinker, Smith and Schwartz, 1979). The suggestion is that images are ... "temporary spatial displays in active memory that are generated from more abstract representations in long-term memory. Interpretive mechanisms (a "mind's eye") work over ("look at") these internal displays and classify them in terms of semantic categories, (as would be involved in realising that a particular spatial confi-

guration corresponds to a dog's ear, for example)" (Kosslyn, et al, 1979, p.536).

No interfering effect on memory due to visual and motor 1st order interference was found when CE was analysed. Comparisons made using VE showed that 1st order visual interference produces more variation than 1st order motor interference. On the assumption that VE is a measure of error due to noise in the memory and output systems and output is assumed to be of a constant noise level, then visual interference has the effect of introducing more noise to the memory for the movement. This is supported by the failure of any (β) regression coefficients to be significantly different from 0. The effects of both 1st and 2nd order visual interference stimuli on VE suggests that the representation in memory of information about linear positioning movements is in a form which is capable of being interfered with by visual/spatial stimulation but not by motor activity.

By using an experimental paradigm similar to that of Finko (1979) in which unexpected biasing after-effects are produced following a mental imagery task it has been possible to show that mental imagery and movement information have some "functional equivalence". The implications of this technique by which imagery can be shown to have some functional significance and which overcomes methodological criticisms raised by Pylyshyn (1973) and others, are profound. Such vague procedures as mental practice can be subjected to experimental analysis to determine the underlying process and memory structure by which improvement following MP is brought about.

5.3. Summary

From the theories of MP two contrasting hypotheses were chosen, each of which implied a different structural account of how imagery is employed in MP. In order to distinguish between these two accounts a second order interference technique showed that imagery does not have any biasing effects on recall when this is competing with a visual/spatial stimuli which involves watching a two dimensional oscillating display.

The interfering effect of a visual/spatial distractor stimuli upon imagery may not be due to competition for some specific resource but due to the greater complexity of the visual/spatial stimuli relative to the motor stimuli. This is unlikely, though, as their effects on motor short-term memory were equal in terms of CE. An alternative explanation is that the motor stimuli did not tax the correct level neuromuscular system. It could have been that squeezing a dynamometer did not interfere with imagery of a movement because it did not involve the same muscle groups required to move the slide along the track. According to Bernstein (1966), and Gallistel (1980) differential control of movement occurs at different levels of the system. The higher up the system hierarchy one goes the greater number of "degrees of freedom" are covered by a particular control centre. The type of movement control involved in operating a squeeze would be different from that involved in moving one's arm to a set position simply because the former involves a different control of the motor system than the latter.

Whilst the possibility of a visual imagery explanation of MP

is suggested further contrasts need to be made between a motor theory of mental imagery and some quasi-pictorial account of imagery. Although the experimental procedure developed in these experiments escapes Pylyshyn's (1973) criticisms mentioned earlier, a purely verbal or symbolic account of mental imagery cannot be ruled out. Future experiments using this technique should be capable of distinguishing between a verbal/symbolic account in which mental imagery is an epiphenomenon of some other form of representation, a motor theory of mental imagery where images are the result of motor programmes for producing an action, and a quasi-pictorial hypothesis in which images are temporary spatial displays in active memory that are generated from more abstract long-term memory representations.

CHAPTER SIX

A FURTHER TEST OF THE PSYCHONEUROMUSCULAR HYPOTHESIS

In the previous experiments it was concluded that MP of a linear positioning task involves the manipulation of a quasi-pictorial representation by an image generation and inspection process. However, there are certain limitations to this conclusion. First the suppression effects of a 2nd order visual/spatial interference stimulus on imagery could be simply due to the complexity of the visual task. Conversely the lack of any inhibitory effects of 2nd order motor interference on imagery could be due to the insufficient complexity of the motor task. More specifically the motor task may not have taxed that part of the motor production system which is brought into play by the act of imagining a linear arm movement. The results so far do not therefore permit us to reject the psychoneuromuscular hypothesis.

Second, the apparatus used in the previous experiments placed a strong emphasis on visual cues due to the track along which movements were made being visible to the subjects throughout the experiment. One simple explanation of the 2nd order interference effect of visual/spatial stimulus is that subjects were prevented from looking at the track. Thus imagery may have been inhibited by the competition between looking at a screen and looking at the track. In order to test this hypothesis a new piece of apparatus was constructed which had a screen preventing subjects from viewing either the track or their arm movements throughout the experiment.

One concern of this research is to show that selective interference tasks can be successfully employed to investigate cognitive processes involved in mental imagery. It has been claimed, Allport (1980), that distinctions between general capacity loading and specific resource demands are not always clear. If it can be assumed that biasing effects caused by imagining a novel linear movement are suppressed by a visual/spatial stimulus then varying the complexity of this stimulus should not change this. Therefore one might predict that if the biasing effect of imagining a linear positioning movement had previously been suppressed by the complex nature of the visual stimulus in Experiment II, namely a 'Lissajous' figure, then a less complex visual/spatial stimulus should not suppress imagery. In addition a visual/spatial stimulus which did not prevent subjects from looking in the region of their imaginary movements might offer a clearer interpretation of the results. Alternatively if the 2nd order motor interference task failed to inhibit imagery because it involved a different part of the motor output system, then a task which uses the same joint and musculature systems as a linear positioning task should inhibit imagery. Finally in Experiment I subjects either learned a 30 cm movement followed by a 60 cm novel movement or learned a 60 cm movement followed by a 30 cm movement. This meant that both groups had different novel movements and different original movements. This could confound the effect of any bias since different movements may have different recall characteristics, such as larger movements being underestimated and shorter movements being overestimated.

6.1. Experiment III

This experiment introduces a visual/spatial stimulus which is less complex than used in the previous experiment, more compatible with the linear positioning task, and does not restrict the subject from looking above the track. Second, a motor stimuli has been devised which bears a closer resemblance to linear arm movements than does squeezing a hand-held dynamometer. Consequently the psychoneuromuscular hypothesis can now be tested more fully. One might predict that a motor stimulus which involved activation of a similar muscle system as the linear positioning movement should suppress any similar activation caused by neuromuscular imagery. Alternatively if a visual/spatial stimulus is used, which does not prevent subjects from looking at the linear positioning apparatus while imagining a linear movement, and that a stimulus of relatively low complexity then any suppression affects on imagery can be attributed to the visual/spatial nature of the stimulus.

6.1.1. Method

(1) Experimental Design

A two factor independent groups design was used, distance/location of the novel movement having two levels, 30 cm and 60 cm. Type of interpolated activity having four levels, novel actual movement (NAM), novel imaginary movement (NIM), novel imaginary movement with 2nd order visual interference (NIMV) and a novel imaginary movement with 2nd order motor interference (NIMM).

(2) Subjects

48 right-handed subjects were randomly selected from a pool of 98 volunteers who were attending an Open University summer school in

psychology at Warwick University. Subjects were of varied occupational back-grounds and ages. An equal number of male and female subjects were assigned to each of the eight experimental groups (6 subjects per group).

(3) Apparatus

(See Figure 6.1). A new slide was constructed, consisting of a 130 cm linear nylon track mounted on a 150 cm x 15 cm x 1.5 cm timber base. Two permanent end stops were fixed to give a useable track length of 125 cm. A moveable stop was used to determine the distance/location of movements along the track. A nylon cursor was free to slide along the track and a millimeter scale was fixed alongside the track. 30 cm above the track a blank screen 125 cm x 55 cm was placed horizontally above the track to screen the subjects' view of their arm and the track. Above this screen, directly parallel to the track, at eye level was a removable rod 125 cm in length with a red and green light, either of which could be positioned anywhere along the rod. Two Birkbeck timers controlled the lights and emitted tones at regular intervals. In addition a 20 cm x 20 cm wooden block was set at the subject's shoulder height approximately 60 cm from the subject. This block was attached to a weighing scale which registered how hard subjects were pushing. A buzzer and light signalled when a correct pressure had been applied.

(4) Task/Procedure

As in Experiments I and II subjects were required to learn a 45 cm movement by sliding the cursor along the track until it reached a stop. After 15 self-paced trials one of the various interpolated

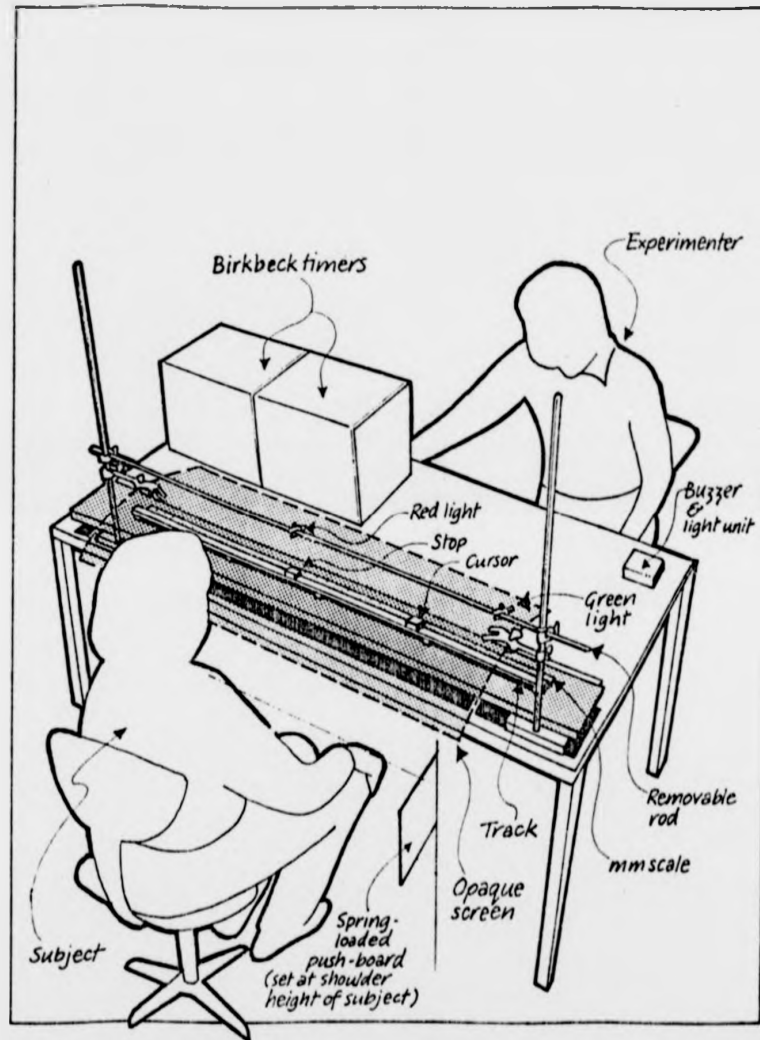


Fig 6.1 Apparatus used in experiment III and subsequent experiments

activities were performed during a 50 sec. retention interval. There then followed ten self-paced recall trials in which subjects had to move the cursor to the original position but with the stop removed. During the whole experiment the screen hid each subject's arm and the track from view. The following types of interpolated activities were used:

6.1.2. Interpolated Activities

(1) Novel actual movements 30 or 60 cms (NAM30, NAM60).

One group of subjects (NAM30) were required to move the cursor to the stop positioned at 30 cm. The red light being repositioned above this new point. The first 10 secs were used to instruct subjects on their task; during the remaining 40 secs 10 movements were made to the novel position, as in previous experiments. Throughout this interval the green and red lights flashed alternately at 2 sec. intervals. The (NAM60) group performed the same task but moving to a 60 cm point.

(2) Novel imaginary movements 30 or 60 cms (NIM30, NIM 60)

As in previous experiments subjects in each of these two groups imagined performing the same movement as the NAM groups. The apparatus being arranged exactly as in the NAM conditions.

(3) Novel imaginary movements with visual interference
(NIMV30, NIMV60)

Subjects in these conditions were required to imagine moving as the NIM groups but with an additional task. The additional task being that they should determine how many times the red light flashed and to discriminate which of the two lights were brighter. (The red light flashed ten times and there was no difference in brightness, although

green is often seen as being brighter). This occurred whilst the lights were in a novel position, but not that to which they were imagining moving. Consequently subjects were asked to imagine one movement but being presented with visual cues which determined a different distance/location. (The green light being placed at the 40 cm point and the red light at the 50 cm point). During the first 10 secs of the retention interval subjects were instructed on their task and given two trials of imagining moving to the 30, or 60 cm points. Whilst this was happening the lights were at the appropriate points, either 30 or 60 cm. At the end of 10 secs subjects were told to carry on imagining moving to the same position but the lights were now moved to the 40 and 50 cm points. Consequently subjects were instructed to imagine moving to one point but given visual cues for a non-relevant movement.

(4) Novel imaginary movement with motor interference
(NIMM30, NIMM60)

The final two conditions required that subjects should imagine a novel movement as in the NIM conditions. In addition they had to perform a 2nd order motor interference task. This task consisted of exerting a 15 kg. pressure by pushing against the 20 x 20 cm block with the same arm as they had been learning the original movement. The block was positioned to the subject's right at below shoulder height. Thus subjects were pushing in the opposite direction to an imagined move.

(5) Recall trials

Immediately following the 50 sec retention intervals subjects were again required to move the cursor to the 45 cm position with the stop and the lights completely removed. Subjects had 10 self-paced trials recalling their original movements. Scoring being to the nearest 0.5 cm as previously.

6.1.3. Results

Subjects error scores at recall are produced in appendix E. From this data CE and VE scores were calculated for each subject, the resultant means and standard errors are shown in Table 6.1.

(1) Constant Error, (C.E.)

A two-way independent groups ANOVA with CE as the dependent variable resulted in a non-significant effect for type of interpolated activity, $F(3,40) = 0.648$ $p > .05$. Distance/location of the novel movement had a significant effect on CE $F(1,40) = 431.926$ $pr < .001$. The interaction between type of interpolated activity and distance/location of the novel movement was significant, $F(3,40) = 44.095$ $pr < .001$. A summary of the ANOVA results is shown in Table 6.2.

Breaking down the significant interaction effect into its simple components using a Scheffé's F test showed that when imagery and 2nd order visual interference occurred together no effect for direction/location of movement occurred, $F(1,40) = 0.187$ $pr > .05$. From Table 6.1 and Fig. 6.2 it can be seen that this lack of any effect for direction/location of the novel movement is because very little error as measured by CE occurs. All other components within the interaction had a significant effect, as can be seen from Table 6.3.

(2) Variable Error (V.E.)

Analysing VE by a two-way independent groups ANOVA, type of interpolated activity had a significant effect on VE, $F(3,40) = 3.752$ $pr < .025$. The direction/location of the novel movement was not significant,

6.1.3. Results

Subjects error scores at recall are produced in appendix E. From this data CE and VE scores were calculated for each subject, the resultant means and standard errors are shown in Table 6.1.

(1) Constant Error, (C.E.)

A two-way independent groups ANOVA with CE as the dependent variable resulted in a non-significant effect for type of interpolated activity, $F(3,40) = 0.648$ $p > .05$. Distance/location of the novel movement had a significant effect on CE $F(1,40) = 431.926$ $pr < .001$. The interaction between type of interpolated activity and distance/location of the novel movement was significant, $F(3,40) = 44.095$ $pr < .001$. A summary of the ANOVA results is shown in Table 6.2.

Breaking down the significant interaction effect into its simple components using a Scheffé's F test showed that when imagery and 2nd order visual interference occurred together no effect for direction/location of movement occurred, $F(1,40) = 0.187$ $pr > .05$. From Table 6.1 and Fig. 6.2 it can be seen that this lack of any effect for direction/location of the novel movement is because very little error as measured by CE occurs. All other components within the interaction had a significant effect, as can be seen from Table 6.3.

(2) Variable Error (V.E.)

Analysing VE by a two-way independent groups ANOVA, type of interpolated activity had a significant effect on VE, $F(3,40) = 3.752$ $pr < .025$. The direction/location of the novel movement was not significant,

		NAM 30	NAM 60	NIM 30	NIM 60	NIMV 30	NIMV 60	NIMM 30	NIMM 60
CE	\bar{X}	-5.95	5.01	-5.48	5.27	-0.15	0.19	-5.11	5.7
	se	1.690	1.110	0.607	0.882	2.022	1.773	0.919	1.303
VE	\bar{X}	1.33	1.36	0.59	1.11	0.94	1.02	1.12	1.16
	se	0.691	0.362	0.115	0.263	0.238	0.369	0.351	0.397

Table 6.1 Experiment III: Mean and standard error for CE and VE under each experimental condition measured in cms.

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
A. Distance/Location of novel movement	810.163	1	810.163	431.926	<.001 ***
B. Type of interpolated activity	3.646	3	1.215	0.648	>.05 NS
AXB Interaction	248.127	3	82.709	44.095	<.001 ***
Error	75.028	40	1.876		
Total	1136.964	47			

Table 6.2 Experiment III: Summary of a 2 way independent groups ANOVA using CE as the dependent variable

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
30) NAM 60)	360.255	1	360.255	192.06	<.001 ***
30) NIM 60)	347.225	1	347.225	185.118	<.001 ***
30) NIMM 60)	350.460	1	350.46	186.842	<.001 ***
30) NIMV 60)	0.350	1	0.350	0.187	>.05 NS
Interpolated activity at 60 cm	120.169	3	40.056	21.355	<.001 ***
Interpolated activity at 30 cm	131.604	3	43.868	23.387	<.001 ***
Error	75.028	40	1.876		

Table 6.5 Experiment III: Decomposition of interaction between type of interpolated activity and distance/location of novel movement

- 164 -
EXPERIMENT III

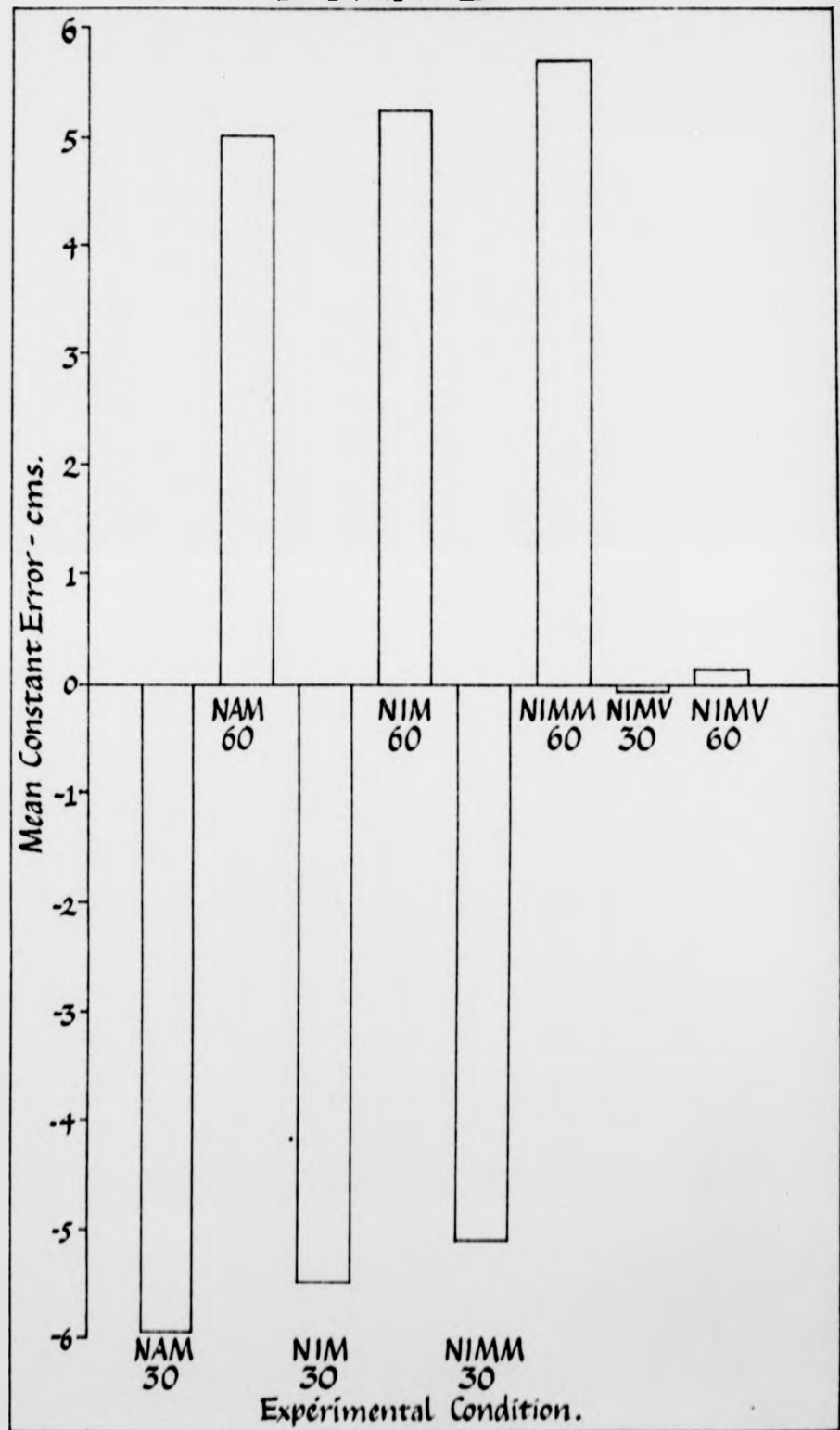


Fig 6.2 Mean Constant Error for each condition of experiment III

$F(1,40) = 2.087$ pr $>.05$. Similarly the interaction between type of interpolated activity and direction/location of the novel movement was not significant, $F(3,40) = 1.212$ pr $>.05$. (ANOVA summary shown in Table 6.4).

Analysing the significant effect for type of interpolated activity further with Tukey's HSD (a) test (summarised in Table 6.5) it was found that "novel actual movements" (NAM) produced a significantly higher amount of VE than a "novel imaginary movement" (NIM). Whilst no significant differences were found between other pairs of means it can be seen from Fig. 6.3 that imagery and movement have different effects on VE. This is most obvious in the 30 cm condition NIM30, but there was no significant interaction between location/distance of the novel movement and type of interpolated activity.

(3) Regression analysis

Finally a regression analysis was performed on the raw data for each subject, regressing trials and error scores as in previous experiments. The results of this analysis are shown in Table 6.6. The slope coefficients (β) are consistently low varying between 0 and .3 with one exception for subject 1 in the NIM60M condition whose regression slope has a β value of .56. Furthermore in condition NAM60, NAM30, NIM60, NIM60M and NIM30M where there appeared a significant bias, this is mirrored by the intercept (α) of the regression analysis. Fig. 6.4 and 6.5 show the mean error per recall trial.

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
A. Distance/location	0.302	1	0.302	2.087	>.05 NS
B. Type of interpolated activity	1.628	3	0.543	3.752	<.025 *
AXB Interaction	0.526	3	0.175	1.212	>.05 NS
Error	5.786	40	0.145		
Total	8.243	47			

Table 6.4 Experiment III: 2-way independent groups ANOVA with VE as the dependent variable

	NAM $\bar{X}=1.344$	NIMM $\bar{X}=1.143$	NIMV $\bar{X}=0.982$	NIM $\bar{X}=0.847$
NAM $\bar{X}=1.344$		0.201	0.362	0.497 *
NIMM $\bar{X}=1.143$			0.161	0.296
NIMV $\bar{X}=0.982$				0.135
NIM $\bar{X}=0.847$				

Table 6.5 Experiment 111: Comparisons of mean VE for type of interpolated activity. ** < .01 pr level of significance on Tukey's (a) test. * < .05 pr level of significance on Tukey's (a) test

- 168 -
EXPERIMENT III

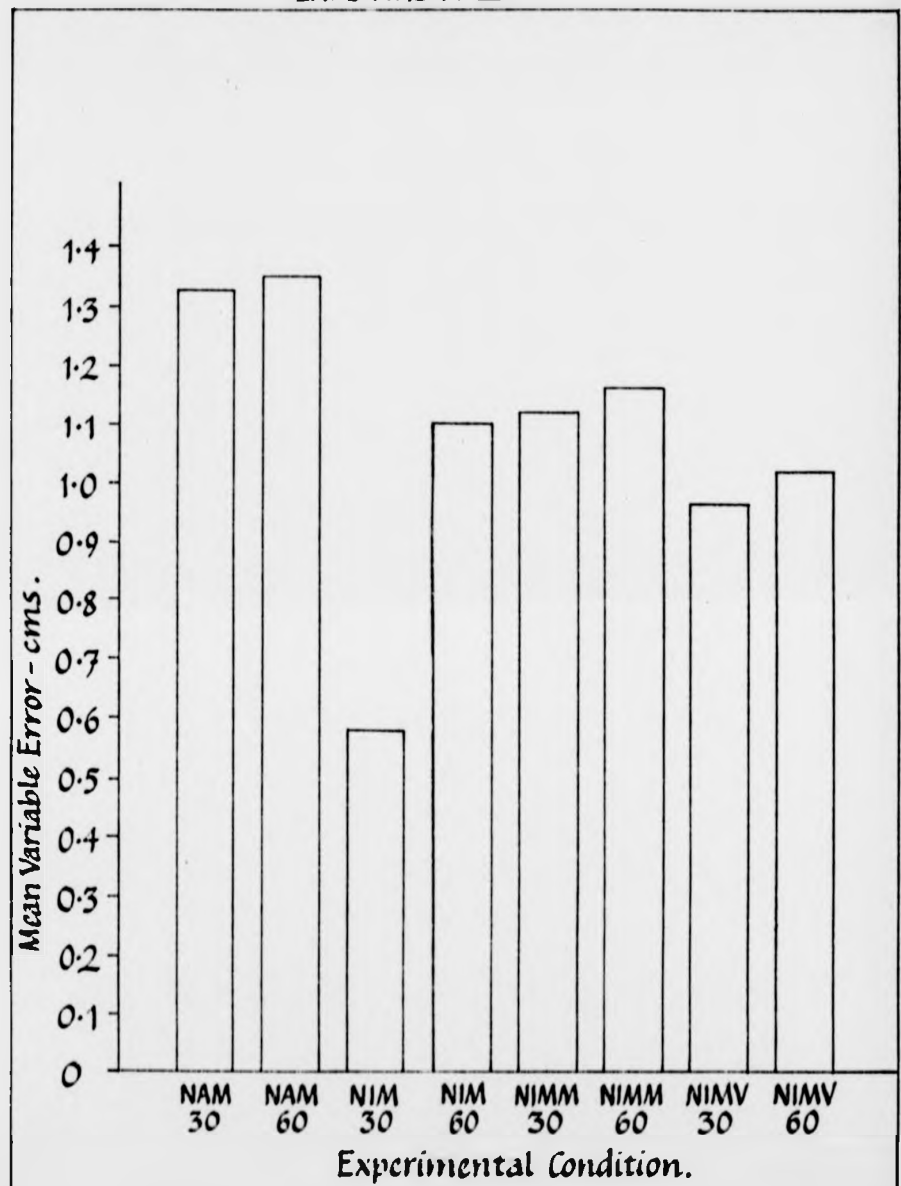


Fig 6.3 Mean Variable Error for each condition of experiment III

Subject		NAMGO	NAM30	NIMGO	NIM30	NIMGOV	NIM30V	NIMGOM	NIM30M
1	α	6.13	-4.73	2.73	-5.48	2.40	0	4.48	-4.33
	β	-0.31	-0.14	0.32	-0.01	-0.04	0	0.56	0.06
2	α	2.87	-6.87	4.23	-6.90	-1.50	-2.33	5.26	-2.93
	β	0.46	-0.13	0.37	0.06	0.11	-0.19	-0.12	-0.23
3	α	2.73	-6.86	5.57	-5.07	0.20	-0.60	8.40	-4.27
	β	0.18	-0.10	0.12	0.05	0.11	0.33	-0.24	-0.08
4	α	4.07	-8.47	4.90	-4.87	1.93	0.27	5.20	-5.50
	β	0.01	0.23	-0.04	-0.02	-0.02	0.28	0.01	-0.08
5	α	3.80	-3.80	4.57	-5.80	-1.43	0.20	5.77	-6.03
	β	0.36	-0.07	-0.20	0.05	-0.17	-0.18	-0.10	0.69
6	α	7.63	-3.53	5.66	-5.47	1.33	-1.53	4.30	-6.70
	β	-0.19	-0.05	-0.24	-0.1	-0.24	-0.03	0.04	0.14

Table 6.6. Experiment III: Regression of error score against trials for each subject in each experimental condition. Each subject's slope coefficient (β) and intercept value (α) is shown

- 170 -
EXPERIMENT III

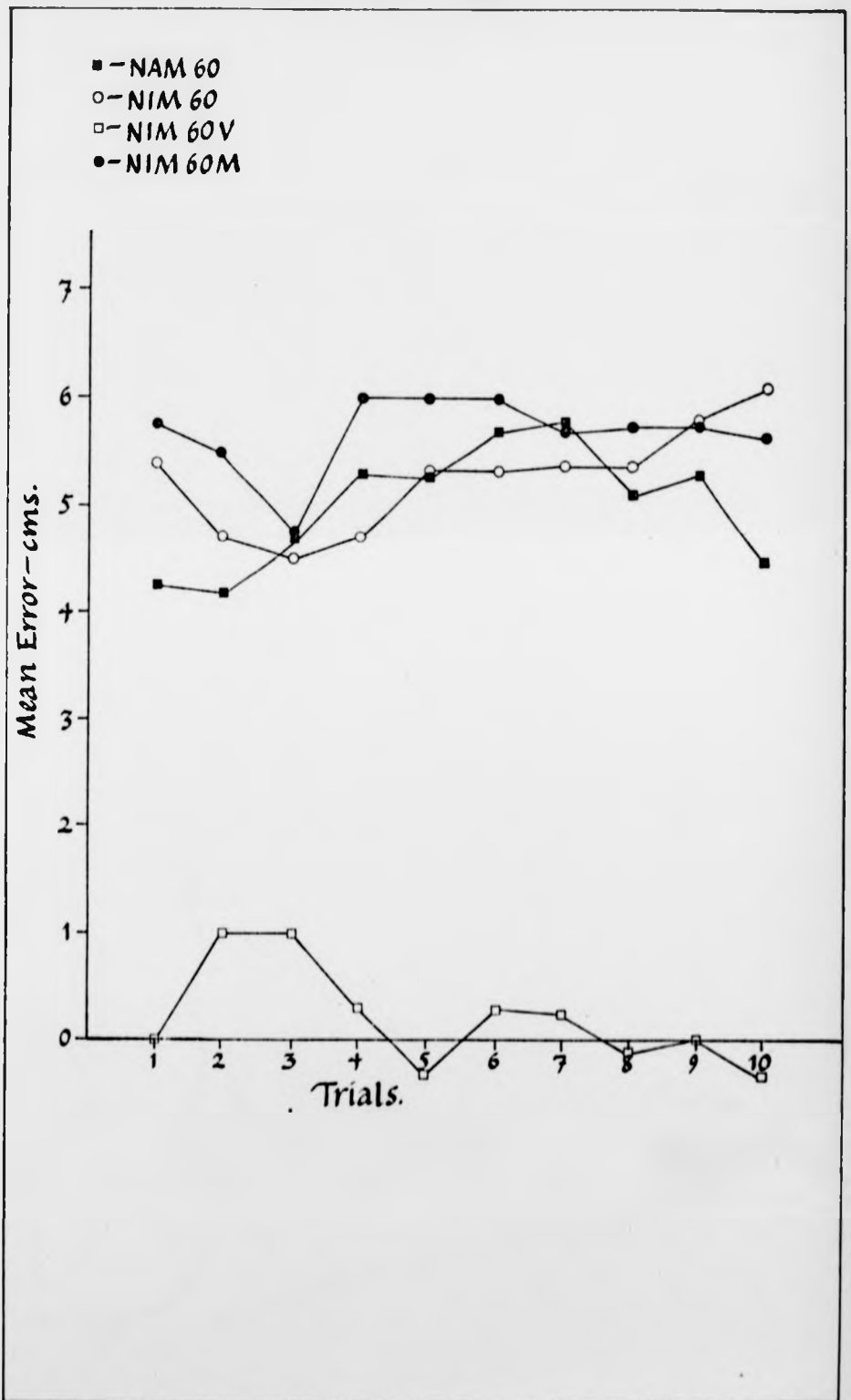


Fig. 6.4. Mean Error over recall trials (60 cms)

- 171 -
EXPERIMENT III

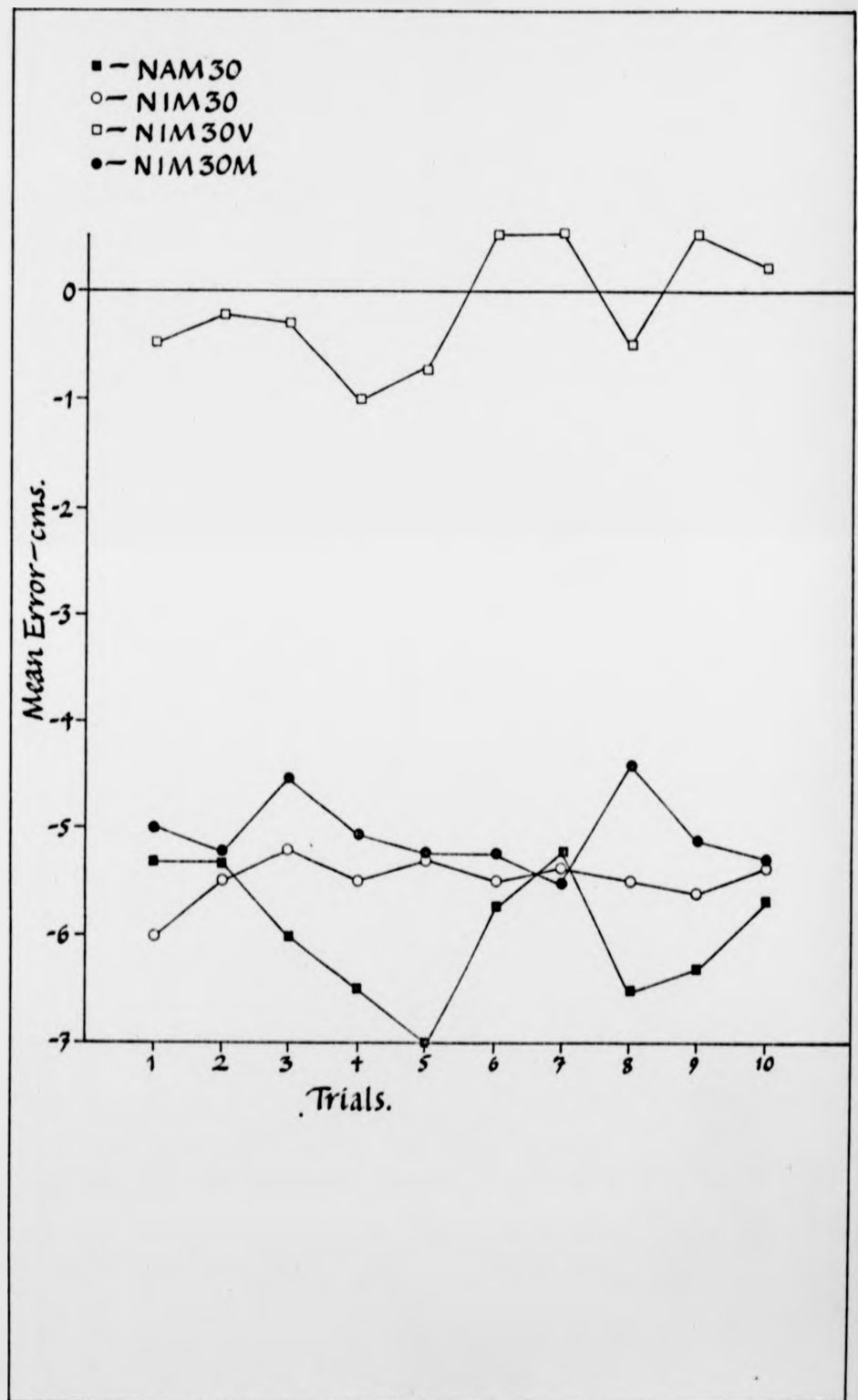


Fig. 6.5. Mean Error over recall trials (30 cms)

6.1.4. Discussion

The results of this experiment show that a visual/spatial interference stimuli suppresses the biasing effect, of imagining a larger linear movement, on the recall of a criterion linear positioning movement. This suggests that imagining a linear positioning movement involves part or all of those cognitive resources normally used to process visual/spatial information. Although it is possible that interference stimuli could suppress imagery effects purely by means of their general capacity loading, this seems unlikely in this instance. If it can be assumed that monitoring two alternating flashing lights involves less of an information processing load than inspecting an oscillating lissajou figure then the finding that both of these tasks suppress imagery suggest that it is not the general information processing demand of the task but the specific resource required to process the stimuli which causes interference with the generation and processing of imagery.

The absence of any interfering effects to imagery with the motor interference task both supports the above arguments and suggests that the psychonouromuscular hypothesis of MP is incorrect. If imagery of a linear positioning movement involved activation of the motor output system with resultant neuromuscular activity, then assuming that pushing with the arm involves similar neuromuscular activity as in moving a linear slide then any biasing due to imagery should have been suppressed. As imagery with a motor interference stimulus still had a biasing effect on all subjects' memory for the criterion position then it seems that imagining a linear positioning movement does not involve the motor output system, to the extent suggested by the psychonouromuscular hypothesis of MP.

An earlier suggestion was that the visual stimuli could have interfered with imagery simply by preventing subjects from "looking" in the direction of their imagined movement. In the present experiment subjects were able to look above the full length of the track while monitoring the visual interference stimulus. Neisser (1976) suggests that eye movements could be important features of visual imagery in so much that such images are often used as "plans" for future visual searches. In the present experiment subjects may have been restricted to some extent from moving their eyes. However, the visual interference stimuli did not prevent subjects moving their eyes in the direction of the imagined movements. Moreover, the role of eye movements is not completely clear since there are large subject variations in scanning items. In addition eye movements are controlled by a different system than other motor acts, which suggests that eye movements themselves may not be considered under the psychoneuromuscular hypothesis.

6.2. Some Conclusions on Imagery and the Psychoneuromuscular Hypothesis

Imagery of linear positioning movements does not appear to be caused by a process involving the activation of the motor output system. It was predicted that if imagery of this sort involved the motor production system then a competing motor task would suppress the imagery biasing effect on an interim linear positioning task. The failure of the motor interference tasks in this and the previous experiment (reported in Chapter Five) strongly suggests that imagery does not involve activation of the motor output system.

The alternative hypothesis that imagery of this sort is based on a visual/spatial processing system is supported by the results of this and the previous experiment. It is possible, however, that a completely different explanation of imagery effects in linear positioning tasks could be suggested which did not involve the visual/spatial information processing system. One might argue that if movements were made at a constant velocity then subjects could rehearse the distance of their movement by counting, perhaps subvocally. Rehearsal by counting would permit subjects to monitor the time interval during which a movement was produced. Imagery of a linear positioning movement might involve the generation of a time interval for the movement at a known constant velocity. In order to vary the distance of an imaginary movement either the length of the movement time interval could be altered by either sub-vocally counting to a higher number or counting at a different rate. Alternatively the rate of movement during the time period could be increased. All of these different strategies rely on a basic time keeping mechanism which may involve sub-vocal counting.

A further limitation to the visual/spatial hypothesis of movement imagery is the strength of the assumption that interference or suppression is caused by competition for a specific resource. It was argued in Chapters Three and Five that this assumption has a considerable amount of support. Further support for this assumption can be found when one considers the way that varying the information processing load of the visual interference stimulus in Experiment III compared to that in Experiment II produced no change in its effects on imagery for a linear positioning movement. While this was not meant to directly test any hypothesis related to the nature of interference

tasks it does support the assumption that interference tasks compete for a specific processing resource. However, Phillips and Christie (1977 a, b) suggest that certain tasks such as mental arithmetic interfere with visualisation through their general response demanding load. In view of this claim it is necessary to investigate the interference effects due to general response demand compared to those due to specific resource demand.

CHAPTER SEVEN

SUBVOCAL REHEARSAL AND PROCESSING LOAD

Recently, Summers and Sharp (1979) have shown that verbal and spatial tasks can interfere with motor tasks, such as finger tapping. They suggest that motor acts contain a spatial and a sequencing component, both of which can be separately interfered with by verbal or visual/spatial tasks. A possible implication of this is that both spatial and sequential rehearsal may occur during MP. It may be the case that subjects who imagine novel movements are using sequential (temporal) or rate information, which from Summers and Sharp's account is in a verbal form. Thus imagery of movements may involve the subvocal rehearsal of verbal labels, perhaps by counting.

An alternative explanation of Summers and Sharp's findings is that the processing load of either interference task could have affected performance on the motor task. Thus while each interference task contained either spatial or sequential material, it was the general processing load of each task, rather than their specific component which influenced motor performance. Therefore one cannot conclude that motor tasks are solely subject to spatial or sequential interference, nor that they contain separate spatial and sequential components.

One possible solution is to vary both the processing load and the specific components of the interference task independently. In this way it might be shown that certain specific tasks produce interference effects which are different from interference effects produced by a

general processing load.

7.1. Experiment IV

Operationalising processing load as the response demand of the interference task it is predicted that if imagery of movements involves a specific resource independently of the response demand then a particular 2nd order interference task should suppress imagery. Furthermore if imagery involves some general capacity then an increase in the response demands of any 2nd order interference task should affect imagery. If imagery of movements involves the subvocal rehearsal of verbal symbols then a 2nd order interference task which requires subjects to monitor a verbal message should inhibit imagery. Alternatively if imagery involves a visual/spatial process then a visual stimulus should inhibit imagery. Finally if imagery involves the activation of a motor programme a motor interference task should inhibit imagery.

7.1.1. Method

(1) Experimental design

A two factor independent groups' design was used with response demand and type of interference stimulus as the two factors. Response demand was manipulated by requiring one set of subjects to respond to the 2nd order interference stimulus, while other subjects were told that the stimulus would be present but they would not have to make any responses to it. The type of 2nd order interference stimulus were either verbal, motor or visual, giving six experimental groups in all.

(2) Subjects

36 right-handed subjects were randomly selected from a pool of 78 volunteers who were attending an Open University summer school at Warwick University. An equal number of male and female subjects was assigned to each group (total number of subjects per group = six). Subjects' ages ranged from 21 - 65 and their occupational backgrounds were varied.

(3) Apparatus

Additional to the apparatus used in Experiment III a Bell and Howell cassette recorder with a 6" diameter extension loudspeaker was used to provide a verbal interference stimulus.

(4) Task

As in previous Experiment III a linear positioning task was used with additional 2nd order interference stimuli.

(5) Procedure

Subjects were required to first learn a 45 cm movement on the linear positioning apparatus as in Experiment III. Following this all subjects were required to imagine making a 60 cm movement during a 50 sec retention period. During this period one of the three types of 2nd order interference stimuli were presented, which subjects either responded to or not, depending upon which condition they were in (R) response or (NR) no response. The three 2nd order interference stimuli were presented as follows:-

7.1.2. Interference Tasks

(1) Verbal (Verb)

A tape-recorded string of random numbers was presented via a loudspeaker, with a 2 second pause between each random number. The verbal response group (Verb R) were required to shadow these numbers by repeating each one in the 2 sec pause while imagining the 60 cm movement. The verbal no response group (Verb NR) was told to imagine the 60 cm movement.

(2) Motor (M)

As in Experiment III a pressure plate was fixed horizontal to the subject at approximately arm's length and shoulder height. The motor response group (MR) were required to monitor their pressure so that a buzzer did not sound, while imagining a 60 cm movement. Thus every time their pressure on the plate varied from a mean pressure of 15 kgs by more than + or - 2 kgs a buzzer would sound. The motor no response group (MNR) were required to push against the plate but there was no specific pressure requirement (i.e. they did not have to monitor their exerted force) and no buzzers were sounded.

(3) Visual (V)

As in Experiment III the guide lights were set at a non-relevant location and flashed on and off alternately. Subjects in the visual response group (VR) were required to indicate which of the two lights were the brighter (they were identical) and how many times the red light flashed on while imagining a 60 cm movement). The visual no response group (VNR) had the same 2nd order interference stimulus as the (VR) group but were simply told to imagine a 60 cm movement.

As in Experiment III, all groups used the first 10 seconds of the retention period to practice carrying out the imagery instruction before the 2nd order interference stimulus occurred. Finally all groups were given 10 recall trials to reproduce the 45 cm movement with all the cues and the stop removed.

7.1.3. Results

Error scores to the nearest 0.5 cms were recorded, from the original 45 cm location. From these scores CE and VE scores were calculated for each subject (a summary is shown in appendix F). The mean and so for each dependent variable in each experimental condition are shown in Table 7.1.

(1) Constant Error (CE)

A two-way independent groups ANOVA of CE resulted in a significant effect for type of interference, $F(2,30) = 78.078$, $pr < .001$. Response demand did not have a significant effect on CE. $F(1,30) = 1.626$, $pr > .05$ nor was there any significant interaction effect, $F(2,30) = 2.376$, $pr > .05$ (Table 7.2 shows an ANOVA summary). Figure 7.1 shows that visual interference prevents imagery producing a significant directionally specific bias in terms of CE. Whilst motor and verbal tasks, whether requiring a response or not, do not suppress the imagery induced bias.

Decomposition of the significant main effect for type of interference using Tukey's HSD (α) test showed that visual interference consistently produced less bias, as measured by CE, when subjects were trying to imagine a 60 cm novel movement (Table 7.3 shows the differences between means for each type of interference).

Type of Interference		Visual		Motor		Verbal	
Response Demand		R	NR	R	NR	R	NR
CE	(\bar{X})	0.39	-0.30	4.92	5.70	5.20	6.73
	(so)	0.70	1.37	1.37	1.61	0.51	2.00
VE	(\bar{X})	0.66	1.20	0.64	1.03	0.68	0.73
	(so)	0.21	0.55	0.18	0.37	0.20	0.23

Table 7.1 Experiment IV: Summary of mean (\bar{X}) and standard error (so), constant error (CE) and variable error (VE) for each experimental condition, measured in cms.

Type of Interference		Visual		Motor		Verbal	
Response Demand		R	NR	R	NR	R	NR
CE	(\bar{X})	0.39	-0.30	4.92	5.70	5.20	6.73
	(se)	0.70	1.37	1.37	1.61	0.51	2.00
VE	(\bar{X})	0.66	1.20	0.64	1.03	0.68	0.73
	(se)	0.21	0.55	0.18	0.37	0.20	0.23

Table 7.1 Experiment IV: Summary of mean (\bar{X}) and standard error (se), constant error (CE) and variable error (VE) for each experimental condition, measured in cms.

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
A. Interference	252.883	2	126.441	78.078	<.001 ***
B. Response Demand	2.6235	1	2.623	1.626	>.05 NS
AXB Interaction	7.631	2	3.816	2.376	>.05 NS
Error	48.583	30	1.619		
Total	311.720	35			

Table 7.2 Experiment IV: ANOVA Summary. 2-way Independent groups design. CE as the dependent variable

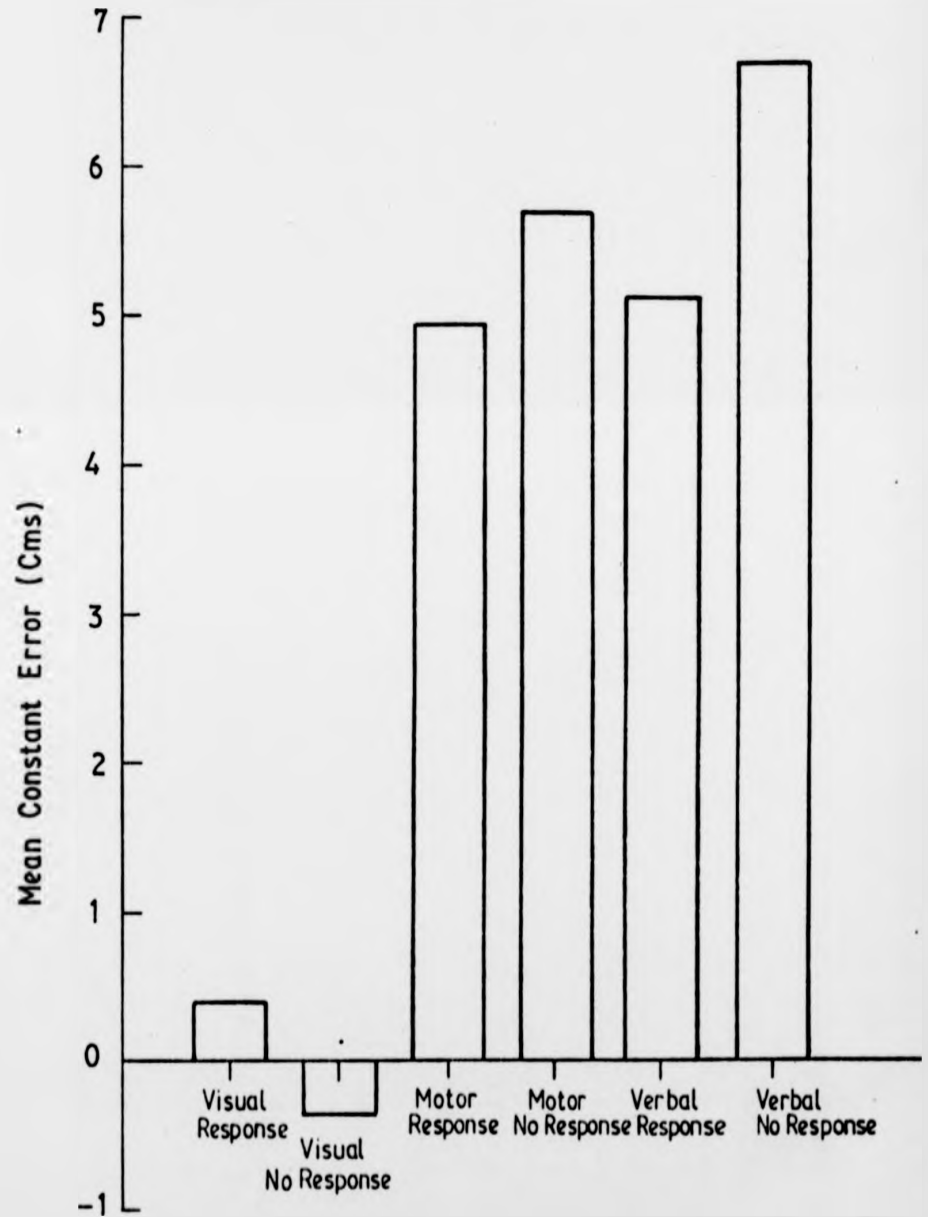
	Verbal $\bar{X}=5.965$	Motor $\bar{X}=5.31$	Visual $\bar{X}=0.045$
Verbal $\bar{X}=5.965$		0.654	5.92 **
Motor $\bar{X}=5.31$			5.266 **
Visual $\bar{X}=0.045$			

Table 7.3 Experiment IV: Differences between mean CE for each type of 2nd order interference (cm).

** <.01 pr level of significance on Tukey's HSD (n) test

EXPERIMENT IV

Fig. 7.1 Mean Constant Error for type of interference and response demand



Type of Interference and Response Demand

2nd order interference $F, 2, 30 = 78.078$ $p < .001$

(2) Variable Error

Using the amount of variation between one subject's 10 responses (VE) as a measure of the strength of the memory trace, a 2-way independent group's ANOVA showed that response demand had a significant effect on VE, $F(1,30) = 13.88$, $pr < .001$. Type of 2nd order interference had no significant simple main effect, $F(2,30) = 1.855$, $pr > .05$, but the interaction between type of 2nd order interference activity and response demand was significant, $F(2,30) = 12.155$ $pr < .001$ (Table 7.4 shows the ANOVA summary).

Decomposition of the interaction effect shows that type of interference had a significant effect on VE with no response demand, $F(2,30) = 5.070$ $pr < .025$ but not when a response was required $F(2,30) = 0.140$ $pr > .05$. Further analysis showed that response demand had a significant effect on VE with visual interference $F(1,30) = 13.665$ $pr < .001$ as did response demand with motor interference $F(1,30) = 6.912$ $pr < .025$ but not with verbal interference $F(1,30) = 0.016$ $pr > .05$. (A summary of this analysis is shown in Table 7.5).

The effect of both the response demand and the interference variable on VE can be seen in Fig. 7.2. No response increases the amount of VE under all types of interference but this is only significant in the case of visual and motor interference.

(3) Regression Analysis

Finally a regression analysis (summarised in Table 7.6) was performed on each subject's error scores. Regressing trials and error scores it was found that there were no slope coefficients β greater than 0.388, with the majority of β values around 0.1. Thus no linear trend

SOURCE		Sums of Squares	Df	Mean Square	F Ratio	Pr level	
A.	Interference	0.2437	2	0.1219	1.855	>.05	NS
B.	Response Demand	0.9117	1	0.9117	13.880	<.001	***
AXB	Interaction	1.5968	2	0.7984	12.155	<.001	***
Error		1.9705	30	0.0657			
Total		4.7227	35				

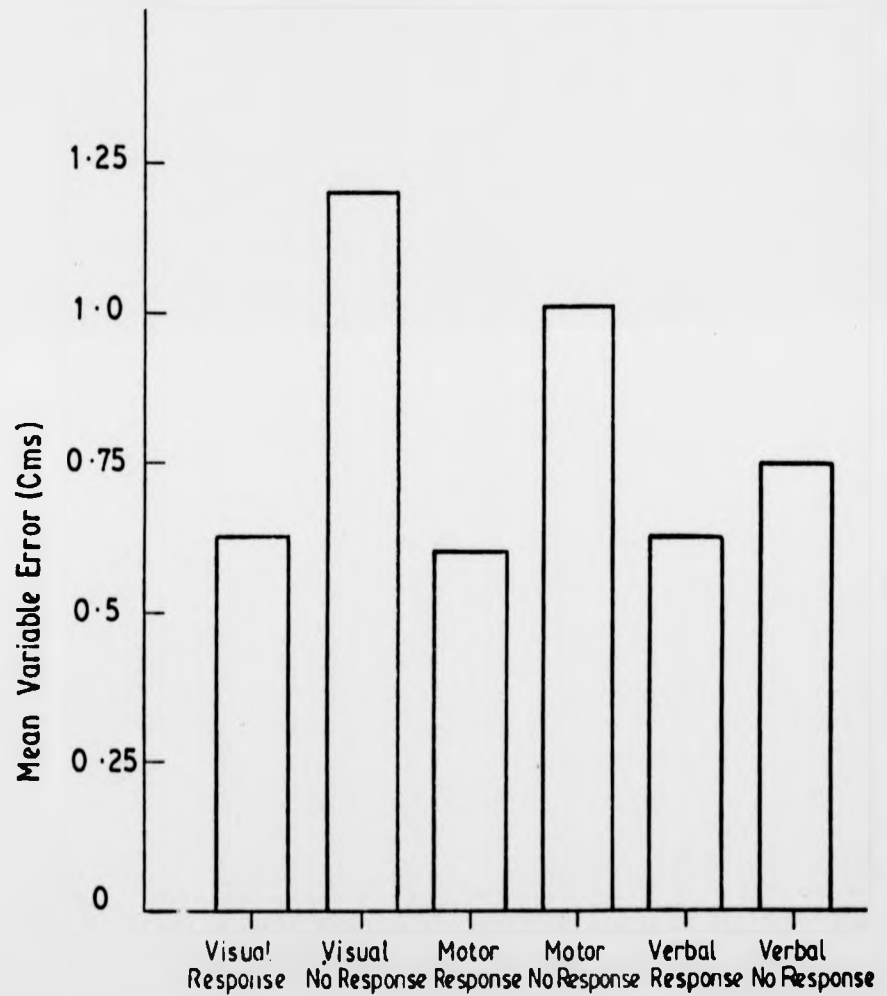
Table 7.4 Experiment IV: ANOVA Summary table VE

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
Response demand at visual interference	0.8976	1	0.8976	13.665	<.001 ***
Response demand at motor interference	0.454	1	0.454	6.912	<.025 *
Response demand at verbal interference	0.001	1	0.001	0.016	>.05 NS
Type of interference at no response	0.666	2	0.333	5.070	<.025 *
Type of interference at response	0.0188	2	0.009	0.140	>.05 NS
Error		30	0.066		

Table 7.5 Experiment IV: Decomposition of significant interaction between type of interference and response demand for VE

EXPERIMENT IV

Fig. 7.2 Mean Variable Error for type of interference and response demand



Type of Interference and Response Demand

Interaction $F, 2, 30 = 12.16 p < .001$

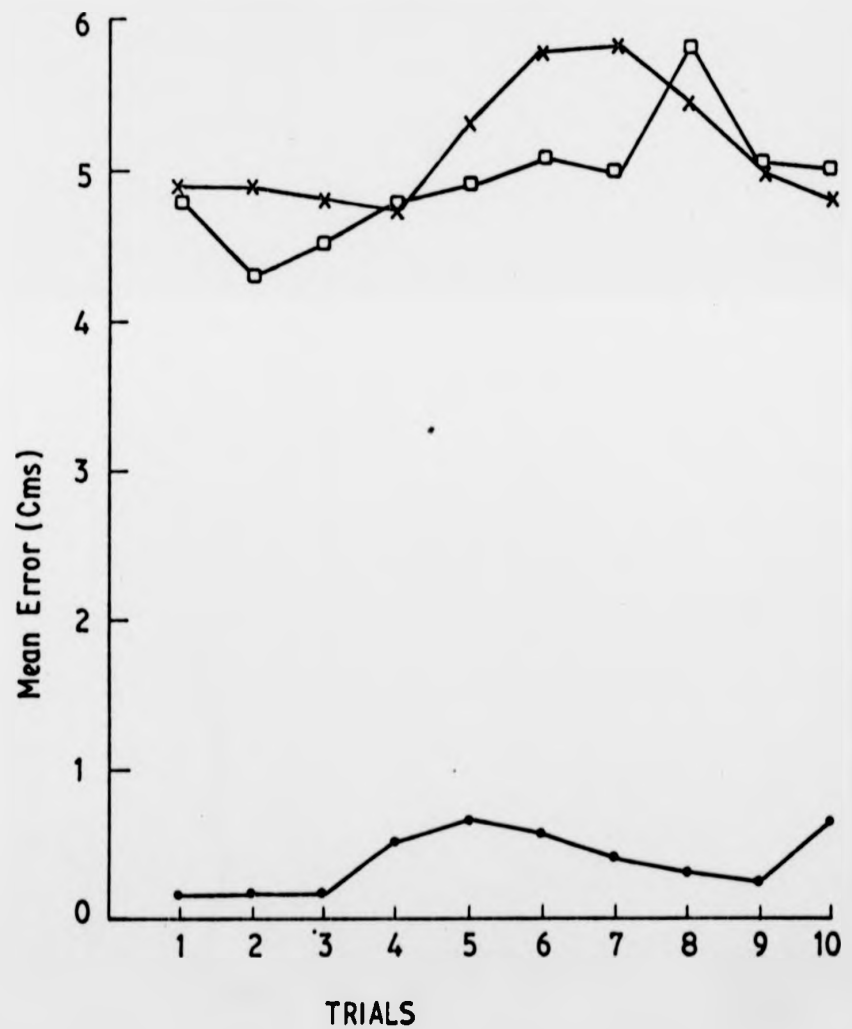
Response Demand $F, 1, 30 = 13.88 p < .001$

Subjects		VR	MR	VERBR	VNR	MNR	VERBNR
1	α	0.600	5.333	6.066	0.867	4.267	11.200
	β	-0.036	0.167	0.067	-0.085	0.206	-0.182
2	α	1.633	4.300	4.933	2.800	3.733	4.200
	β	-0.081	0.018	0.158	-0.182	0.085	0.109
3	α	0.800	4.133	6.067	-3.467	2.533	6.000
	β	0.027	0.103	-0.158	0.248	0.339	-0.036
4	α	-0.267	3.467	4.433	-1.533	-1.533	5.667
	β	0.085	0.170	0.103	0.261	0.261	0.006
5	α	-0.133	4.933	4.200	-3.333	7.667	6.133
	β	0.042	0.048	0.036	0.388	0.097	0.339
6	α	-1.400	4.600	4.267	-0.867	7.533	5.600
	β	0.127	0.000	0.152	0.012	-0.079	0.073

Table 7.6 Experiment IV: Regression analysis. Regressing trial Number and error score of each subject's recall of the 45 cm movement, α = intercept, β = slope coefficient

EXPERIMENT IV

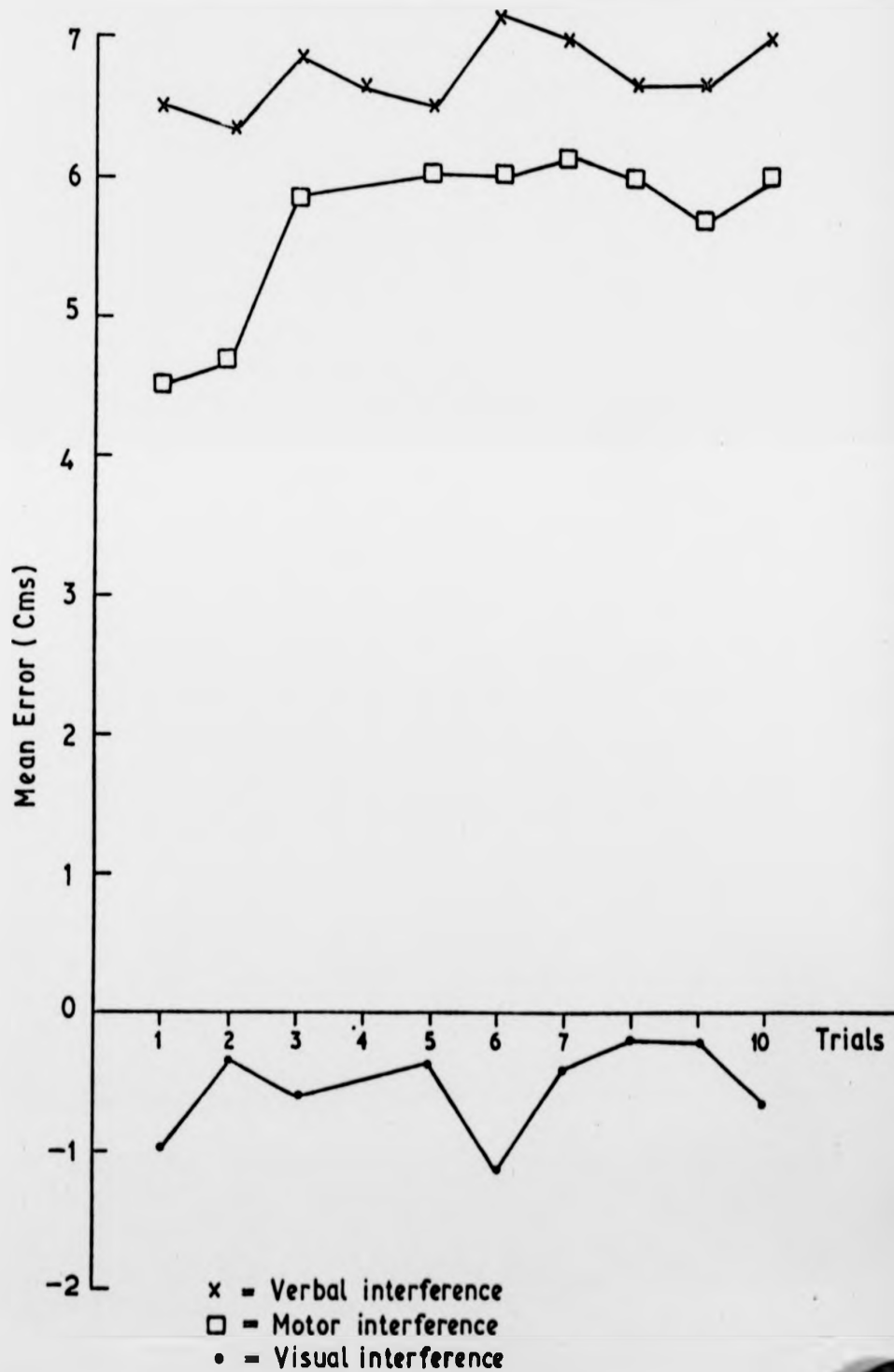
Fig.7.3 Effects of type of 2nd order interference on imagining a 60 cm movement (Response required)



x = Verbal Interference
□ = Motor Interference
• = Visual Interference

EXPERIMENT IV

Fig. 7.4 Effects of type of 2nd order interference on imagining a 60 cm movement (No response required)



appears to be present in individual subjects' positioning movements. As in previous experiments the intercept coefficient α of the regression equation varies according to the type of interference, verbal and motor interferences produced high positive values while visual interference results in low or negative intercept coefficients. In Figures 7.3 and 7.4 the mean response per trial for each condition of the experiment is shown. The effect of visual interference is consistently to reduce the amount of positioning error in recalling the original movement, indicating that imagining a 60 cm movement has either had no effect on memory or else imagery has been suppressed. Furthermore the lack of any linear trend over recall trials is clearly shown.

7.1.4. Discussion

The results of this experiment clearly show that imagery of movements is not suppressed by motor or verbal interference stimuli. It may be that interference is caused by competition for a "specific" resource as Allport (1980) suggests. If so, then imagery involves part of, or possibly the whole of, the visual/spatial processing system. Alternatively interference may be caused by a loading being placed upon a general processing capacity. The results of this experiment, however, suggest that interference due to a loading of a general capacity has a differential effect than that caused by a specific loading of the visual system. Manipulation of the response demand of the various interference stimuli produced a higher VE in the "no response" conditions than the "response" conditions.

According to Laabs (1973) VE is a measure of the strength of the memory trace and in addition a "noise" component. The weaker the memory trace the more it will be swamped by "noise" from other sources

and the more variable it is. If this is so then the two component model may reflect general, and specific, resource demands. It was found that as the response demand increased, VE decreased. One possibility is that the "noise" component in a positioning response is reduced by a load being placed upon a general resource capacity. The load may act in the same way as a filter, by cutting out interference or noise from within the system. Hence, movements produced when a response to interference stimuli is necessary have a reduced noise component. Consequently, the noise component of VE is inversely related to a general resource demand. In the case of a visual interference task, however, the specific resource required to produce an image of a movement is taxed by the interference task, therefore, biasing is suppressed.

One other aspect of this experiment is that a verbal rehearsal hypothesis can be rejected since biasing was not suppressed by a verbal interference task. Summers (1977) and Summers and Sharp (1979) suggest that motor control includes both a spatial and a temporal sequencing component and that covert rehearsal of movements can be either spatial or temporal. They also suggest that these components are hemispherically segregated. They consider that temporal rehearsal is a function of the left hemisphere while spatial rehearsal is a function of the right hemisphere. This leads them to conclude that temporal rehearsal involves some verbal processing capacity. The results of the present experiment make it very unlikely that verbal rehearsal of movements is responsible for the bias produced by rehearsing or imagining a linear movement to a novel location. One possible implication is that linear positioning movements are not rehearsed in terms of their temporal or sequential components. Instead it is suggested that the

spatial component of linear movements is rehearsed by visual/spatial imagery processes.

Further evidence for the rejection of a temporal rehearsal hypothesis arises when the nature of the verbal interference is considered. One way in which subjects might rehearse a temporal sequence is by counting (perhaps subvocally). The verbal interference stimulus, however, was comprised of random numbers, which would have inhibited any counting operation which may have been employed. Furthermore the sequencing of the random numbers was at 2 sec intervals which may have conflicted with any other temporal sequencing which subjects might have employed. Consequently the temporal component of memory was not used to rehearse a linear positioning movement. The results of this and previous experiments strongly support a hypothesis that the spatial component of memory is used to rehearse movements and that this rehearsal is the function of an image generation and processing system. Furthermore this image system appears to be largely a function of the visual/spatial system, in so far as it appears to be relatively unaffected by concurrent motor and verbal interference tasks.

7.2. Summary and Conclusions

There is some concern within certain areas of cognitive psychology about distinctions between specific and general resource allocation. Allport (1980) extends Neisser's argument that interference tasks should be considered to affect specific resources. Further evidence for the importance of specific resource allocation comes from current trends in artificial intelligence, in the form of distributed processing models. Hinton (1981), for example, is currently developing a distri-

buted computational model of human movement control. In view of these recent developments it is important to identify performance differences between specific and general resource demands.

If "general resource demand" is operationalised as the response demand of the task and the "specific resource demand" is operationalised as the source and type of stimulus, then this experiment shows one way in which these two processes differ in the motor control of linear positioning movements. It seems that increasing the response load of an interference task affects VE but not CE, while varying the source and type of the interference stimulus affects CE. When the response demand is great there is no difference between the VE scores for each type of interference task, however, when the response demand is low visual and motor interference tasks significantly affect VE.

Subjects in the verbal interference task conditions do not seem to have been affected by the response demand of a task. It is possible that subjects in both the "response" and "no response" conditions shadowed the message, regardless of the experimenter's instruction except that those in the no response condition shadowed sub-vocally. This does not detract from the general finding that separate effects can be ascribed to manipulation of response demand and source/type of stimulus in linear positioning experiments with interpolated interference tasks.

Summers and Sharp's suggestion that subjects might rehearse the sequential or temporal aspects of a motor task is unsupported by the present experiment.

puted computational model of human movement control. In view of these recent developments it is important to identify performance differences between specific and general resource demands.

If "general resource demand" is operationalised as the response demand of the task and the "specific resource demand" is operationalised as the source and type of stimulus, then this experiment shows one way in which these two processes differ in the motor control of linear positioning movements. It seems that increasing the response load of an interference task affects VE but not CE, while varying the source and type of the interference stimulus affects CE. When the response demand is great there is no difference between the VE scores for each type of interference task, however, when the response demand is low visual and motor interference tasks significantly affect VE.

Subjects in the verbal interference task conditions do not seem to have been affected by the response demand of a task. It is possible that subjects in both the "response" and "no response" conditions shadowed the message, regardless of the experimenter's instruction except that those in the no response condition shadowed sub-vocally. This does not detract from the general finding that separate effects can be ascribed to manipulation of response demand and source/type of stimulus in linear positioning experiments with interpolated interference tasks.

Summers and Sharp's suggestion that subjects might rehearse the sequential or temporal aspects of a motor task is unsupported by the present experiment.

If we assume that subvocal rehearsal of a linear positioning movement involves a counting procedure then the finding that a digit-shadowing task did not suppress biasing, due to imagery, does not support the hypothesized subvocal rehearsal of temporal information of linear positioning movements.

The results of this experiment taken along with those of the three previous experiments strongly support a hypothesis of visual/spatial processes operating during the mental rehearsal of linear positioning movements. Furthermore these processes seem to be subject to both specific and general interferences but in different ways. It may be that VE and response demand follow a "U" shaped function, with extreme low and high response demands producing relatively high VE while some optimum level of response demand produces relatively low VE.

CHAPTER EIGHT

DISTINCTIONS BETWEEN
VISUAL AND SPATIAL PROCESSING

The previous experiments have consistently shown that visual/spatial stimuli suppress imagery. It was argued in Experiment IV that memory for movements includes both spatial and temporal information, although a verbal interference stimulus failed to suppress imagery. Consequently it was concluded that imagery involved the manipulation of spatial information contained within the memory for movements. None of the experiments in this research, however, have directly manipulated spatial information. Each interference stimulus has been primarily visual, motor or verbal in nature. It could be argued that the visual interference used in past experiments was a spatial/visual stimulus. The same cannot be said for the motor and verbal interference tasks, which had little or no spatial content.

The experimental evidence presented so far is not capable of distinguishing between rehearsal of the visual characteristics of movements and rehearsal of their spatial characteristics. With regard to imagery, Kosslyn (1980) strongly claims that images are not just spatial representations but "quasi-pictorial representations" which contain brightness and colour information as well as spatial information. Fiske and Schmidt (1977, 1978) have shown that orientation and colour information are contained within images.

If imagery or rehearsal of movements involves the manipulation of some representation normally used in remembering and producing move-

ments then a purely visual hypothesis of mental imagery is difficult to maintain. It has been shown by Adams, Gopher and Lintern (1977) and Johnson (1980) amongst others, that linear positioning movements are remembered relatively accurately when subjects are deprived of visual feedback. Furthermore learning a positioning movement without visual feedback followed by recall with visual feedback produced greater error in accuracy than having no visual feedback at recall. One possible explanation is that movements were being remembered in terms of a spatial representation but with some fine tuning to particular modalities of input.

Further arguments against a "visual display" model of movement images comes from studies of the congenitally blind, who are able to represent, anticipate and plan their actions and order their environment largely on the basis of movement information. Hermlin and O'Connor (1975) review the experimental and clinical evidence for non visual coding. More recently Millar (1978) reports work on tactile maze learning in blind and sighted children which supports a spatial representation hypothesis.

8.1. Experiment V

This experiment is designed to investigate the relationship between visual and spatial images of linear positioning movements. If images are based on visual displays and not spatial representations then a 2nd order interference task which is visual but not spatial should suppress any imagery produced bias in memory. Alternatively if imagery involves the manipulation of spatial information then a visual task with a spatial component should suppress any imagery produced

biasing effect on memory. Furthermore if images do involve manipulating spatial representation then a 2nd order interference which is spatial but not visual should also suppress the imagery produced bias.

8.1.1. Method

(1) Experimental Design

A two-factor independent groups design was used, with type of interference and spatial content as the two factors. The type of interference was either visual, auditory or motor, while the spatial factor was either little or no spatial content or with spatial content.

(2) Subjects

36 right-handed subjects were randomly selected from a pool of 90 Open University psychology students who had volunteered to take part in experiments while attending a summer school at Warwick University. Six subjects per group were used - with equal numbers of each sex.

(3) Apparatus

In addition to the slide and display lights used in previous experiments a frequency amplifier was used to generate tones. These tones were transmitted through one or more of eight loudspeakers hidden behind the subject (see Fig. 8.1). The experimenter was able to select which loudspeaker(s) the tones were emitted from by means of a bank of eight switches.

(4) Task

As in past experiments subjects were first required to learn a 45 cm movement on a linear positioning task, followed by instructions

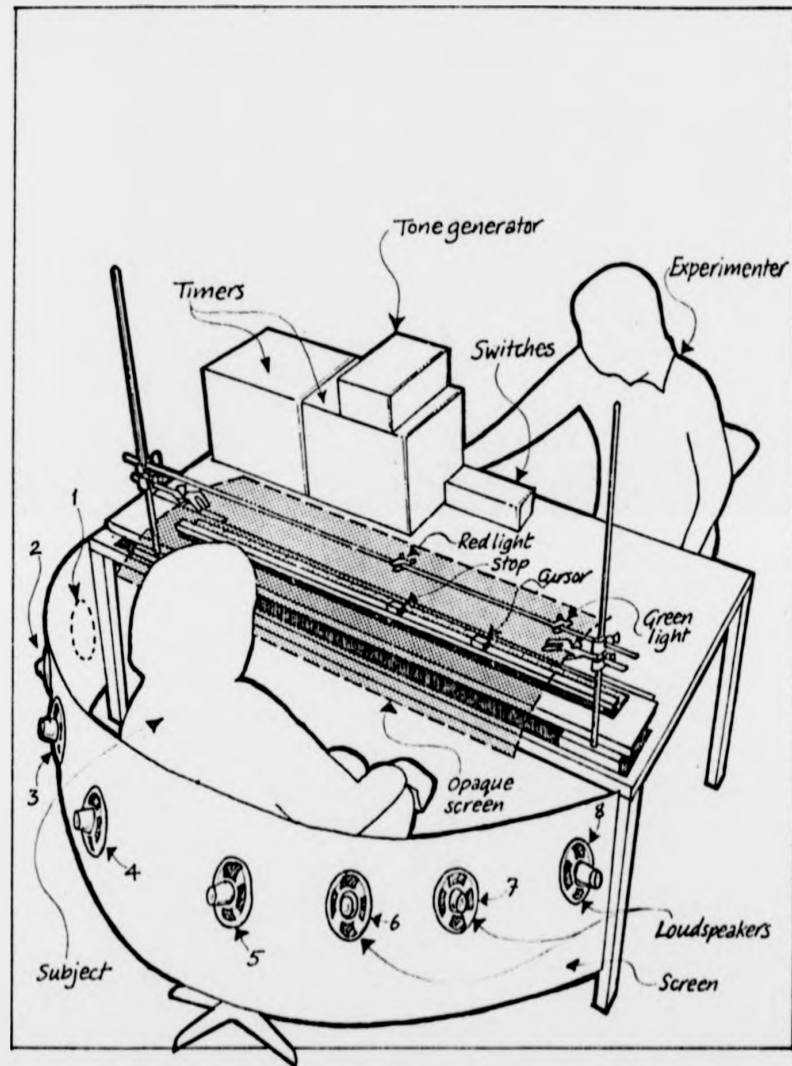


Fig 8.1 Additional auditory apparatus for experiment V

to imagine a 60 cm movement whilst performing one of the 2nd order interference tasks.

(5) Procedure

Learning the 45 cm movement consisted of subjects having 15 trials at moving to a stop with the track and arm movements hidden from view, as in Experiment III. This was followed by instructions to imagine a 60 cm movement without any overt movement. The imagery instructions and cues (such as lights) were as described in Experiment III. Subjects were instructed to make 10 imaginary moves to the 60 cm location during the 50 sec retention interval (the first 10 secs of which were used for practice and instructions). While imagining this new movement subjects were given one of the two levels of the six types of interference stimuli.

8.1.2. Interference Tasks

(1) Visual Interference - spatial (VS) and non-spatial (VNS)

The visual interference stimulus was comprised of the cue lights set in a non-relevant location. Subjects were instructed to report which was the brighter of the two lights and how many times the red one appeared. The spatial components of the visual stimulus were provided by the two lights being set at separate locations along the track. The visual non-spatial (VNS) interference stimuli consisted of the two lights being placed at one location along the track with the red light immediately above the green light.

(2) Auditory Interference - spatial (AS) and non-spatial (ANS)

The auditory interference stimulus consisted of a tone sounded at 2 sec intervals from one of eight possible loudspeakers. In the

auditory spatial interference condition the tone would first come from loudspeaker 1 then 8, alternating throughout the 40 sec interference interval. Subjects were required to identify where each sound source was by calling out the appropriate number (i.e. 1 - 8). In the auditory non-spatial interference condition the sound was emitted from speaker 5 at 2 sec intervals, again subjects had to verbally identify the sound source.

(3) Motor Kinaesthetic Interference - spatial (MS), non-spatial (MNS)

The motor kinaesthetic interference stimulus consisted of a pressure applied to the subject's right arm by a blunt pointer. In the spatial (MS) condition the pointer was applied at either of two separate locations on the subject's arms at 2 sec intervals. The subject was required to report which of the two locations had been pressed. In the non-spatial condition (MNS) the pointer was applied to one location and the subject had to report that it had occurred.

Finally all groups were required to reproduce the original 45 cm movement with the stop and cue lights removed. Subjects hasten recall trials with no knowledge of results.

8.1.5. Results

As previously, error scores to the nearest 0.5 cm from the 45 cm location were recorded. From these scores CE and VE scores were calculated for each subject (a summary can be found in Appendix G). The means and standard error of each dependent variable in each experimental condition is shown in Table 8.1.

Type of Interference		Visual		Motor/kinaesthetic		Auditory	
Spatial Component		S	NS	S	NS	S	NS
CE	\bar{X}	0.57	7.42	2.40	7.40	1.68	7.15
	se	0.41	4.83	1.11	2.49	0.27	0.64
VE	\bar{X}	0.68	1.05	1.00	0.75	0.85	1.43
	so	0.15	0.57	0.25	0.19	0.43	0.29

Table 8.1 Experiment V: Summary of mean error cms. (\bar{X}) and standard error (se), constant error (CE) and variable error (ve) for each type of interference stimulus at each level of spatial component

(1) Constant Error (CE)

A 2 x 3 independent groups ANOVA using CE resulted in a significant effect for the spatial component $F(1,30) = 57.225$, $pr < .001$. No other significant effects were found. The effect of the spatial interference stimuli was to suppress any bias as measured by CE, $\bar{X} = 1.55$, while non-spatial interference stimuli failed to suppress the biasing effect of imagery $\bar{X} = 7.32$. (See Table 8.2 for ANOVA summary and Fig. 8.2).

(2) Variable Error (VE)

Using the amount of variation (VE) in a series of recall trials as the dependent variable for a 3 x 2 independent group's ANOVA a non-significant effect was found for type of interference stimuli, $F(1,30) = 4.122$, $pr > .05$. No significant effects were found for spatial content alone but a significant two-way interaction was found $F(2,30) = 4.717$, $pr < .05$. (See Table 8.3 for ANOVA summary).

Decomposition of the interaction effect showed that the type of interference only had a significant effect on VE in the non-spatial condition while the spatial content of the stimulus differentially affected performance in the auditory condition (see Table 8.4). As can be seen from Fig. 8.3 the auditory stimulus produces much higher VE in the non-spatial condition than any other stimulus.

(3) Regression Analysis

Finally a regression analysis, summarized in Table 8.5, was performed, regressing each subject's error score per recall trial against the trial number. The first thing to note is that the slope coefficients (β) are all below 0.5 and are not significantly different

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
A. Type of interference	4.957	2	2.479	0.473	>.05 NS
B. Spatial content	299.867	1	299.867	57.225	<.001 ***
AXB Interaction	5.554	2	2.777	0.530	>.05 NS
Error	157.205	30	5.240		
Total	467.583	35			

Table B.2 Experiment VI: Constant error, ANOVA Summary

EXPERIMENT V

VIS = VISUAL
MOT = MOTOR
AUD = AUDITORY
S = SPATIAL
NS = NONSPATIAL

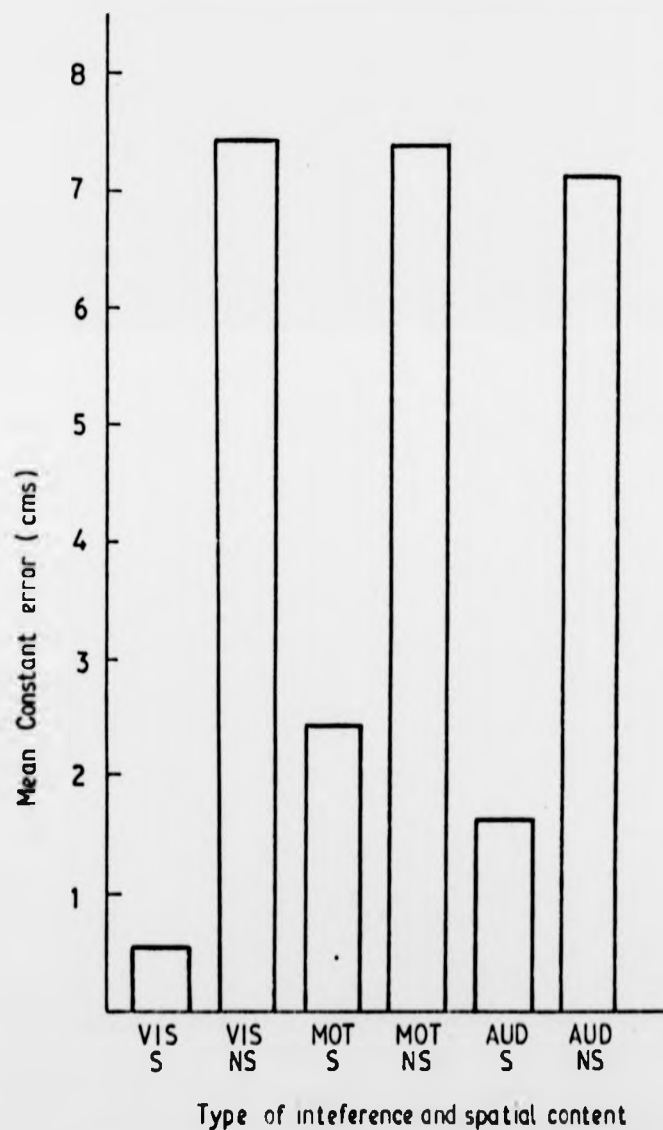


Fig. 8.2 MEAN CONSTANT ERROR FOR ALL INTERFERENCE GROUPS.
SPATIAL INTERFERENCE $F(1,30) = 56.329$ $p < .001$.

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Type of interference	0.587	2	0.294	2.470	>.05 NS
B. Spatial content	0.490	1	0.490	4.122	>.05 NS
AXB Interaction	1.122	2	0.561	4.717	<.05 *
Error	3.567	30	0.119		
Total	5.766	35			

Table 8.3 Experiment V: ANOVA Summary table VE

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
Spatial Content/ Visual	0.41	1	0.41	3.445	>.05 NS
Spatial Content/ Auditory	1.16	1	1.16	9.748	<.01 **
Spatial Content/ Motor/kinaesthetic	0.19	1	0.19	1.597	>.05 NS
Interference/ No spatial	1.41	2	0.75	6.302	<.01 **
Interference/ Spatial	0.47	2	0.24	2.017	>.05 NS
Error	3.567	30	0.119		

Table 8.4 Experiment VI: Decomposition of the significant interaction between spatial content and type of interference for VE

- 309 -
EXPERIMENT V

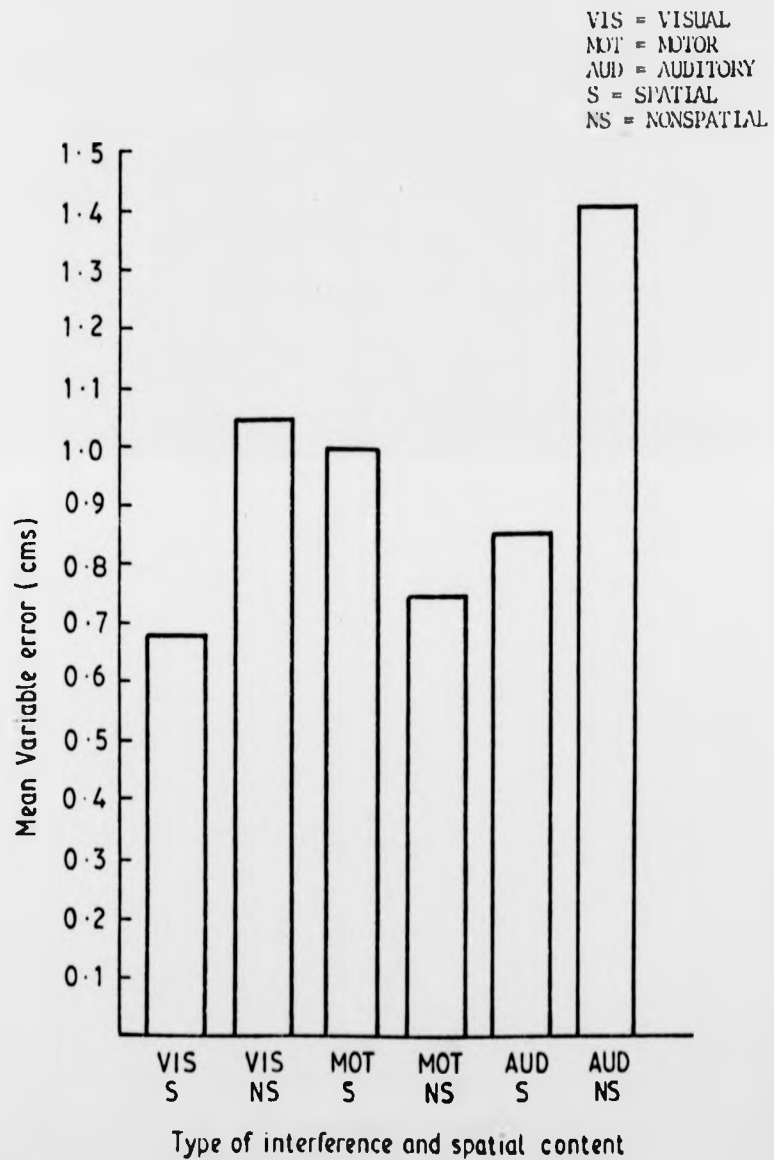


Fig. 8.3 MEAN VARIABLE ERROR FOR ALL INTERFERENCE GROUPS.

INTERACTION BETWEEN INTERFERENCE AND SPATIAL CONTENT $F(2, 50) = 4.717$ $PR < .01$

Subject		Visual Spatial	Visual non-Spatial	Motor Spatial	Motor non-Spatial	Auditory Spatial	Auditory non-Spatial
1	α β	0.400 0.000	10.733 -0.261	2.067 -0.167	3.667 0.042	3.133 -0.206	8.593 -0.152
2	α β	1.700 -0.133	12.133 6.121	0.467 0.215	7.400 -0.118	1.833 -0.088	7.800 -0.036
3	α β	1.667 -0.167	1.667 0.042	1.733 -0.006	11.8 -0.056	2.667 -0.194	7.333 -0.133
4	α β	-0.867 0.139	6.067 0.006	3.333 -0.188	8.167 -0.194	0.900 0.091	7.933 -0.279
5	α β	1.400 -0.091	2.000 0.018	3.467 0.024	6.800 -0.027	2.100 -0.082	4.900 0.364
6	α β	0.400 -0.009	11.667 0.115	4.267 -0.067	8.800 -0.055	3.467 -0.267	7.967 -0.130

Table 8.5 Experiment V: Summary of Regression analysis, regressing each subject's error score against the recall trial number, α = intercept, β = slope coefficient

EXPERIMENT V

X= VISUAL INTERFERENCE
□= AUDITORY INTERFERENCE
●= MOTOR INTERFERENCE

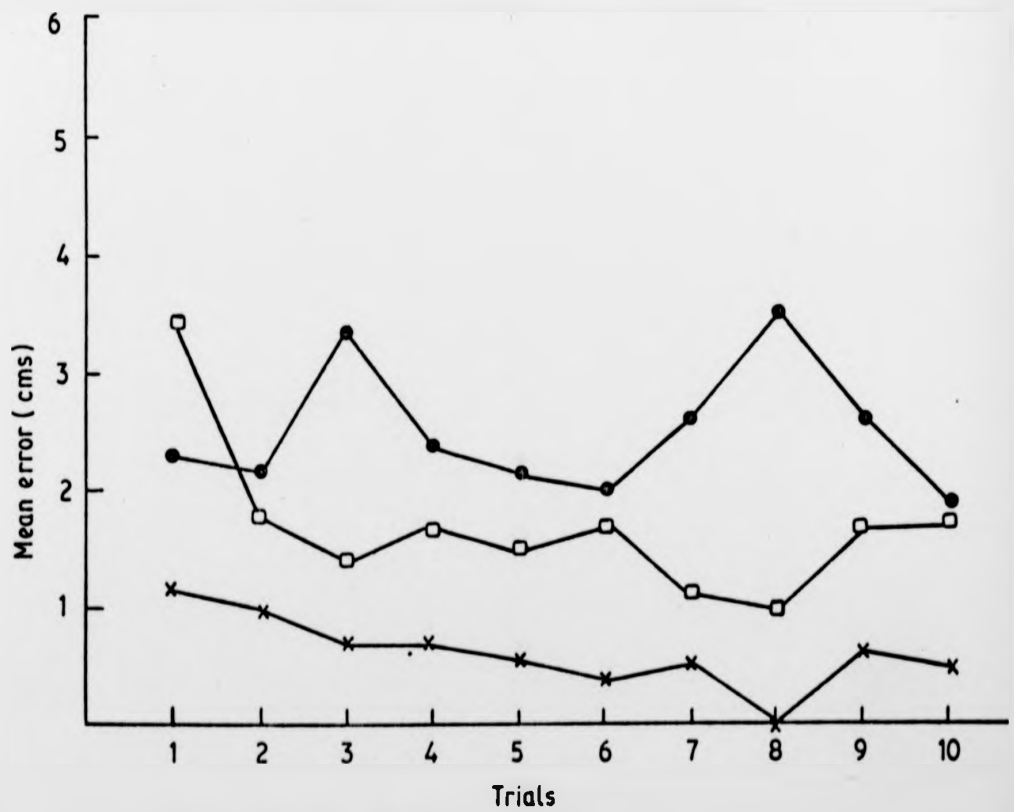


Fig. 8.4 MEAN ERROR PER RECALL TRIAL WITH SPATIAL INTERFERENCE

EXPERIMENT V

X = VISUAL INTERFERENCE
□ = AUDITORY INTERFERENCE
● = MOTOR INTERFERENCE

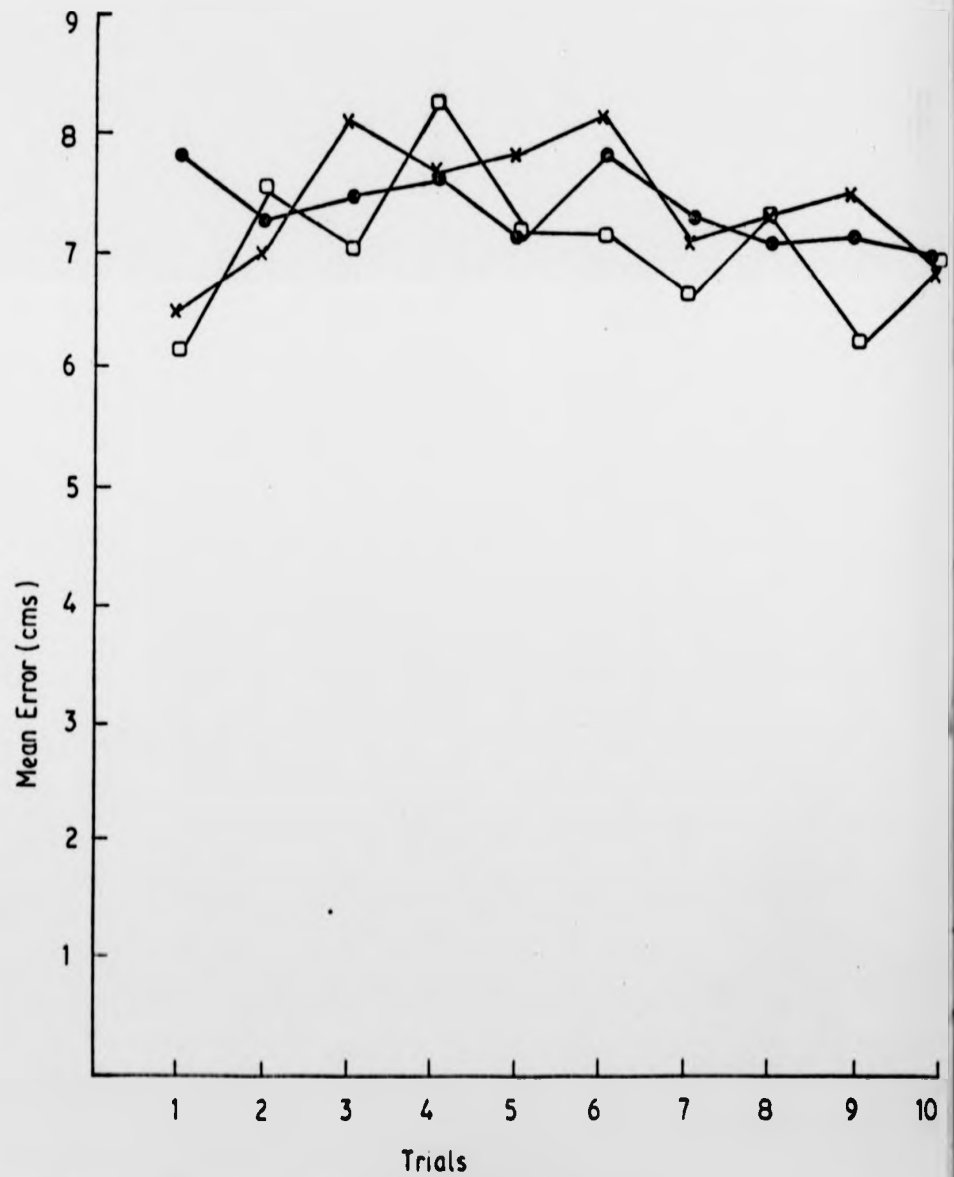


Fig. 8.5 MEAN ERROR PER RECALL TRIAL WITH NONSPATIAL INTERFERENCE

from 0. Second, the intercept values (α) systematically vary with the spatial content of the stimulus. In all cases where there was a no spatial interference stimulus the intercept is a high positive value, while a non-spatial interference stimulus results in a low positive or negative intercept value. Figures 8.4 and 8.5 graphically show the mean error over trials for each spatial and non-spatial interference stimulus. It can be seen that this mean performance reflects similar characteristic (α) and (β) values as the individual regression analysis showed. Consequently a spatial component to the interference inhibits any imagery produced bias in memory.

8.1.4. Discussion

The results show that it is the spatial components of an interfering stimulus which suppress the biasing effect of imagery on memory. This strongly suggests that images of linear positioning movements involve the processing of spatial information. Further confirmation for this hypothesis comes from the lack of any suppressing effects with a visual stimulus which had little or no spatial content. In this experimental condition a visual stimulus failed to suppress the biasing effects of imagining a novel movement. Furthermore non-visual stimuli involving spatial information did suppress this imagery produced bias.

8.2. Summary and Conclusions

Kosslyn's claim that images contain not only spatial information but other pictorial qualities cannot be contested on the basis of the present experiment. It seems to be the case that imagery of movements primarily involves spatial representations and not other

quasi-pictorial properties which images may possess.

In Experiment IV it was argued that differential interference effects were produced by general and specific resource demanding tasks. These were explained in terms of the two component model of VE (i.e. VE = memory and "noise"), in which specific interference tasks affected memory while general interference affected any noise in the system. Furthermore, interference to memory, by biasing, is reflected by CE. Analysis of the present experiment in terms of VE showed that in the case of an auditory or a visual interference stimulus a spatial content produced lower VE than a non-spatial content. While the motor interference task had the opposite effects, with spatial content producing higher VE than a non-spatial content of the stimulus. One possible explanation of this inconsistency is that the visual and auditory tasks containing spatial information were more complex and required more general capacity than the spatial motor kinaesthetic task. The visual and auditory interference tasks not only had a specific resource component but, because of their increased complexity, they also had a general capacity load.

The proposed "U" shaped function between VE and response demand seems to offer a possible explanation of these results. It may be the case that the motor/kinaesthetic interference task in the spatial condition was less complex than the auditory or visual interference stimuli. The visual and auditory spatial stimuli seem to fall in the optimum response band for a low VE while the motor/kinaesthetic task failed to reach the optimum level and consequently produced a relatively high amount of VE.

The auditory interference stimulus was the only one which significantly varied in terms of VE with manipulation of the spatial content of the stimulus. The non-spatial manipulation of the auditory stimulus produced higher VE than the spatial manipulation. The visual stimuli, on the other hand, had no difference in terms of VE between the spatial and non-spatial condition.

It is not completely clear whether the differences between the visual, motor/kinaesthetic and auditory tasks in terms of VE are due to the complexity of the tasks or their specific processing demands. Perhaps this is because the tasks are not equal in terms of their processing loads, therefore interactions are difficult to interpret. However, it does seem that spatial tasks, regardless of their stimulus source, do suppress imagery of linear positioning movements. Furthermore both visual and auditory tasks do tend to follow a similar trend in terms of VE. The lack of a significant difference between visual, non-spatial and spatial interference stimuli in terms of VE may be due to the similarity of the stimuli in the two conditions; in both cases the same two lights were used. There may have been a higher informational content in the visual non-spatial condition than the auditory non-spatial condition since there was only one tone with the auditory stimulus while there were two lights with the spatial stimulus.

CHAPTER NINE

FURTHER DISTINCTIONS BETWEEN SPATIAL AND NON-SPATIAL
PROCESSES IN IMAGES OF LINEAR POSITIONING MOVEMENTS

It is supposed that the interference to imagery found in Experiment V is due to the spatial characteristics of the stimuli. The sensory media of the stimuli (visual, auditory or kinaesthetic/motor) does not appear to be the primary source of interference to imagery. An interference stimulus which contained no (or little) spatial information had no significant effect on a subject's ability to imagine linear positioning movements. The interference effects of visual and auditory stimuli with a spatial content were similar but the motor/kinaesthetic spatial stimuli interfered less with imagery than the others.

It has been reported by Craske (1980) that subjects who are required to judge the locations of pressure on their arms experience an illusion which alters their perceived arm length. This rather strange effect may account for the lower interference effect of a motor/kinaesthetic spatial stimulus. This leads one to question the appropriateness of pressure stimulation as a spatial interference task.

If the supposition that images of movements are interfered with by stimuli containing spatial information is correct, then an increase in the spatial information contained within the stimulus should produce increased interference regardless of the modality or source of the stimulus. Consequently a motor task with a greater amount of spatial information should result in increased interference to imagery.

Moreover, a task which contains a uniform amount of spatial information regardless of the modality or source of stimulation should have a uniform interference effect upon imagery.

One task containing a high amount of spatial information is the learning of a finger maze. Warden (1924) and Husband (1931) have found that subjects report using verbal, motor/kinaesthetic and visual informational strategies to learn the correct path through a maze. Woodworth and Schlosberg (1955) include a review of maze learning in their experimental psychology text, in which they conclude that linear mazes are capable of being learned either verbally, visually or motorically. Sackett (1935) reports that subjects who were required to "symbolically rehearse" a linear maze claimed to be using either visual, verbal or motoric "symbolism" during rehearsal although reports of visual imagery were more frequent. Similar strategies were also reported during learning and relearning phases of the experiment.

These reports suggest that learning a linear maze primarily involves the representation of spatial relationships. Furthermore the spatial information contained within the maze can be processed from different sources of information. This suggests that the sources or sensory modalities are less important than the informational content, and that the correct path can be learned either motorically, visually or verbally.

2.1. Experiment VI

The present experiment compares the interference effects upon imagery of movement, of visual, auditory and motor/kinaesthetic

stimuli. It is predicted that the interference effects of these stimuli should be equal when the stimulus contains a high component of spatial information as in learning a linear maze. When the information contained within the stimulus has little or no spatial content then there should be little or no interference effect upon imagery of a linear movement.

2.1.1. Method

(1) Experimental Design

A two factor independent groups design was used, with spatial content and source of stimulation as the two factors. Spatial content had two levels, high and low, while source of stimulation had three levels, visual, auditory and motor/kinaesthetic, giving six experimental groups in all.

(2) Subjects

36 right-handed subjects were randomly selected from a pool of 54 volunteers who were attending an Open University summer school at Warwick University. An equal number of male and female subjects were assigned to each group (total number of subjects per group = six). Subjects' ages ranged from 23 - 54 and their occupational backgrounds were varied.

(3) Apparatus

In addition to the slide and display lights used in Experiment III a stylus maze, shown in Fig. 9.1, was used to provide spatial information. This was done with the aid of a 12" x 12" video monitor which was positioned at eye-level in front of the subject. Previously a video-tape had been recorded showing the stylus move through the

correct path of the maze 5 times. An audio-tape recording was also made describing the correct path through the maze in terms of left, right and upward movement directions, again correct paths through the maze were described 5 times. To provide kinaesthetic/motor information of the maze a stylus 17 cm x 0.5 cm diameter, with a point at one end was used to guide the subject through the maze by the experimenter. To provide visual non-spatial interference a single dot appeared in the centre of the display monitor and would flash on and off at 2 sec intervals. Auditory non-spatial interference was provided by a string of random numbers played over the air from a centrally positioned loudspeaker. Motor/kinaesthetic non-spatial interference was provided by means of the pressure apparatus described in Experiment III.

(4) Task/Procedure

As in previous experiments subjects were required to learn a 45 cm movement from left to right along the hidden track, moving up to a stop. The cue lights were positioned above the start and stop positions as in previous experiments and flashed at two sec intervals. After 15 learning trials all subjects had a 50 sec retention interval during which time they were instructed to imagine a 60 cm movement, without making any overt movements themselves. As in previous experiments the cue lights were placed at a new 60 cm location and flashed at 2 sec intervals. After ten trials at imagining moving to the 60 cm location subjects were tested on their recall performance for the 45 cm movement, with the stop and cue lights removed, by moving ten times to where they thought the 45 cm movement to end.

During the 50 sec retention interval, in addition to imagining

a 60 cm movement, subjects were required to perform one of six different interference tasks.

9.1.2. Interference Tasks

(1) Visual Spatial (VS)

A video-tape showing the stylus moving through the maze was shown on the video-monitor. Subjects were told that they would see 5 trials of the correct path through the maze. They were not told that they would be later tested on this maze.

(2) Auditory/Verbal Spatial (AS)

An audio-tape recording containing instructions of the correct path through the maze was played through a centrally positioned loudspeaker. Subjects were told that they would hear 5 trials of the correct path through the maze, but not that they would be tested later.

(3) Motor/Kinaesthetic Spatial (MS)

Subjects had their right hand passively guided through the maze by the experimenter. Subjects grasped a stylus which the experimenter was able to guide. The maze was hidden beneath the card screen (shown in Fig. 9.1). All subjects were taken through the correct path of the maze 5 times, but not told that they would be tested later.

(4) Visual non-Spatial (VNS)

A dot of white light appeared in the centre of the display monitor, which subjects were instructed to watch. The dot flashed on and off at 2 sec intervals but did not move at all. Subjects were required to report verbally when the light was on.

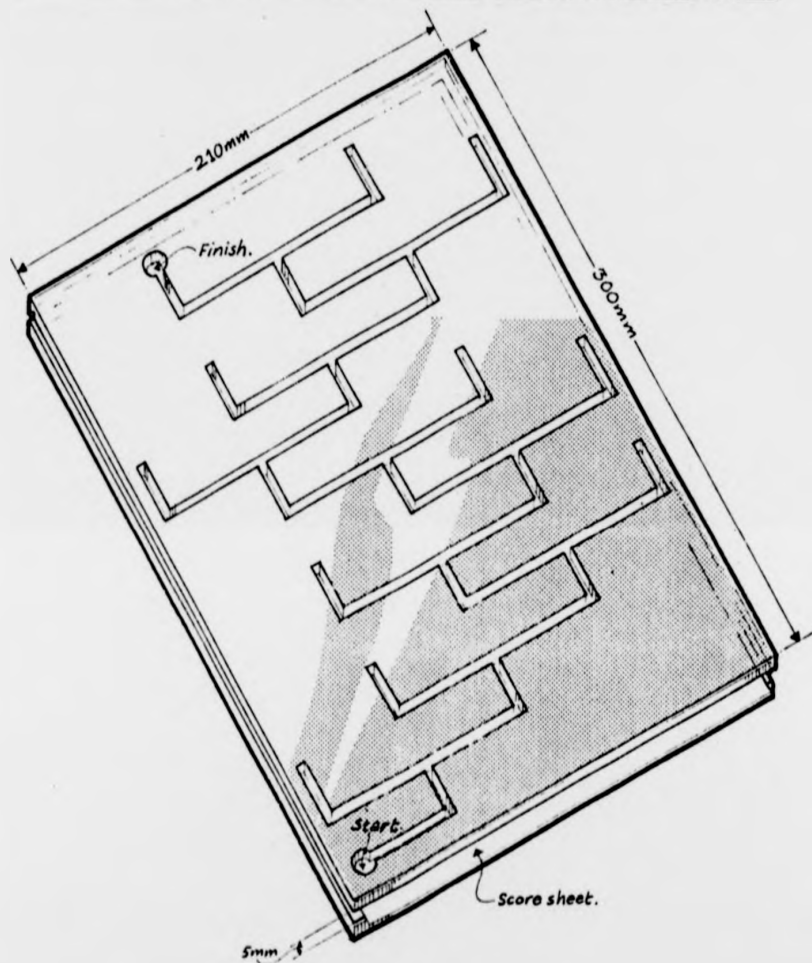


Fig 9.1 Maze used in experiments VI & VII

(5) Auditory/Verbal non-Spatial (ANS)

A string of random numbers was presented via a centrally positioned loudspeaker. Subjects were required to shadow these random numbers.

(6) Motor/Kinaesthetic non-Spatial (MNS)

A pressure plate was connected to a buzzer as in Experiment III. Subjects were required to maintain a mean pressure of 15 kg with their right arm in order to prevent the buzzer sounding, while imagining making a linear positioning movement.

At the end of the experiment, after recalling the 45 cm movement, all subjects were required to trace through the maze blindfolded with a stylus pen. The total time on the maze and number of errors made were recorded by the experimenter.

9.1.3. Results

All subjects' positioning movements at recall and their time and error performance on the linear maze were recorded.

(1) Positioning Movement Errors

Error scores to the nearest 0.5 cm from the 45 cm point were recorded. From these scores CE and VE scores were calculated for each subject (a summary is shown in Appendix H). The mean and standard error of these CE and VE scores in each experimental condition is shown in Table 9.1 below.

(2) Constant Error (CE)

Analysing the amount of bias as measured by CE in a two-way

		VS	AS	MS	VNS	ANS	MNS
CE	\bar{X}	-1.97	1.60	-0.90	6.35	5.38	5.78
	se	2.00	4.60	1.90	3.10	1.00	1.24
VE	\bar{X}	2.12	2.48	2.55	1.07	0.73	0.83
	se	1.30	1.40	0.80	0.40	0.30	0.30

Table 9.1 Experiment VI: Summary of mean (\bar{X}) and standard error (se) of CE and VE for each experimental condition measured in cms

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
A. Spatial Content	352.814	1	352.814	52.428	<.001 **
B. Source of stimuli	11.420	2	5.710	0.849	>.05 NS
AXB Interaction	51.629	2	15.814	2.350	>.05 NS
Error	201.885	30	6.730		
Total	597.748	35			

Table 9.2 Experiment VI: Summary of ANOVA for spatial constant and source of stimuli in terms of the constant error (CE) at recall

- 225 - EXPERIMENT VI

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL (MAZE)
ANS = AUDITORY/NONSPATIAL

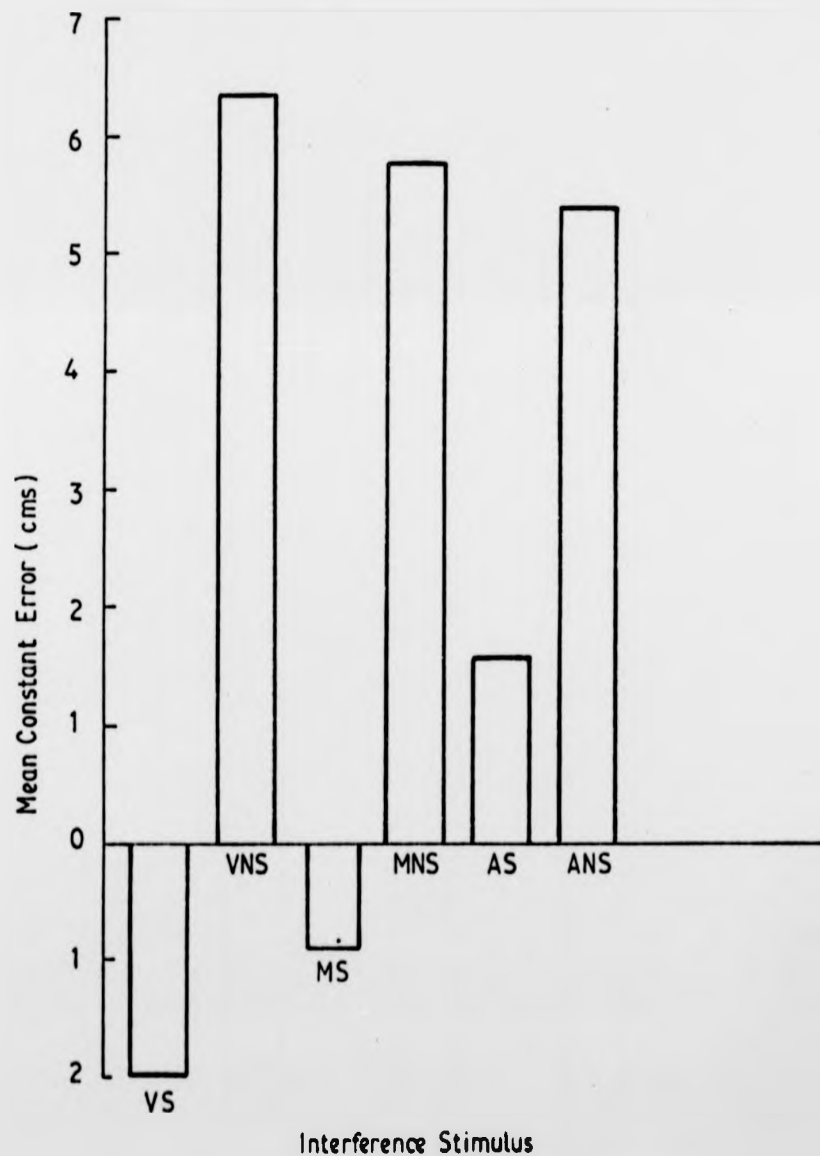


Fig. 9.2 MEAN CONSTANT ERROR (CE) FOR ALL INTERFERENCE GROUPS
(SPATIAL = MAZE)
SPATIAL INTERFERENCE $F(1,30) = 52.428$ $PR < .001$

ANOVA, the only significant main effect was for the spatial content of the interference stimulus, $F(1,30) = 52.428$ pr $<.001$. The mean CE for subjects in the non-spatial conditions was 5.83 cms while subjects in the spatial condition had a mean CE of -0.42 cms. Table 9.2 contains a summary of the ANOVA and Figure 9.2 shows the mean CE for each experimental condition.

(3) Variable Error (VE)

Analysis of the amount of variation within a series of memory/recall trials by VE, a two-way independent groups ANOVA resulted in a significant effect for the spatial content of the stimuli, $F(1,30) = 26.074$ pr $<.001$. The mean VE for subjects in the non-spatial conditions was 0.876 cms while subjects in the spatial conditions had a mean VE of 2.55 cms. No other significant effects were found. A summary of the ANOVA is shown in Table 9.3 and the mean VE for each experimental condition is shown in Fig. 9.3.

(4) Performance on Maze

Performance on the maze was analysed in terms of errors and time to completion. The mean and standard errors for each group of subjects' error and completion times are shown in Table 9.4.

ERRORS

Analysis of the number of errors in performance by a two way ANOVA resulted in a significant effect for spatial content, $F(1,30) = 4.899$, pr $<.05$. (See Table 9.5 for ANOVA summary). The mean number of errors for those groups of subjects who had not experienced the maze as an interference stimulus was 6.40 incorrect turns. Those groups of subjects who had experienced the maze as an interference stimulus had

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Spatial content	20.400	1	20.400	26.074	< .001 ***
B. Source of stimuli	0.069	2	0.034	0.044	> .05 NS
AXB Interaction	0.936	2	0.468	0.598	> .05 NS
Error	23.472	30			
Total	44.877	35			

Table 9.3 Experiment VI: Summary ANOVA for spatial content and source of stimuli in terms of the variable error (VE) at recall

EXPERIMENT VI

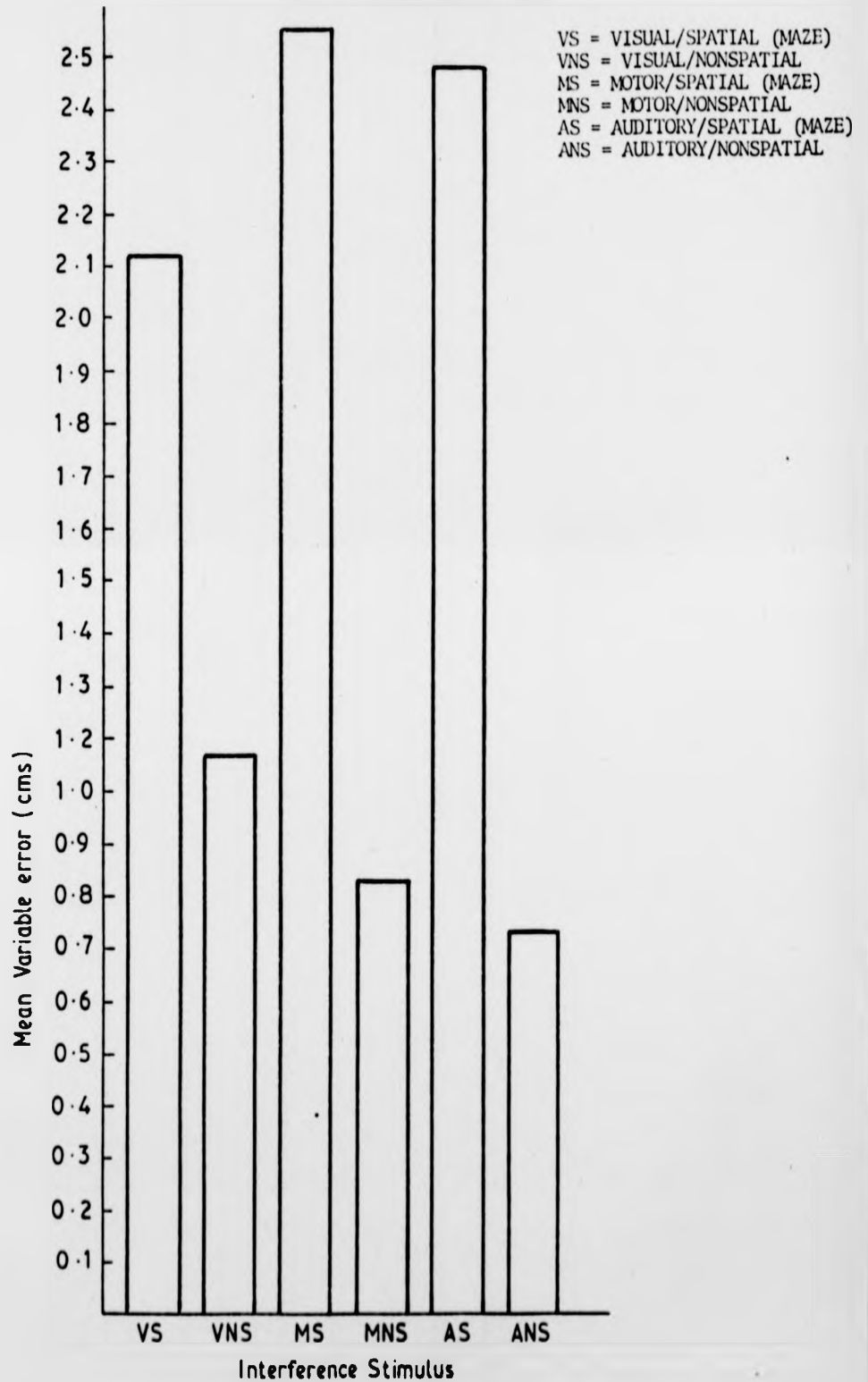


Fig. 9.3 MEAN VARIABLE ERROR (V.E.) FOR ALL INTERFERENCE GROUPS.
SPATIAL INTERFERENCE $F(1,30) = 26.074$ $PR < .001$

		Spatial (Maze)			Non-Spatial		
		VS	AS	MS	VNS	ANS	MNS
Errors	\bar{X}	5.50	4.67	5.00	7.50	6.17	6.00
	se	1.87	1.21	1.67	2.81	1.47	2.28
Completion Time	\bar{X}	48.28	40.17	49.67	114.17	77.00	79.33
Secs.	se	11.90	11.77	11.02	13.04	12.41	12.52

Table 9.4 Experiment VI: Summary of means and standard errors for performance on the maze. Both time in seconds and total errors are shown for each experimental condition

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Spatial Content	18.778	1	18.778	4.899	<.05 *
B. Stimulus Source	7.389	2	3.694	0.964	>.05 NS
AXB Interaction	1.056	2	0.528	0.138	>.05 NS
Error	115.000	30	3.833		
Total	142.223	35			

Table 9.5 Experiment VI: ANOVA Summary for number of incorrect turns (errors) on the maze at recall

- 231 -
EXPERIMENT VI

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL
ANS = AUDITORY/NONSPATIAL

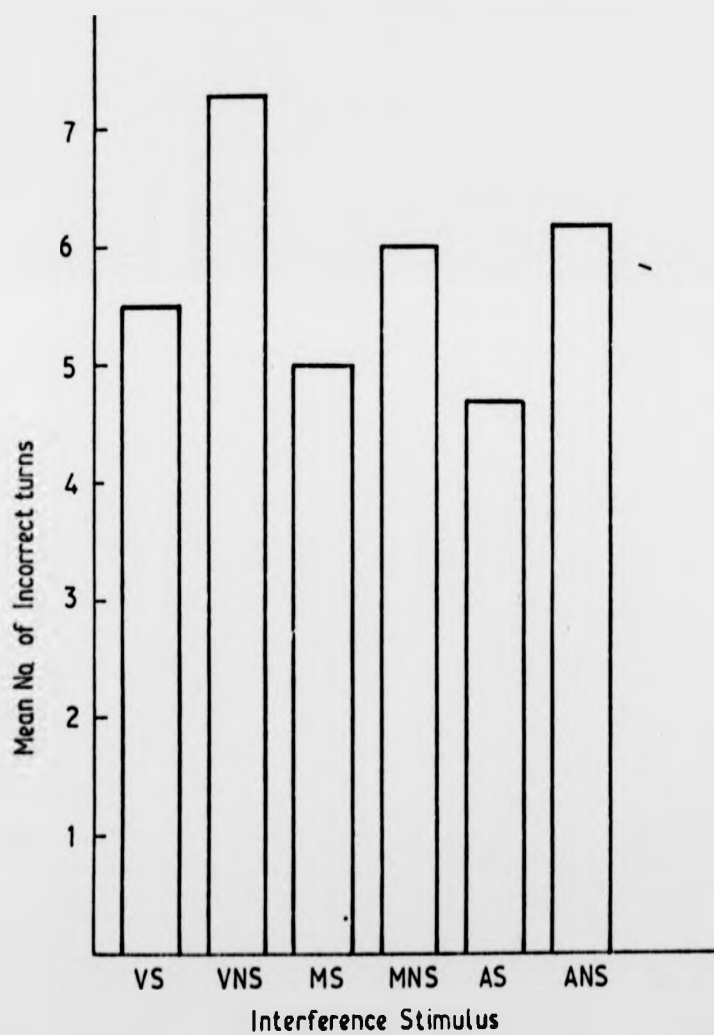


Fig. 9.4 MEAN NUMBER OF INCORRECT TURNS ON RECALL OF MAZE FOR ALL INTERFERENCE GROUPS. SPATIAL INTERFERENCE $F(1,30) = 4.899$, $PR < .001$

a mean number of 5.05 incorrect turns (Fig. 9.4 shows the mean number of incorrect turns per condition). No other effects were significant.

TIME

A two-way ANOVA of the completion time on the maze resulted in a significant effect for the spatial content of the interference task, $F(1,30) = 13.967$, $pr < .001$. No other effects were significant (see Table 9.6 for ANOVA summary). The mean completion time for subjects who had experienced the maze as an interference stimulus was 46.04 secs. Those subjects who had not experienced the maze as an interference stimulus had a mean completion time of 90.17 secs. (Fig. 9.5 shows the mean completion time per condition).

(5) Regression Analysis

Finally a regression analysis (summarised in Table 9.7) was performed, regressing each subject's error score on the linear positioning task against the recall trial number. Taking β , the slope coefficient, as an indication of any linear trend in error over trials it can be seen that the majority of subjects had no such trend. However, there are six exceptions to this, four out of the six subjects in the auditory spatial (AS) condition have relatively high (approx. 1.0) β coefficient, as does one subject in the visual spatial condition. Subject 1 in the motor spatial condition (MS) has a high negative coefficient suggesting a negative trend to the size of his/her error score as the trial number increases.

Inspection of the intercept coefficients (α) shows that in those conditions where a significant bias occurred in terms of CE,

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Spatial Content	17525.40	1	17525.40	13.967	<.001 ***
B. Source of stimuli	3309.53	2	1654.76	1.319	>.05 NS
AXB Interaction	2206.90	2	1103.45	0.879	>.05 NS
Error	37643.80	30	1254.79		
Total	60685.63	35			

Table 9.6 Experiment VI: ANOVA Summary for completion time on maze

EXPERIMENT VI

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL (MAZE)
ANS = AUDITORY/NONSPATIAL

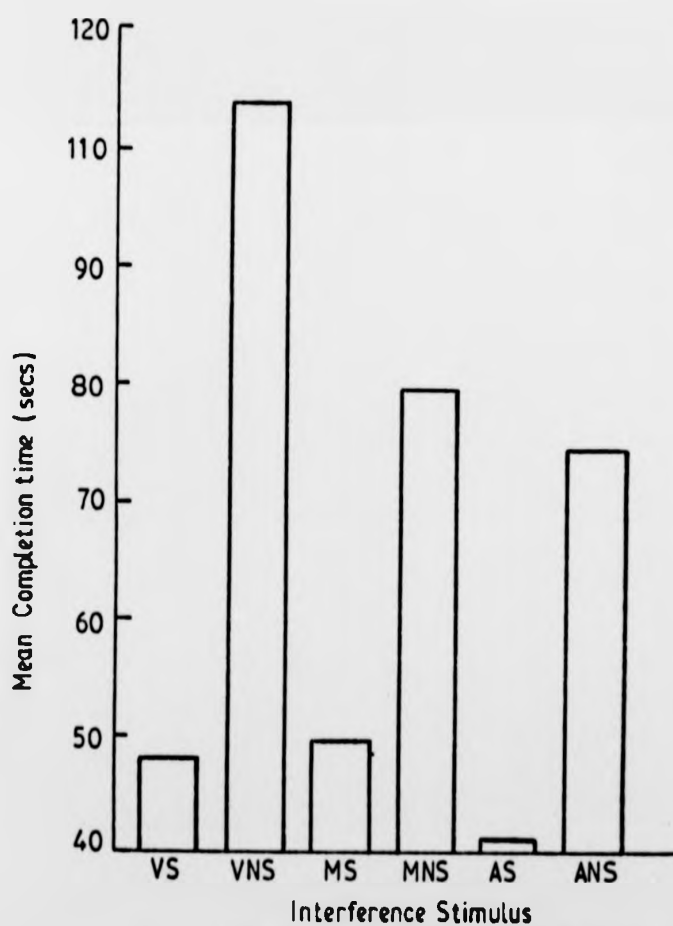


Fig. 9.5 MEAN COMPLETION TIME ON MAZE FOR EACH INTERFERENCE GROUP
(SPATIAL = MAZE)
SPATIAL INTERFERENCE (MAZE) $F(1,30) = 13.967$, $PR. < .001$

Subject		Visual Spatial	Auditory Spatial	Motor Spatial	Visual non- Spatial	Auditory non- Spatial	Motor non- Spatial
1	α	0.467	-26.400	2.600	3.930	6.330	8.733
	β	-0.112	-0.964	-0.963	-0.006	0.139	-0.170
2	α	-0.900	-4.867	1.600	2.867	4.933	4.600
	β	0.109	0.830	-0.400	0.188	0.084	-0.036
3	α	-6.930	0.670	-1.930	5.400	3.670	5.330
	β	0.897	-0.012	-0.176	0.073	0.024	-0.024
4	α	-3.500	3.730	-0.367	11.200	5.067	5.470
	β	0.091	0.667	-0.197	0.273	0.024	-0.103
5	α	0.400	-0.933	-0.333	5.130	6.200	7.600
	β	-0.036	1.350	0.106	0.139	-0.091	-0.200
6	α	-3.000	1.400	0.200	7.100	5.330	4.130
	β	-0.109	-0.218	0.360	-0.136	-0.079	0.321

Table 9.7 Experiment VI: Regression Analysis; regressing trial number and error score for each subject in each experimental condition.
 β = slope coefficient, α = intercept value

EXPERIMENT VI

- 236 -

X= VISUAL INTERFERENCE
 □= AUDITORY INTERFERENCE
 ●= MOTOR INTERFERENCE

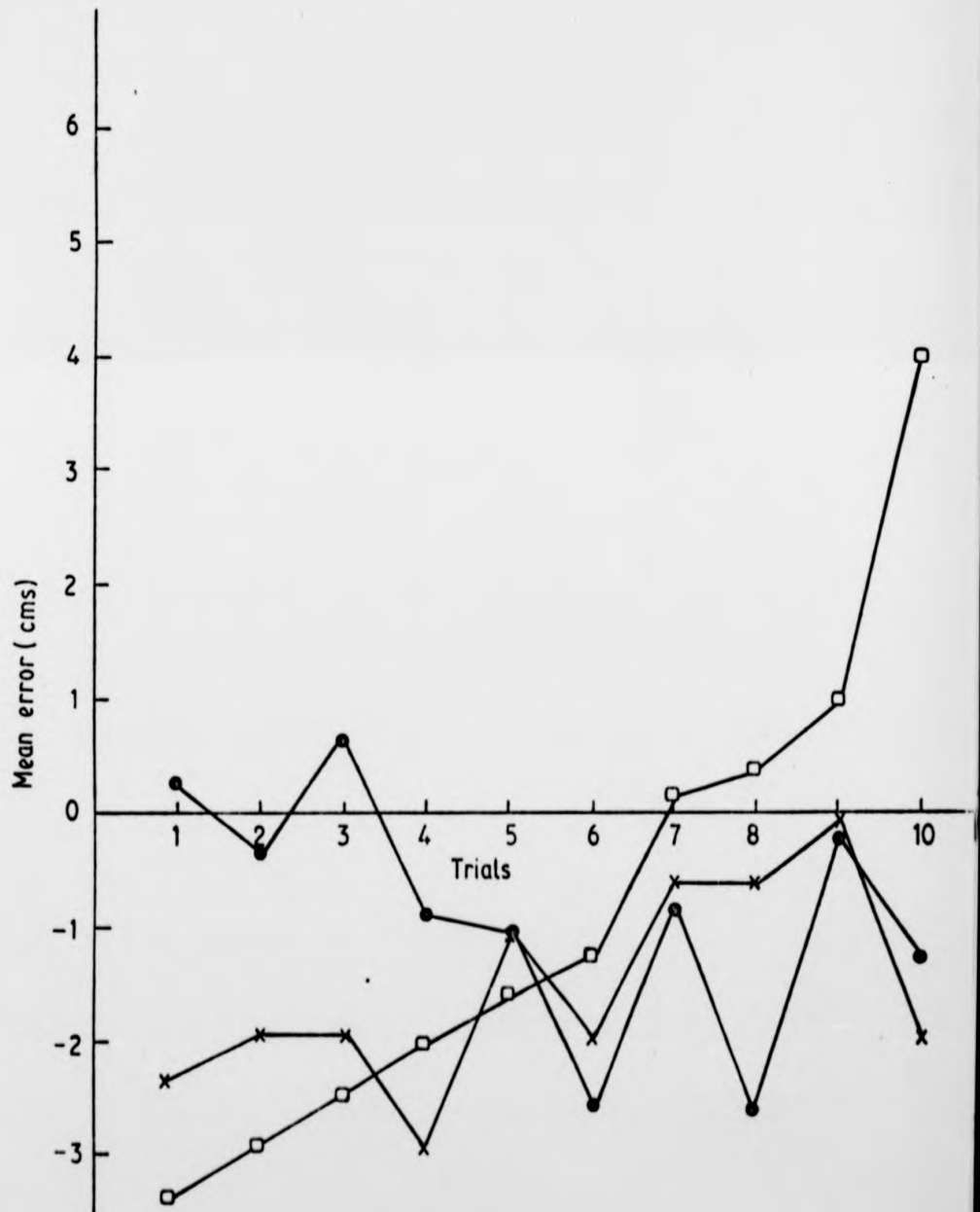


Fig. 9.6 MEAN ERROR PER RECALL TRIAL WITH SPATIAL INTERFERENCE.

EXPERIMENT VI

X= VISUAL INTERFERENCE
□= AUDITORY INTERFERENCE
●= MOTOR INTERFERENCE

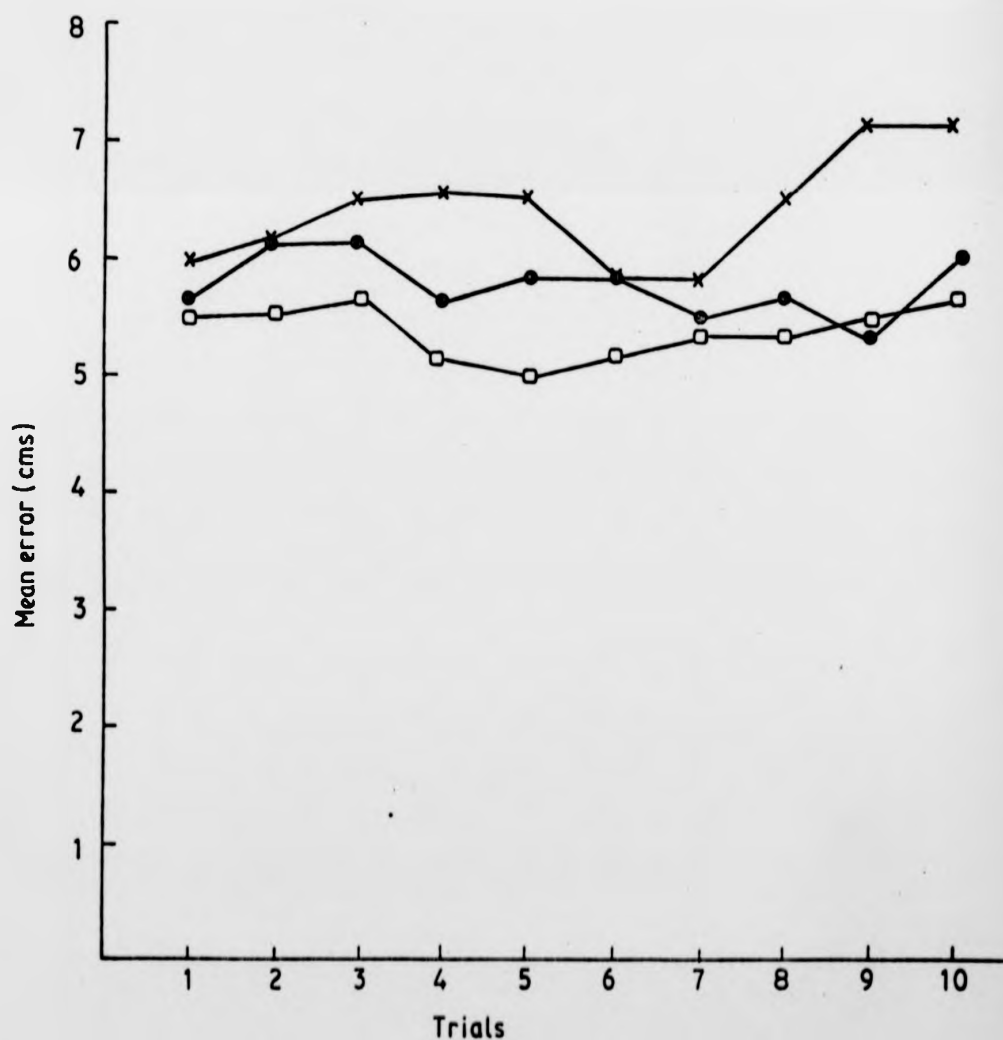


Fig. 9.7 MEAN ERROR PER TRIAL WITH NONSPATIAL INTERFERENCE.

namely VNS, ANS, MNS, each subject has a high, positive, intercept value. This reflects the bias caused in memory by imagining a larger (60 cm) movement. The intercept values of the VS, MS and AS groups are all either 0, or in some cases negative, reflecting no directionally specific biasing. Figures 9.6 and 9.7 show the mean error per trial for each stimulus source and each level of spatial content.

9.1.4. Discussion

The predicted suppression effect of spatial interference stimuli on imagery was found to occur with all such sources of stimulation. In contrast none of the various interference tasks had a suppression effect on imagery in the non-spatial conditions. Assuming that interference is caused by competition for a specific resource then imagery of a linear movement seems to involve spatial processing. It has been argued in previous chapters that interference effects could be due to the general capacity loading by the stimulus rather than competition for a specific resource. In the present experiment the complexity of the stimulus was increased in terms of its spatial properties and it seems that it is primarily the spatial nature of the stimulus which is interfering with imagery.

The effects of the spatial interference stimuli in terms of VE are to increase the variability in all conditions over the non-spatial tasks. If, as previously assumed, VE measures the strength of the memory trace, plus any noise within the motor output system, then we can conclude from this high VE that spatial interference tasks are affecting memory. It seems that in this experiment, in addition to the suppression of imagery, the memory for the original movement is also being interfered with.

namely VNS, ANS, MNS, each subject has a high, positive, intercept value. This reflects the bias caused in memory by imagining a larger (60 cm) movement. The intercept values of the VS, MS and AS groups are all either 0, or in some cases negative, reflecting no directionally specific biasing. Figures 9.6 and 9.7 show the mean error per trial for each stimulus source and each level of spatial content.

9.1.4. Discussion

The predicted suppression effect of spatial interference stimuli on imagery was found to occur with all such sources of stimulation. In contrast none of the various interference tasks had a suppression effect on imagery in the non-spatial conditions. Assuming that interference is caused by competition for a specific resource then imagery of a linear movement seems to involve spatial processing. It has been argued in previous chapters that interference effects could be due to the general capacity loading by the stimulus rather than competition for a specific resource. In the present experiment the complexity of the stimulus was increased in terms of its spatial properties and it seems that it is primarily the spatial nature of the stimulus which is interfering with imagery.

The effects of the spatial interference stimuli in terms of VE are to increase the variability in all conditions over the non-spatial tasks. If, as previously assumed, VE measures the strength of the memory trace, plus any noise within the motor output system, then we can conclude from this high VE that spatial interference tasks are affecting memory. It seems that in this experiment, in addition to the suppression of imagery, the memory for the original movement is also being interfered with.

9.2. Summary and Conclusions

The interference effect on memory and suppression of imagery is evident by the increased variability in recall of the criterion movement, and the lack of any directionally specific biasing. Thus subjects are not being influenced by any images they may have produced, but their memory for the correct movement is being disrupted by a highly spatial task. This effect is not so surprising if one considers how images of linear positioning movements and linear movements themselves might be related. Imagery seems to be a memory process involving the recall of specific information. In order to remember movements along a linear track subjects may be remembering the position in space of the movement, (i.e. its start and end points and the direction of travel). When asked to imagine another linear movement along the same track they use existing information from memory about linear movements but adapt this by storing the new end points (in this experiment the start point never varied). It may well be that because of the similarity between the two points within the same frame a bias is caused in memory. A similar argument has been put forward by Fishburne (1980) for biasing caused by actual interpolated movements. Interestingly, these biases only occur when the two movement lengths are within certain ranges. Once the new movement is much smaller or much larger than the old movement no systematic biasing occurs. Thus images and movements involving linear spatial relationships are related in memory processing.

It is possible that interference stimuli which affect imagery will also affect memory for movements themselves. Therefore, it seems that a task such as maze learning containing a relatively high propor-

tion of spatial information interferes with a spatial memory system that is used to remember movements and produce images of movements.

Those subjects who had been presented with information relating to the maze had fewer errors and faster completion times, when subsequently tested on the maze itself, than those who had experienced other forms of interference. This suggests that some use was made of the maze information and that it had been stored in memory. If one assumes that these experiments are primarily concerned with "working memory" rather than long term memory then the most recent information being about the maze would be the best recalled. Hitch (1980) describes working memory as being rather like a blackboard on which things are written and then wiped clean ready for the next entry, or in some cases, by the next entry.

Badddeley and Hitch (1974) developed the concept of working memory as an extension of short-term memory, but as a more general purpose system. Working memory is best considered as consisting of separable sub-systems. Hitch (1980) identifies four such sub-systems, the input register, the articulatory output system, a central executive and a visual-spatial store. The input register and articulatory output systems, are both used for verbal material, whilst the visual/spatial system is assumed to handle non-verbal material. Hitch (1980) has investigated the role of working memory for verbal material but has little to say about its role in visual-spatial information processing. Recently, Badddeley (1981) has begun to focus upon the visual-spatial store but as yet only its mere existence has been postulated. It seems, however, that experiments such as those of Phillips and Christie (1977 (a), (b)) involving visual storage and suppression effects will

be most useful in investigating the visual-spatial store.

One suggestion, Baddeley (1981), is that the visual-spatial store is rather like a sketch pad, such as a child's "etch-a-sketch", on which pictorial information can be represented, but which can be written over by further visual-spatial inputs. It seems that the concept of working memory and in particular the sub-system assumed to be concerned with visual-spatial information bears a close relationship with the visual-spatial properties of images. The results of Experiments II to VI all suggest that in imagining linear positioning movements subjects generate or transform a representation of visual-spatial information in something which may well be called "working memory". Particularly the results of Experiment VI suggest that this visual/spatial store can be re-written by incoming visual-spatial information.

CHAPTER TEN

RELATIONSHIPS BETWEEN IMAGERY AND MEMORY FOR LINEAR POSITIONING MOVEMENTS

It is suggested that images of linear movements and actual linear movements are related through a memory representation system. In the case of linear positioning movements it seems that movements and images of movements share a common spatial representation system. Both linear movements and images of those movements involve the representation of spatial information in memory. In order to be able to remember correctly a particular linear movement subjects encode and store such spatial information as the start and end points of the movement, the direction of the movement, the distance from the start to the end point and other information relating the desired end point to other frames of reference such as their own body and objects in the same visual field. The production of an image of a linear movement also appears to be based on spatial information. It has been repeatedly shown in past experiments that only 2nd order interference tasks which involve subjects in processing spatial information suppress imagery effects.

Whilst the experimental evidence for spatial processing in image generation is quite strong the link between images and movements in terms of a spatial representation system is only speculative. In Experiment VI it seemed that the 2nd order interference task with a spatial component not only interfered with imagery of a novel 60 cm movement, but also interfered with memory for the correct 45 cm movement. Although the experiment was not designed to investigate

memory for movements directly, it seems that if one is to explain how images are generated and how they are capable of producing a bias in memory for movements then some common source for both images and movements must exist.

10.1. Experiment VII

If images of linear movements and actual linear movements are both generated from the same representational base in memory, then those 2nd order interference tasks which have previously been shown to interfere with image production should also affect subjects' recall of a standard linear movement when no imagery is required. Thus if movements and images of movements have a common source which is based on a spatial representation system, a task involving spatial processing interpolated between learning and recall of a standard 45 cm linear movement should interfere with the recall of that movement. Alternatively, if images and movement do not share a common spatial representation system then tasks with a spatial component which suppressed image production should not interfere with memory for a 45 cm movement.

Consequently this experiment aims to investigate how images and movements are related. It is assumed that tasks which interfere with either imagery, motor memory or both, do so because a particular resource normally used for those purposes is being utilised by the interference task.

10.1.1. Method

(1) Experimental Design

A two-factor independent groups design was used. Spatial content had two levels, high and low, while stimulation source had three levels, visual, auditory/verbal and motor/kinaesthetic, giving a total of six experimental groups.

(2) Subjects

36 right-handed subjects were randomly selected from a pool of 42 volunteers who were all taking a first year undergraduate course in psychology at Warwick University. An equal number of male and female subjects was assigned to each of the six experimental groups (six subjects per group).

(3) Apparatus

As in Experiment VI.

(4) Task/Procedure

All subjects were required to learn a 45 cm movement from right to left along the hidden track. Each movement was determined by a start and stop block along the track and had accompanying warning lights signalling where the two points were, and when each movement was to begin. As in previous experiments subjects performed 15 learning trials. This was followed by a 50 sec retention interval during which time one of six types of interpolated tasks was performed. The interpolated tasks were as in Experiment VI, visual spatial (VS), auditory/verbal spatial (AS), motor/kinaesthetic spatial (MS), visual non-spatial (VNS), auditory non-spatial (ANS), motor non-spatial (MNS).

Following the retention interval all subjects had ten trials at recalling the original 45 cm movement with the stop and cue lights removed. Finally all subjects were tested for speed and accuracy on the maze as in Experiment VI.

10.1.2. Results

Data were collected for all subjects' errors in positioning movements at recall and their total time and number of false turns on the maze.

(1) Positioning Movement Errors

Error to the nearest 0.5 cm from the 45 cm point was recorded from which CE and VE scores were calculated as in previous experiments (a summary is shown in Appendix I). The mean and standard error of these CE and VE scores in each experimental condition is shown in Table 10.1.

(2) Constant Error (CE)

Analysis of the amount of bias in each subject's memory for the 45 cm movement showed that neither the spatial content nor the source of the stimuli affected the amount of bias (Table 10.2 shows the ANOVA summary for CE). The mean constant error for each condition shown in Figure 10.1 does not significantly vary. If, however, one looks at the standard errors of these means in Table 10.1 one can see that the three conditions in which there was a high spatial interference task (namely a maze) these are 6.07, 5.97 and 5.19; compared with 0.77, 0.60 and 1.20 for the non-spatial conditions. This shows that the effects of a spatial interference task introduced a large amount of variation between subjects in the terms of their error, some of

	VS	AS	MS	VNS	ANS	MNS	
CE	\bar{X}	2.25	2.30	1.42	-0.68	0.25	0.23
	se	6.07	5.97	5.19	0.77	0.60	1.21
VE	\bar{X}	2.17	1.68	1.76	0.70	0.77	0.61
	se	0.49	0.40	0.61	0.17	0.17	0.20

Table 10.1 Experiment VII: Summary of mean (\bar{X}) and standard error (se).
CE and VE for each experimental condition measured in cms.

SOURCE	Sums of Squares	Df	Mean Square	F Ratio	Pr level
A. Spatial Content	7.362	1	7.362	0.434	>.05 NS
B. Stimulus source	25.438	2	12.719	0.749	>.05 NS
AXB Interaction	29.475	2	14.738	0.868	>.05 NS
Error	509.135	30	16.971		
Total	639.410	35			

Table 10.2 Experiment VII: ANOVA Summary for spatial content and source of stimuli in terms of the constant error (CE) at recall of 45 cm movement

EXPERIMENT VII

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL (MAZE)
ANS = AUDITORY/NONSPATIAL

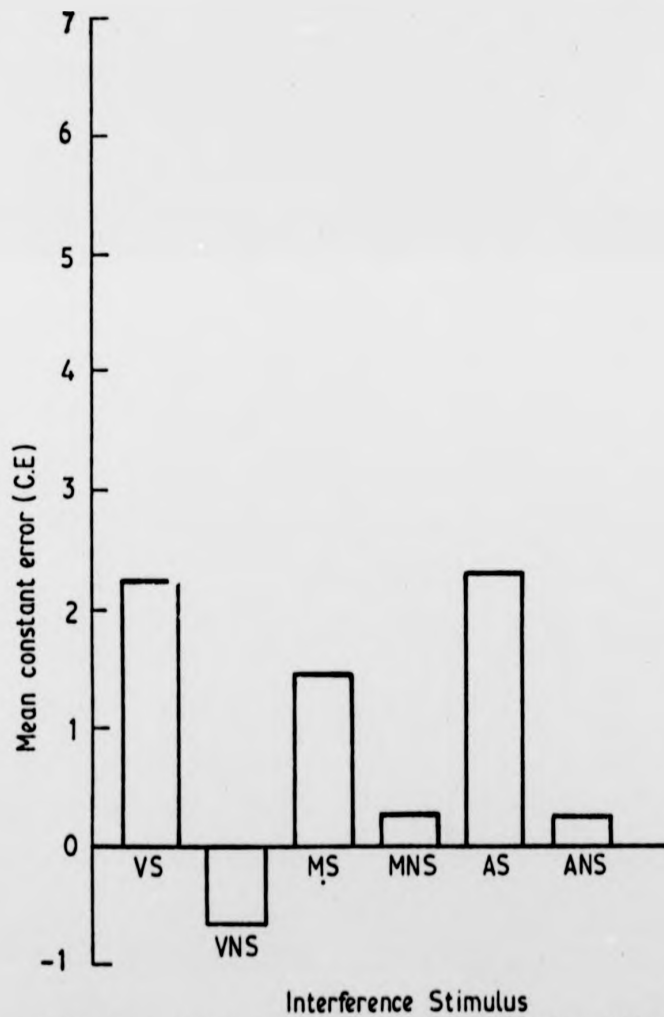


Fig. 10.1 MEAN CONSTANT ERROR (C.E.) FOR ALL INTERFERENCE GROUPS.
(SPATIAL = MAZE).

which were positive, others negative. Consequently the mean bias is not greater than that of the non-spatial interference groups.

(3) Variable Error (VE)

The amount of variation within a subject's series of recall trials was analysed by a two way ANOVA. The results showed that the level of spatial content of the interference stimulus significantly affected VE, $F(1,30) = 85.511$, $pr < .001$. The mean VE for subjects in the high spatial content (maze) condition was 1.87 cms while subjects in the low spatial condition had a mean VE of 0.69 cms. No other effects were significant. Fig. 10.2 shows the mean VE for each experimental condition, while Table 10.3 shows the ANOVA summary.

(4) Maze Performance

Table 10.4 shows the mean and standard error of completion time and number of incorrect turns on a final test of all subjects' performance on the maze.

TIME

A two-way ANOVA of subjects' completion times resulted in a significant main effect for the spatial content of the interference stimulus, $F(1,30) = 157.214$, $pr < .001$ (see Table 10.5). The mean completion time for subjects who had the maze as an interference stimulus was 44.36 secs, while subjects who did not have the maze as an interference stimulus had a mean completion time of 103.79 secs (see Fig. 10.3). No other effects were significant.

ERRORS

Analysis of the number of incorrect turns resulted in a significant effect for the spatial content $F(1,30) = 101.292$, $pr < .001$ (see Table 10.6). The mean number of incorrect turns for subjects who had

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Spatial Content	12.567	1	12.567	85.511	<.001 ***
B. Stimulus source	0.420	2	0.210	1.427	>.05 NS
AXB Interaction	0.470	2	0.235	1.600	>.05 NS
Error	4.409	30	0.147		
Total	17.866	35			

Table 10.3 Experiment VII: ANOVA Summary for spatial content and source of stimulus in terms of the variable error (VE) at recall of 45 cm movement

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Spatial Content	12.567	1	12.567	85.511	<.001 ***
B. Stimulus source	0.420	2	0.210	1.427	>.05 NS
AXB Interaction	0.470	2	0.235	1.600	>.05 NS
Error	4.409	30	0.147		
Total	17.866	35			

Table 10.3 Experiment VII: ANOVA Summary for spatial content and source of stimulus in terms of the variable error (VE) at recall of 45 cm movement

EXPERIMENT VII

- 251 -

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL (MAZE)
ANS = AUDITORY/NONSPATIAL

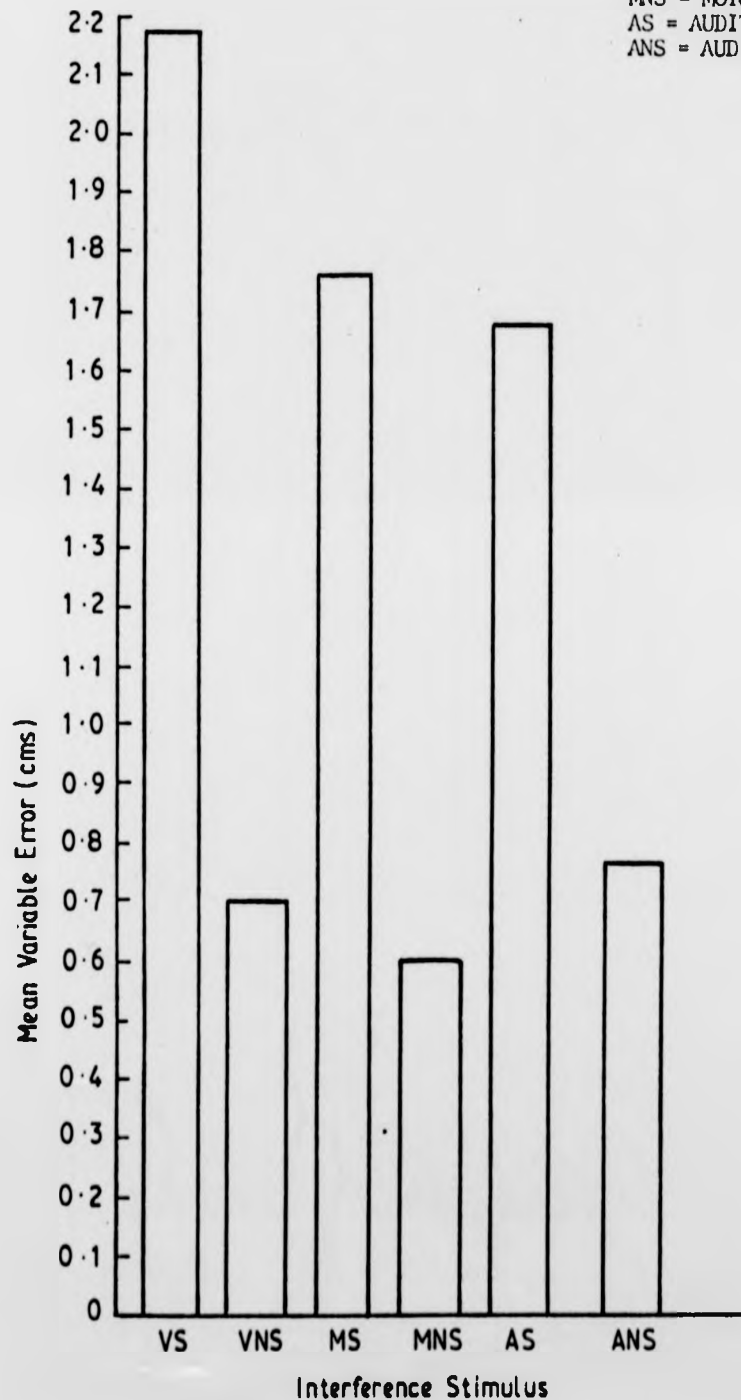


Fig.10.2 MEAN VARIABLE ERROR (V.E.) FOR ALL INTERFERENCE GROUPS
(SPATIAL = MAZE). SPATIAL INTERFERENCE $F(1,30) = 85.5$ $PR < .001$

		Maze as interference			Other interference		
		VS	MS	AS	VNS	MNS	AS
Incorrect turns	\bar{X}	1.67	1.67	2.83	7.00	6.83	7.17
	se	1.21	1.03	0.75	1.79	1.47	2.14
Completion Time Secs.	\bar{X}	36.42	47.83	48.83	103.67	100.00	107.50
	se	11.60	11.39	8.23	13.09	22.03	14.88

Table 10.4 Experiment VII: Mean (\bar{X}) and standard error (se) of the number of incorrect turns and completion times for all subjects' performance on the maze

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
A. Spatial Content	31713.700	1	31713.7	157.214	<.001 ***
B. Stimulus Source	396.375	2	198.188	0.982	>.05 NS
AXB Interaction	343.406	2	171.703	0.851	>.05 NS
Error	6051.700	30	201.723		
Total	33055.181	35			

Table 10.5 Experiment VII: ANOVA Summary for completion time on maze

EXPERIMENT VII

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL (MAZE)
ANS = AUDITORY/NONSPATIAL

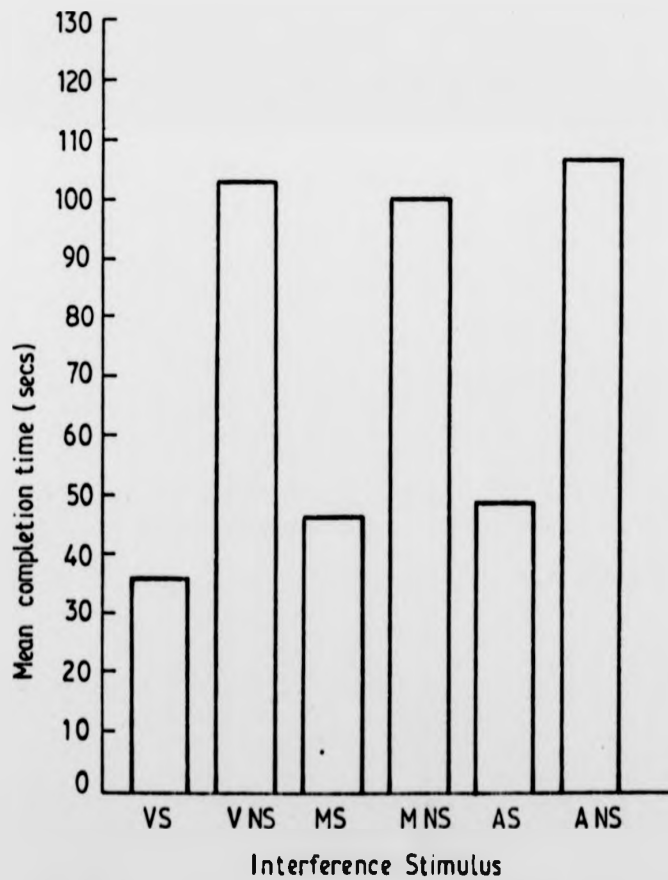


FIG. 10.3 MEAN COMPLETION TIME FOR ALL INTERFERENCE GROUPS ON MAZE (SPATIAL = MAZE).

SPATIAL INTERFERENCE (MAZE) $F(1,30) = 157.214$ $PR < .001$

been given the maze as an interference stimulus was 2.06 turns, while subjects who had not been given the maze had a mean of 7 incorrect turns (see Fig. 10.4). No other significant effects were found.

(5) Regression Analysis

Finally a regression analysis was performed on each subject's error scores for the linear positioning task. As in previous experiments the recall trial number and the appropriate error for the 45 cm point were regressed for all subjects (see Table 10.7 for a summary). It can be seen from Table 10.7 that in the non-spatial interference conditions the intercept value (α) for all subjects is uniformly low and the slope coefficient β is also low, indicating that subjects had a uniform error pattern which was low and constant.

Subjects in the spatial interference conditions have a completely different series of intercept values (α) which tend to be high positive or high negative values, whilst their slope coefficients (β) are low. This suggests that subjects in the spatial interference conditions were not uniformly biased in their recall responses but were, however, seriously affected by the interference task. Because some subjects had high positive error scores while others had high negative the mean error per trial is not a reliable indicator of the group data, therefore no further analysis over trials is possible.

10.1.7. Discussion

The results of this experiment strongly suggest that linear positioning movements are produced with reference to a spatial representational system. It has been shown that tasks with a high spatial component (mazes) interfere with the subject's memory for a linear position-

SOURCE	Sums of Square	Df	Mean Square	F ratio	Pr level
A. Spatial Component	220.028	1	220.028	101.292	<.001 ***
B. Stimulus Source	4.056	2	2.028	0.934	>.05 NS
AXB Interaction	1.722	2	0.861	0.396	>.05 NS
Error	65.167	30	2.172		
Total	290.973	35			

Table 10.6 Experiment VII: ANOVA Summary for number of incorrect turns on maze

EXPERIMENT VII

VS = VISUAL/SPATIAL (MAZE)
VNS = VISUAL/NONSPATIAL
MS = MOTOR/SPATIAL (MAZE)
MNS = MOTOR/NONSPATIAL
AS = AUDITORY/SPATIAL (MAZE)
ANS = AUDITORY/NONSPATIAL

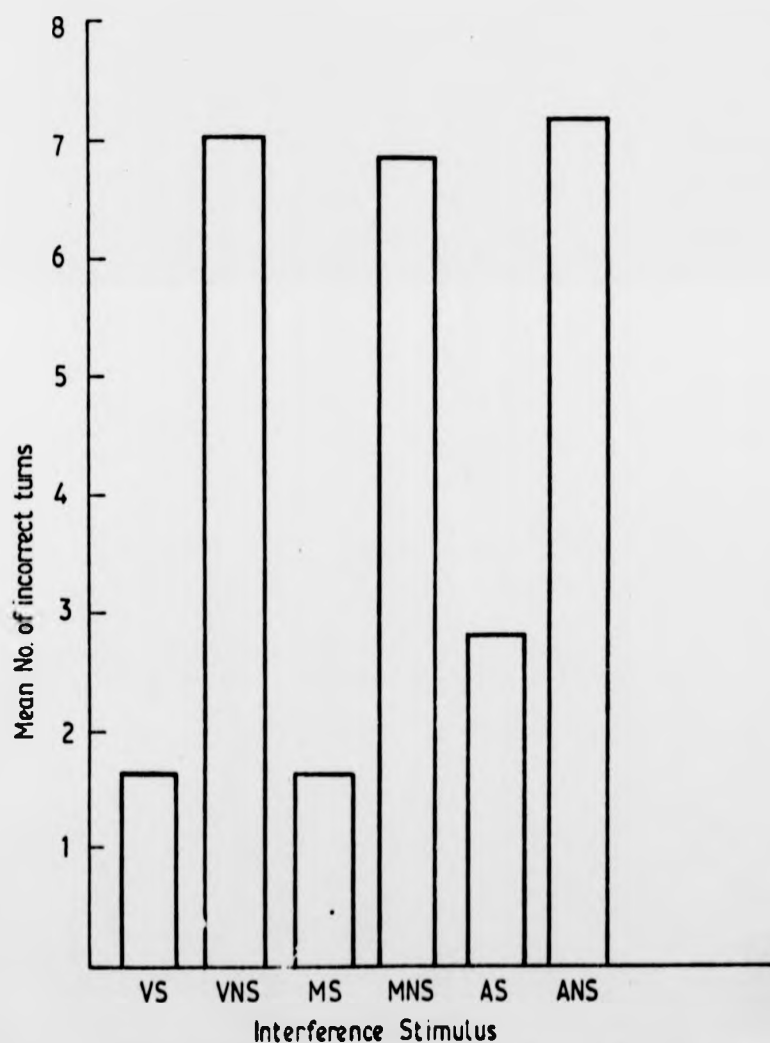


Fig. 10.4 MEAN NUMBER OF INCORRECT TURNS ON RECALL OF MAZE FOR ALL INTERFERENCE GROUPS (SPATIAL = MAZE)

SPATIAL INTERFERENCE $F(1, 50) = 101.292$ $PR < .001$

Subject		Visual Spatial	Visual Non-Spatial	Motor Spatial	Motor Non-Spatial	Auditory Spatial	Auditory Non-Spatial
1	α	-5.07	1.07	0.27	-1.07	4.13	0.53
	β	-0.30	-0.08	-0.68	-0.20	0.27	0.02
2	α	5.13	0.87	4.60	2.41	5.60	-1.00
	β	0.19	-0.12	0.38	-0.19	-0.12	0.05
3	α	6.60	-0.73	-3.00	0.67	7.50	0.53
	β	0.00	0.06	-0.38	0.06	-0.30	0.05
4	α	-3.70	-1.73	-4.53	-0.27	7.33	-0.20
	β	-0.10	0.06	-0.03	-0.01	0.08	0.07
5	α	4.87	0.27	4.00	-1.07	-0.13	-1.60
	β	0.08	-0.07	-0.09	-0.04	-0.63	0.27
6	α	7.67	0.00	-3.60	1.47	-5.40	0.73
	β	-0.23	0.11	-0.33	-0.05	-0.25	-0.04

Table 10.7 Experiment VII: Regression analysis, regressing recall trials number against error score for each subject in each condition (α) = intercept, (β) = slope coefficient

ing movement. Tasks with a very low spatial information component had little or no effects on the subject's recall of a linear movement. Therefore it seems that the subject's memory for a linear movement is represented in terms of the spatial characteristic mentioned earlier.

It is interesting to note that the effects of the maze interference tasks on subjects' memory for the linear movements were not biasing, as imagery or production of a linear movement are. Instead, subjects who had been presented with the maze as an interference stimulus, experienced a "forgetting" of where the 45 cm position was. The error patterns of these subjects show that some subjects overshot the 45 cm point by as much as 7 cm while others undershot by similar or even greater amounts. Furthermore, individual subjects varied considerably in their own positioning movements over the ten recall trials. The variable error (VE) scores for each of the subjects who were presented with the maze during the retention interval is considerably greater than that of the non-spatial interference groups.

Given the two component model of VE described earlier it seems possible that the greater amount of variation introduced by the spatial interference task is a result of interference to the memory trace for the 45 cm movement.

The implications of this experiment when taken with the results of the previous experiments on imagery are to suggest that linear positioning movements and images of those movements have a common base. More precisely this common basis comprises a spatial representational system in memory. This suggests that images and learned movements, specifically linear positioning movements, are generated from a memory

store which contains representations of spatial information.

One important finding is that linear positioning movements appear to be remembered not in terms of their motoric or temporal qualities, nor in terms of their sensory qualities, instead it seems as if they are remembered as abstract representations of spatial information. As these experiments have only used linear positioning movements it is not possible to generalise these conclusions to all movements. It does seem, however, that in movements which are primarily concerned with arriving at a specific point in space, memory for those movements is based on spatial information, as suggested by Howarth (1978).

The analyses of the subsequent performance on the linear maze showed that those subjects who had been given information about the maze as an interference stimulus were faster and more accurate at finding their way through the maze. This suggests that the memory trace for the 45 cm positioning movement was overshadowed by storage of the correct path through the maze.

10.2. Summary and Conclusions

The results of all the previous experiments in this study seem to point towards the importance of spatial information in the recall and imagery of linear positioning movements. If, as Hitch (1980) and Badddeley (1981) suggest, a general purpose system such as working memory exists, then it seems that linear positioning movements are represented in the visual-spatial store, or at least the visual-spatial aspects of these movements. At the same time as providing a store for

visual-spatial information, this sub-system also permits further processing operations to be carried out on the information contained therein. There is a distinction, however, between images generated from a permanent store and more transient representations in a short-term store. The latter would seem to apply to working memory, and are concerned with phenomenon as that reported in the experiments of Phillips and Christie (1977 (a), (b)).

Following the presentation of a visual-spatial stimulus certain properties of the stimulus are found to exist longer than the presentation period and longer than would be permitted by an iconic store, Neisser (1966). Images generated from long-term memory, however, are less tied to the previous stimulus and consequently may have different processing characteristics. It is not clear whether these two types of visual-spatial representations reflect the same system being operated under different circumstances or two different systems. There appears to be some similarity between the concept of a visual-spatial store in working memory and Kosslyn's (1980) notion of a visual buffer in his model of mental imagery. Kosslyn's model of mental imagery devotes a dual role to the "visual buffer" of representing images generated from long-term memory and the short-term storage of visual spatial information.

Experiments VI and VII do not distinguish between short-term storage and images generated from long term memory. It might be argued that these experiments are primarily concerned with short-term storage, except that when subjects are asked to imagine a linear-positioning movement this is in fact a novel movement. However, the movement is similar to a previously produced movement, except that some form of information processing must transform the memory for a 45 cm linear

visual-spatial information, this sub-system also permits further processing operations to be carried out on the information contained therein. There is a distinction, however, between images generated from a permanent store and more transient representations in a short-term store. The latter would seem to apply to working memory, and are concerned with phenomenon as that reported in the experiments of Phillips and Christie (1977 (a), (b)).

Following the presentation of a visual-spatial stimulus certain properties of the stimulus are found to exist longer than the presentation period and longer than would be permitted by an iconic store, Neisser (1966). Images generated from long-term memory, however, are less tied to the previous stimulus and consequently may have different processing characteristics. It is not clear whether these two types of visual-spatial representations reflect the same system being operated under different circumstances or two different systems. There appears to be some similarity between the concept of a visual-spatial store in working memory and Kosslyn's (1980) notion of a visual buffer in his model of mental imagery. Kosslyn's model of mental imagery devotes a dual role to the "visual buffer" of representing images generated from long-term memory and the short-term storage of visual spatial information.

Experiments VI and VII do not distinguish between short-term storage and images generated from long term memory. It might be argued that these experiments are primarily concerned with short-term storage, except that when subjects are asked to imagine a linear-positioning movement this is in fact a novel movement. However, the movement is similar to a previously produced movement, except that some form of information processing must transform the memory for a 45 cm linear

movement into an image of a 60 cm linear positioning movement.

Because of these distinctions between images generated from long-term memory and short-term visual-spatial storage it is not clear whether similar interference effects should be found for images generated from long term memory, although one might expect little difference between the two representations.

CHAPTER ELEVEN

IMAGERY EFFECTS IN A PRESSURE LEARNING TASK

Previous experiments have shown that images of linear positioning movements or the rehearsal of those movements consists of manipulating the spatial component of a memory representation. This has been shown consistently throughout this series of experiments. Furthermore it appears that this is not purely a function of the visual system, but of a more abstract spatial representation. However, all past experiments in this series featured a linear-positioning task, which is primarily a spatial task, since it is the distance/location of a movement that has to be remembered. Therefore, the predominant features of the memory representation for this task are probably spatial.

It could be the case that a task which had different features to be remembered would result in a different kind of rehearsal and imagery. For instance, one hypothesis, which has been rejected by the past experiments, is that rehearsal or imagery involves neuromuscular activation. It may be possible that a task which primarily concerns motor activity but with a very low spatial information component will be rehearsed in such a manner. Learning a pressure is a good example of a task which has very little spatial information (apart from the direction of the pressure, up, down, etc.), Amott (1959).

Pepper and Herman (1970) have shown that a similar biasing of memory occurs when subjects are required to first learn one pressure,

then during a retention interval are required to learn a novel pressure. The result is that subsequent recall of the original pressure contains an error which is biased towards the intervening novel pressure. If imagery of movements is indeed varied according to the task in hand, then in imagining a pressure subjects should not use spatial information, but some other kind of task relevant information.

It is possible that in tasks of this nature, which require subjects to learn and remember a specific pressure then "force" may be the most important parameter. Information regarding the force applied during a particular motor response can be fed back via the proprioceptive and kinaesthetic receptors in the joint and muscle groups, Kelso and Stelmach (1976). However, feedback is not only the means for controlling force. Under an oscillatory mechanism, as described by Gallistel (1980), force parameters can be specified prior to output. In recording forces it is difficult to distinguish between force applied at the termination of the motor act and the force applied during its execution unless continuous recording is used. Gallistel shows that changes in force output during motor acts can be determined in advance by oscillatory units. This suggests that force is an important parameter for motor control and may be determined by "higher" levels of the motor output system.

11.1. Experiment VII1

If subjects can and do use some alternative information to generate images then bias in recalling a pressure when the intervening

pressure is imagined should occur. This imagery produced bias should be similar to that produced by exerting a novel pressure during the retention interval.

Alternatively, if imagery or rehearsal of movements is primarily concerned with rehearsing spatial information, then no equivalent bias should occur. If this is the case then the errors produced by imagining a novel pressure should be no different from those produced by a control group who simply count backwards in threes.

11.1.1. Method

(1) Experimental Design

A one way independent groups design was used, with type of intervening task as the independent variable and CE and VE as the dependent variables. Type of intervening task had three levels, producing a novel pressure, imagining a novel pressure, or counting backwards.

(2) Subjects

18 undergraduate students from the Psychology Department of Warwick University who had volunteered to take part in the experiment were assigned to one of the experimental conditions. Each group contained 6 subjects (3 male, 3 female). Only right-handed volunteers were used.

(3) Apparatus

As shown in Figure 11.1 a steel handle was mounted 90 cm from the floor in a wooden frame. The handle made contact with a vertical steel rod which transferred any pressure on the handle to a spring

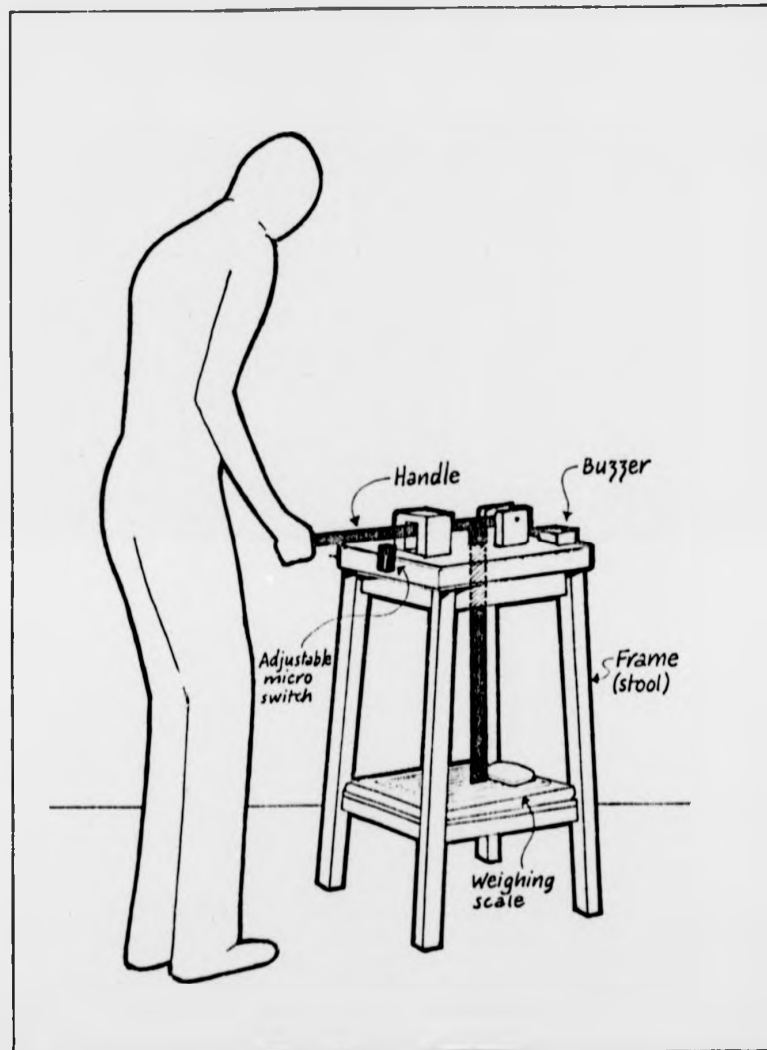


Fig 11.1 Pressure recording apparatus
used in experiment VIII

loaded weighing scale which recorded the amount of pressure exerted. The handle also made contact with a micro switch which could be set at different positions. As the required pressure was reached a buzzer sounded. The total amount of movement in the handle was only 1 cm (i.e. 0.5 cm either up or down).

(4) Task/Procedure

All subjects were first required to learn a 15 kg downward pressure by pressing down on the handle until a buzzer sounded. On hearing the buzzer subjects were instructed to maintain that pressure for 2 secs until the experimenter instructed them to release the handle. Following a further 2 secs pause subjects were required to again press down on the handle. This was repeated 15 times. After learning a 15 kg pressure in this manner subjects engaged in one of the three intervening tasks depending upon which experimental group they were in.

11.1.3. Intervening Tasks

(1) Producing a 30 kg pressure (30P)

Subjects in this group were then required to learn a new pressure, 30 kg, by exerting twice the original force on the handle. This time the buzzer sounded when a 30 kg pressure registered on the scale. Subjects had 10 trials at producing the new pressure.

(2) Imagining a 30 kg pressure (30I)

This group of subjects was instructed to imagine that they were now pressing down on the handle twice as hard as before, to achieve a 30 kg pressure. They were provided with buzzer feedback and commands to grasp and release the handle by the experimenter, but no overt

movements were made and the apparatus was not touched by the subject. As in the 30P group subjects had 10 trials at imagining this activity.

(3) Counting Backwards (CB)

The control group of subjects were required to count backwards in threes during the retention interval from a 3 figure random number.

All subjects had a 50 sec retention interval. Immediately following the retention interval subjects were instructed to reproduce the 15 kg pressure 10 times. Each recall trial was started by the experimenter, but no feedback from the buzzer was available. Subjects were instructed to say "now" when they thought they had reached the correct pressure and then maintain it for 2 secs until the experimenter said "release".

11.1.3. Results

The error of each recall trials from the 15 kg point was noted together with the sign of the error. From this CE and VE scores for each subject were calculated (see Appendix J). The mean CE and VE scores for each condition are shown in Table 11.1.

(1) Constant Error

Analyses of the amount of bias at recall were carried out by inputting subjects' CE scores to a one-way ANOVA. The results of this ANOVA showed that type of intervening task had a significant effect on the amount of bias (CE), $F(2,15) = 144.857$, $pr < .001$. (See Table 11.2 for ANOVA summary).

30P			30I		CB	
	\bar{X}	se	\bar{X}	se	\bar{X}	se
CE	5.87	0.78	0.58	0.58	0.22	0.54
VE	1.65	0.69	1.01	0.40	0.58	0.18

Table 11.1 Experiment VIII: Mean (\bar{X}) and standard (se) of CE and VE for each condition measured in kgs.

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
Intervening task	119.941	2	59.971	144.857	<.001 ***
Error	6.210	15	0.414		
Total	126.151	17			

Table 11.2 Experiment VIII: ANOVA Summary, one-way independent groups - CE

Decomposition of the significant effect using Tukey's HSD (a) test showed that producing a 30 kg pressure (30P) resulted in significantly greater bias than imagining a 30 kg pressure (30I). There was no difference, however, between the amount of bias produced by the 30I group and the counting backwards group. (see Table 11.3 for differences between means and Fig. 11.2)

(2) Variable Error (VE)

Analysis of the strength of the memory trace, as measured by VE, in a one-way independent group ANOVA showed that type of intervening task had a significant effect, $F(2,15) = 7.790$, $pr < .005$. (see ANOVA summary in Table 11.4)

Decomposition of the significant effect for type of intervening task using Tukey's HSD (a) test showed that counting backwards in threes had a lower VE than producing a 30 kg pressure. There was no significant difference between imagining and producing a 30 kg pressure; (Table 11.5 and Figure 11.3 show the individual means for each condition), nor between imagining a pressure and counting backwards.

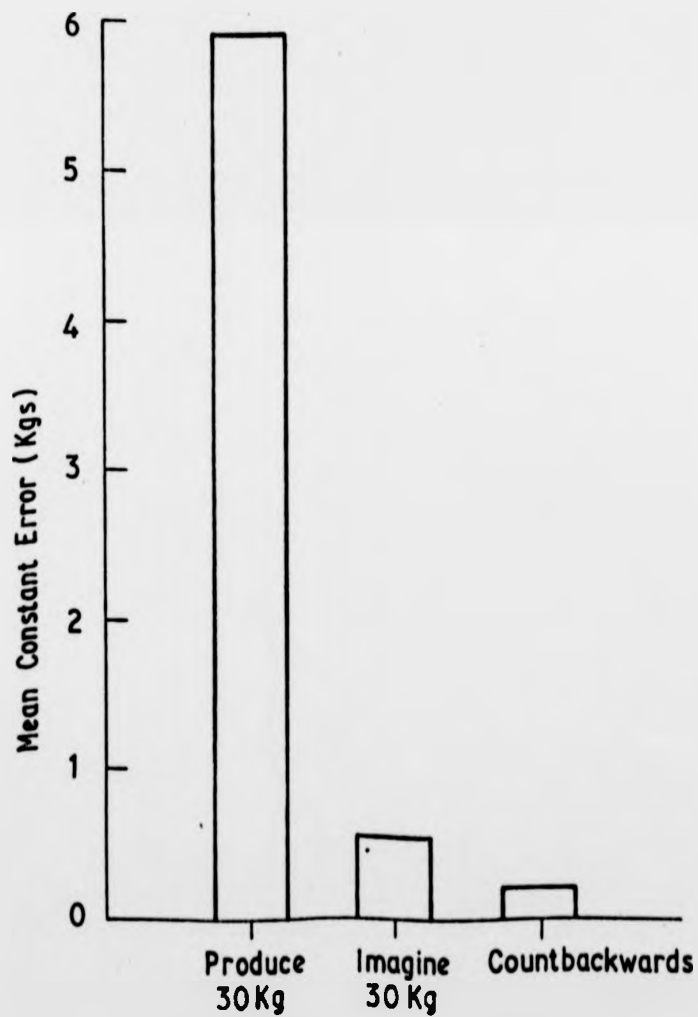
Finally, although the level of VE is relatively low in all conditions Figure 11.4 suggests that the higher VE score found in the production of a 30 kg pressure is accounted for by a negative trend. It can be seen that the mean pattern of errors for trials in the 30I and CB conditions have a similar function with no trend. The 30P condition has a completely different function, in which the amount of error reduces over trials. Because of the relatively low variability (VE) a regression analysis would add very little further information.

30P $\bar{X}=5.87$	30I $\bar{X}=0.58$	CB $\bar{X}=0.22$
30P $\bar{X}=5.87$	5.29**	5.65**
30I $\bar{X}=0.58$		0.36
CB $\bar{X}=0.22$		

Table 11.3 Experiment VIII: Differences between mean CE for each type of intervening task. ** < 0.01 pr level of significance on Tukey's HSD (α) test.

- 373 -
EXPERIMENT VIII

Fig. 11.2 Mean Constant Error for each type
of 1st Order interference



Type of Interference (1st Order)

$F, 2, 15 = 144.857$ $Pr < .001$

SOURCE	Sums of Squares	Df	Mean Square	F ratio	Pr level
Intervening task	3.483	2	1.742	7.790	.005 **
Error	3.353	15	0.223		
Total	6.836	17			

Table 11.4 Experiment VIII: ANOVA Summary, one-way Independent groups - VE

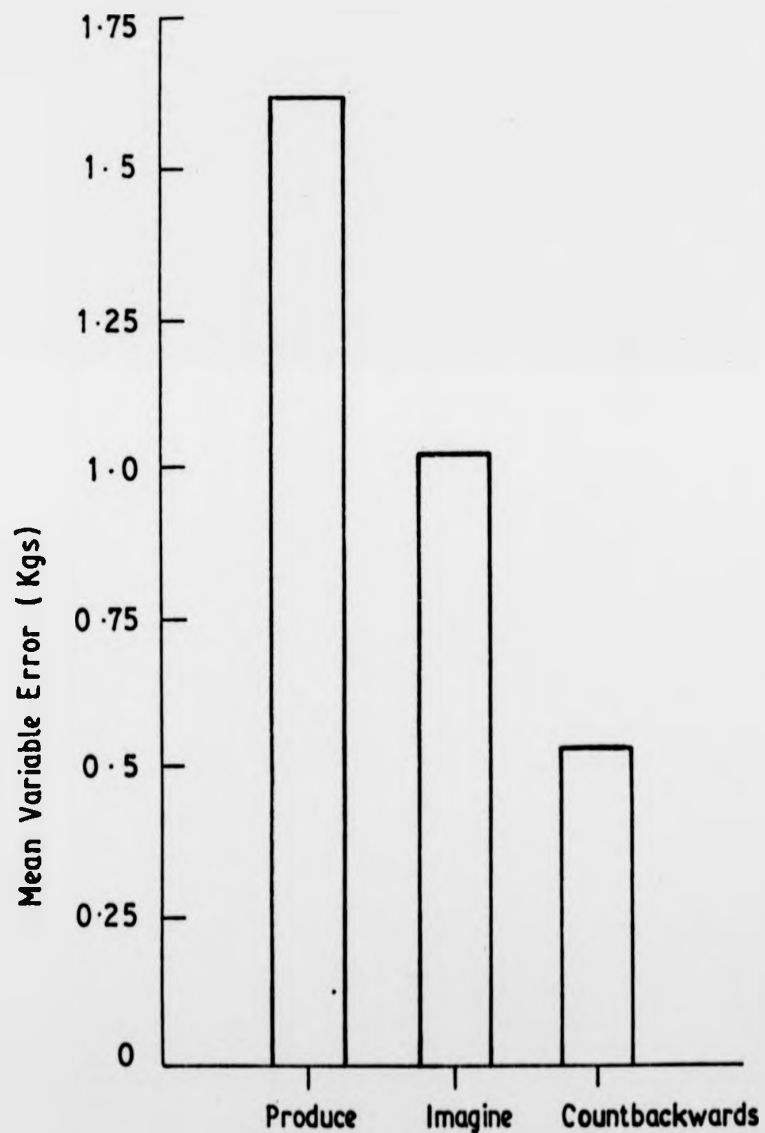
	30P $\bar{X}=1.65$	30I $\bar{X}=1.01$	CB $\bar{X}=0.58$
30P $\bar{X}=1.65$		0.64	1.07 **
30I $\bar{X}=1.01$			0.43
CB $\bar{X}=0.58$			

Table 11.5 Experiment VIII: Differences between means VE for each type of intervening task. ** <.01 pr level of significance on Tukey's HSD (a) test

EXPERIMENT VIII

Fig. 11.5

Mean Variable Error for each type
of 1st Order interference

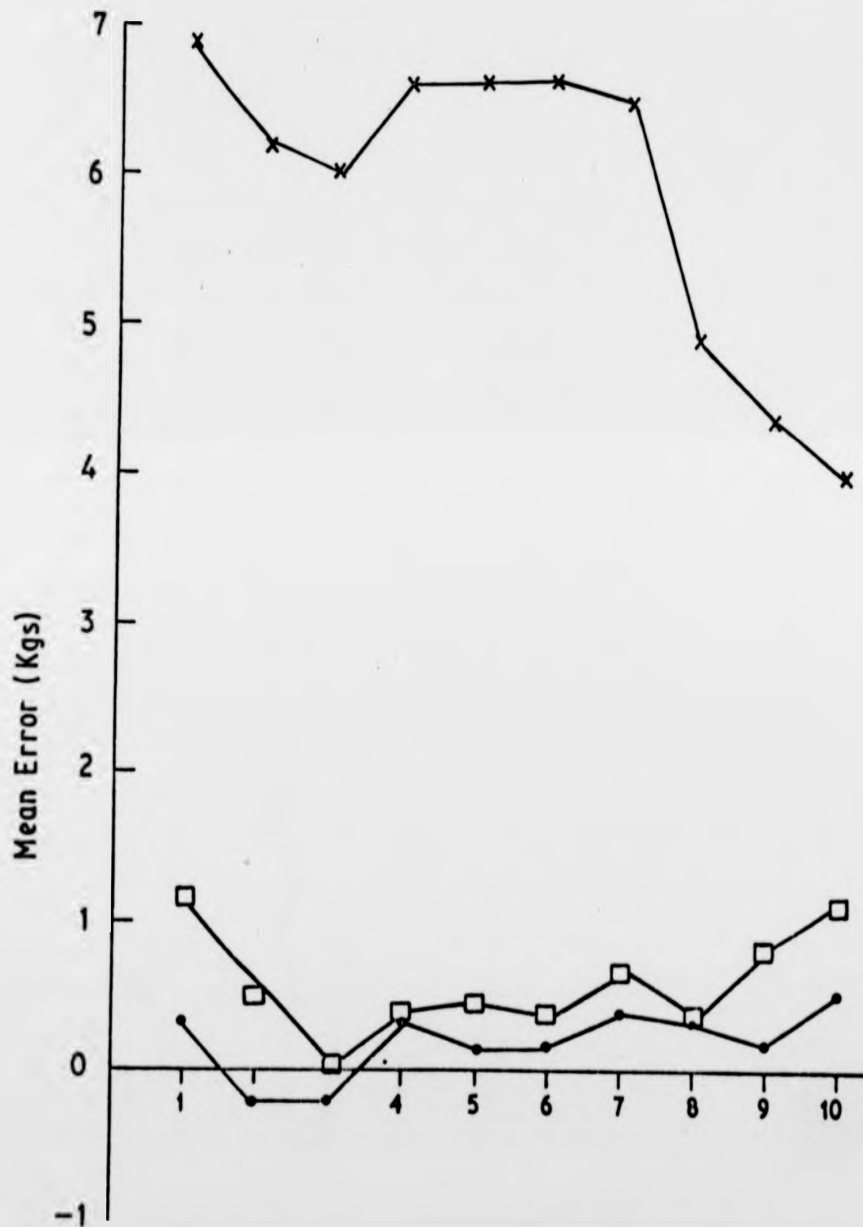


Type of Interference (1st Order)

$F_{2,15} = 7.79$, $Pr < .005$

EXPERIMENT VIII

Fig. 11.4 Mean Effect per trial of Imagining or producing a novel force on memory for a 15 Kg downward force



- x = Producing a 30 kg force during retention interval.
- = Imagining producing a 30 Kg force during retention interval.
- = Counting backwards during retention interval.

11.1.4. Discussion

Imagery of a pressure has been shown not to have any biasing effect on memory for a learned pressure. The biasing effects, previously noted by Pepper and Herman (1970) were found when a novel pressure interferes with the learning and recall of a criterion pressure response. The equivalence between images and linear positioning movements that was found in previous experiments has not been found when the task involved exerting a pressure. The results of this experiment suggest that imagery of motor acts involves the manipulation of spatial information rather than force or pressure information.

In a debriefing session in which subjects were questioned about their imagery it was commonly stated by all subjects in the imagery condition that they had imagined pressing the handle. Their images consisted of "snapshots" of an arm holding the handle and the handle travelling downwards. For example, subject L.P. was asked "what can you tell me about your imagery?", to which it was replied "I imagined I was pushing down on the handle. I could see my hand holding the white plastic grip on the handle - it was my right hand. The handle moved, downwards, much more than it did when I actually pushed it". Similarly subject C.D. in reply to the same question reported "I imagined pushing the bar downwards. I imagined the distance I had to push the bar and I was watching the distance the bar moved. It was a visual image. I could not feel anything". These reports suggest that subjects had indeed formed an image of "pressing the handle twice as hard" as instructed. The images they formed, however, were not motor images but quasi-pictorial images which primarily featured spatial information, i.e. the downward movement

of the handle. It seems that the failure to bias recall of a pressure by imagery was primarily due to the nature of the representation upon which an image generation process was activated. Subjects did not fail to produce an image but used inappropriate information to construct the image. It cannot be concluded that imagery is confined to the manipulation of spatial representations. It does, however, appear that these subjects' images contained spatial information, rather than, or in a greater proportion to, neuromuscular information.

There are some rather intriguing reports from child developmentalists such as Piaget that in some cases images do produce biasing effects on force and pressure control. Young children, for example, are often tricked by 2 identical amounts of plasticine, if one is rolled into a ball and the other into a sausage shape. Besides judging the sausage shape to contain more plasticine the child, when being handed the sausage shape, overestimates its weight and the child's hand jumps upward slightly, Piaget and Inhelder (1974). This can be explained if one assumes the child is imagining what the sausage shape should weigh and is producing an appropriate lifting force. As the weight has been overestimated the force applied is too great and as a result the hand raises slightly when the plasticine is taken.

This intriguing phenomenon suggests that in some cases images can affect a force component of the motor production system. One does not, however, have to abandon a spatial representation stance to explain this effect. The primary feature of the sausage and ball effect is that size information is used to build up expectations of weight. Hence a size weight illusion is created, in which the perceived sizes

mislead the child's expectations about weight. This suggests that it is still the spatial component of the stimulus which is being used to generate an image. Furthermore this spatial information is then capable of affecting other components of the motor production system.

Further evidence of the dominance of spatial information over pressure or force information comes from an effect first noted by Annett (1959). One feature of Annett's experiment was that subjects had to learn a pressure with the aid of visual feedback from a pointer. Quite by chance on some occasions the pointer stuck and did not move as the subjects increased their pressure. This resulted in subjects proclaiming that the lever that they were pressing had suddenly become much stiffer (which in fact was not true). This led Annett in a subsequent experiment to remove the visual feedback from the dial in some conditions, the result being that subjects' pressures increased. This study might well be interpreted in the same way as the child with the plasticine. Subjects were representing the spatial information from the dial and using this to generate the appropriate pressures. When the pointer failed to move, the spatial feedback (or lack of it) determined their expected motor output.

11.2. Some Conclusions on Images and Motor Acts

To conclude, the present experiment confirms the previous findings that imagery of motor acts is primarily a process which manipulates spatial representations derived from the stimulus information available in previously experienced situations. However, this conclusion must still be limited by the narrow range of motor tasks

on which this hypothesis has been tested. In linear-positioning tasks, where the task itself is largely a spatial one, instructions for subjects to imagine the task result in significant biasing effects on memory. This result has been used to infer that imagery of motor acts involves the processing of spatial information. When a motor task which is assumed to involve little or no spatial information processing is used instructions for subjects to imagine the task appear to have no biasing effects on memory. However, subjects' reports suggest that images of the task had been generated but that these images were of a visual/spatial nature. While subjective reports of images may be incorrect, for reasons discussed in Chapter Three, when taken with other empirical evidence from previous experiments in this study it seems reasonable to assume that in both linear positioning and lever pressing tasks instructions to imagine the task affect the visual-spatial information processing system.

The finding that imagery instructions bias subjects' memory in a linear positioning task but not in a lever pressing task might suggest differences between how the two tasks are remembered rather than in the imagery process. Linear positioning tasks being remembered primarily in terms of the spatial relationships between the start and end points of the movement together with frame of reference in which the movement is produced. Lever pressing tasks may well be remembered primarily as an applied force. One distinct difference between the two tasks is the amount of movement involved. Linear positioning tasks require arm movement at the shoulder and elbow joints and wrist movement, while lever pressing tasks require little or no overt movement of the limbs. In this particular lever pressing task the total amount of movement in the lever was 1 cm, which transferred through the joints of

of the wrist, elbow and shoulder, produces little in the way of overt movement.

The difference between a force and a movement is normally not apparent since the two are rarely separated, either in the laboratory or in normal motor behaviour. Motor acts normally involve applying a force to a movement, in a particular direction. Indeed, one manner in which movement extent might be controlled is by monitoring the force applied. If this is the case, however, then imagery of motor acts does not appear to involve the same control structures as used in actual motor acts. In the following chapter the implications of this study are considered in connection with theories of motor control and other cognitive processes.

CHAPTER TWELVE

MEMORY, REHEARSAL AND PERCEPTUAL MOTOR SKILL; CONCLUSIONS, POSITIONS AND DIRECTIONS

The previous chapters review experimental and theoretical relations between memory, rehearsal and perceptual motor skill. A series of experiments have been fully described and some conclusions made. This final chapter has three objectives; first, final conclusions from the present study are presented. Second, an attempt is made to position this research within a wider framework of skill and cognition. Third, possible directions for future research in theoretical and applied settings are suggested.

12.1. Conclusions From The Present Study

Mental practice is a cognitive procedure which permits the covert rehearsal of skilled actions. This rehearsal employs an image processing system in conjunction with memory representations. In particular images function to elaborate and refresh existing representations. From the analysis of cues available during MP in Chapter Two it seems that relevant visual cues produce greater improvements following MP than other or no cues. This suggests that imagery has a visual/spatial basis. One possibility is that MP enables "plans" for actions to be constructed and refined prior to a response being made.

Cognitive psychology has devoted some of its efforts to exploring mental imagery. Current theories of imagery are centred around the functional/representational debate. Mistakenly the functional and

CHAPTER TWELVE

MEMORY, REHEARSAL AND PERCEPTUAL MOTOR SKILL; CONCLUSIONS, POSITIONS AND DIRECTIONS

The previous chapters review experimental and theoretical relations between memory, rehearsal and perceptual motor skill. A series of experiments have been fully described and some conclusions made. This final chapter has three objectives; first, final conclusions from the present study are presented. Second, an attempt is made to position this research within a wider framework of skill and cognition. Third, possible directions for future research in theoretical and applied settings are suggested.

12.1. Conclusions From The Present Study

Mental practice is a cognitive procedure which permits the covert rehearsal of skilled actions. This rehearsal employs an image processing system in conjunction with memory representations. In particular images function to elaborate and refresh existing representations. From the analysis of cues available during MP in Chapter Two it seems that relevant visual cues produce greater improvements following MP than other or no cues. This suggests that imagery has a visual/spatial basis. One possibility is that MP enables "plans" for actions to be constructed and refined prior to a response being made.

Cognitive psychology has devoted some of its efforts to exploring mental imagery. Current theories of imagery are centred around the functional/representational debate. Mistakenly the functional and

representational states of imagery have been confounded. It is conceivable that images do not constitute a distinct or specific form of representation but do have a complementary, functionally specific, role to play in a cognitive system. It appears that imagery of motor acts is a functional part of a cognitive process enabling the rehearsal of motor acts. The present investigations of mental practice, imagery and perceptual motor skills showed that images of motor acts do have functional properties in skill acquisition as far as linear positioning tasks are concerned. These images appear to be closely related to the representation of the motor act and are especially concerned with spatial information.

A serious problem for this research was the lack of an adequate experimental methodology with which to investigate images and mental practice. Recent experiments by Finke (1979, 1980) suggest that biasing or after-effects which normally occur in reality can be produced by imagery instructions. This method permits one to investigate those cognitive processes involved in imagery in a more formal manner.

The first experiment in this series showed that instructions to imagine a novel linear positioning movement had a biasing effect on a subject's memory for a criterion linear positioning movement similar to that obtained by actual movements. This demonstrates that images of linear positioning movements do indeed function in skill acquisition. It might be inferred from the lower variability of movement error with imagery instructions that images do not involve the motor production system. Two separate systems might be proposed, one for action production and one for action recognition. Imagery might be thought to involve the

recognition system but not the action or motor production system. One of the ways in which imagery may function in the MP of a previously learned movement, is to consolidate the memory trace and in this way reduce the amount of variability in successive attempts to reproduce the learned movement.

Subsequent experiments employ what I have termed a "second order" interference technique to investigate images. "First order" interference in the form of interpolated tasks is used to show how imagery affects memory. "Second order" interference tasks are then used to interfere with imagery processes and suppress imagery produced biasing.

The second experiment (reported in Chapter Five) showed that imagery is interfered with by a visual/spatial task but not by a motor task. This provides further support for the earlier assumption that imagery does not involve the motor production system. In the third experiment (Chapter Six) visual/spatial cues during the movements were reduced by screening the track and subject's arm from view. Further bias may have been due to the differences in the general processing demand of the second order interference tasks. Consequently, the visual/spatial stimuli of the second order interference were simplified while the motor interference stimuli were increased in complexity. The results again showed that only visual/spatial interference stimuli suppressed the imagery produced biasing. Therefore any suggestion that the interference effects were due to general processing demands rather than specific resource demands are unsupported. All the earlier interference effects suggest that it is the visual/

spatial nature of the interference task which suppresses image processes.

The seventh chapter introduced the possibility of linear positioning movements being rehearsed by sub-vocally counting. It is possible that temporal or rate of execution information could be either rehearsed or imagined by subjects counting sub-vocally. No interference effects were found when a concurrent verbal shadowing task was introduced, and therefore it was concluded that linear movements are not rehearsed by such a counting procedure. Separate effects were also found for the response demand of the interference task and its specific resource demands. The response demands were manipulated separately from the source or type of interference stimulus. Increasing the response demand appears to reduce the size of "variable error" (VE) while varying the type or source of the interference stimulus affects "memory" and results in a biasing of memory, reflected by CE and an increase in the amount of variability (VE) when memory for the criterion position is affected.

Chapters Eight and Nine show that images are interfered with by the spatial properties of a stimulus rather than its visual, motor or auditory properties. Images of linear positioning movements are based on the abstract representations of spatial information. These spatial representations include location, distance, and direction information. In Experiment VII (Chapter Ten) it was shown that linear movements themselves are subject to interference from spatial rather than visual, motor or auditory tasks. Therefore images of linear positioning movements and linear positioning movements themselves

share a common representation, based on spatial information.

The eighth experiment (Chapter Eleven) assumes that if images of other motor acts are primarily spatial in nature then a motor task with little or no spatial requirements should not be affected by imagery instructions. By using a lever pressing device with little spatial information involved in the task it was shown that instructions to imagine a novel interpolated pressure had no effects on subjects' memory for a criterion pressure. Images of motor acts do not seem to share a full relationship with memories for those acts. Imagery of motor acts appears to be a process which is most effective when the act is primarily concerned with spatial information. Subjects in the lever pressing experiment did report experiencing images but these often were of a "magnified" movement of the lever in the direction they were pressing. While such subjective reports cannot be taken as direct evidence, they do support a spatial processing hypothesis of imagery.

12.2. A Position for Imagery in Skill and Cognition

Images of movements appear to function as a process in organising and planning motor skills, especially those primarily involving movements through space. Through organising and planning, images are able to aid rehearsing and remembering of motor acts.

Images are a functional process within a cognitive model of perceptual motor skill, but they do not appear to be a permanent form of representation. Instead of being thought of as a form of representation, imagery might best be considered as a cognitive process

which utilises other forms of representation. While this research suggests that imagery of motor acts commonly involves spatial information it could be otherwise. Under certain conditions imagery processes could be shown to operate on temporal or force information. Natadze (1960) suggests that contrast illusions between weights can be produced by purely imaginary practice. In a series of experiments Natadze found that imaginary lifting of weights could produce similar biasing effects as has been found with images of linear movements. However, it is not clear from Natadze's report what instructions were given to subjects, which he claims are of paramount importance, since the effect does not occur if the instructions are varied. More specifically, if subjects are instructed to "experience" holding two objects then Natadze reports a contrast illusion. However, if subjects are instructed to "picture" holding two objects no contrast illusion occurs. This distinction between "picturing" and "experiencing" is not made any clearer by Natadze's report.

A further point of Natadze's study is that no data appears anywhere in the report. While he reports the occurrence of an illusion effect he does not report how this effect was measured. It appears that subjects were asked to make discriminatory judgements between objects and that the subsequent percentage of subjects who make a false judgement is taken as evidence for an imagery effect. Of course, no statistical significances are attached to these percentages, although most are above the 50% mark.

While these results are intriguing, in that they raise some interesting questions to be addressed by future, more rigorous, experimentation, it is not possible to form any conclusions on the basis of

such a loosely reported study. Natadze's experiments appear to have been concerned with imagery effects on subsequent perceptual judgements, while the present series of experiments is concerned with imagery effects on short-term or working memory. Given this difference it may be interesting to attempt to replicate Natadze's experiments both in terms of perceptual judgements and memory effects and also to compare the effects of instructions to "picture" as opposed to "experience" a particular event. Distinctions between these two types of instructions should be considered together with subjects' own reports as to the nature of their images.

The relationship between image processes and spatial representations within a cognitive model of skills may reflect the dominance of spatial information in motor control. Indeed, Lashley (1951) developed a space co-ordinate reference system which Russell (1976) and Howarth (1978) suggest forms a basis for movement production. Thus motor acts may be generated on the basis of stored spatial information rather than specific neuromuscular information. If motor acts are controlled primarily by a spatial reference system then other parameters such as force and velocity could be derived at a more autonomous stage of motor control. It seems reasonable to assume that in developing a particular action the first piece of information required is the existing and desired limb positions. In the process of skill acquisition it may well be that spatial parameters become less dominant than force or velocity parameters as a function of the amount of actual practice. This would simply reflect the dynamic nature of skill acquisition and the automatization process. Consequently the first stage in automatizing a skill might be to correctly represent the required spatial reference points for the various movements.

The planning and organising of a skill may primarily reflect the manipulation of spatial information. In preparing to execute a particular motor action subjects may actively rehearse and refine the appropriate spatial information, in which case processing capacity is freed during the movement to deal with other (temporal, etc.) information.

Turvey and his associates, Turvey (1977), Turvey, Shaw and Mace (1978), Turvey and Shaw (1979), Fowler and Turvey (1978), Kugler, Kelso and Turvey (1980), Kelso, Holt, Kugler and Turvey (1980), Turvey, Shaw, Reed and Mace (1981) and Turvey and Carello (1981) have described a rather complex model of action which equates perception and action. Within a Gibsonian framework Turvey argues that action and perception are part of a human system for interaction with the environment and that the three form an ecological system. Action is central to understanding perception, they are complementary descriptions of the same event. The precise motor activities by which a person adjusts their actions (such as walking) to suit the environment are complementary to the optical information that "tunes" that adjustment. Within Turvey's model "co-ordinative structures" are "tuned" to accommodate environmental demands. For example the two wrists and fingers on each hand of a drummer form a co-ordinative structure for drumming. (They are not directly linked but they become "tuned" to function as one unit). These co-ordinative structures operate in a "coalition" between perception action and the environment (see Figure 12.1). This coalition requires that the organisation and tuning of these collectives constrain perception. That is, the way we perceive actions and indeed our entire environment is influenced (if not completely determined by) the way we act. Evidence of this can be found in Johansson (1973) and Cutting and

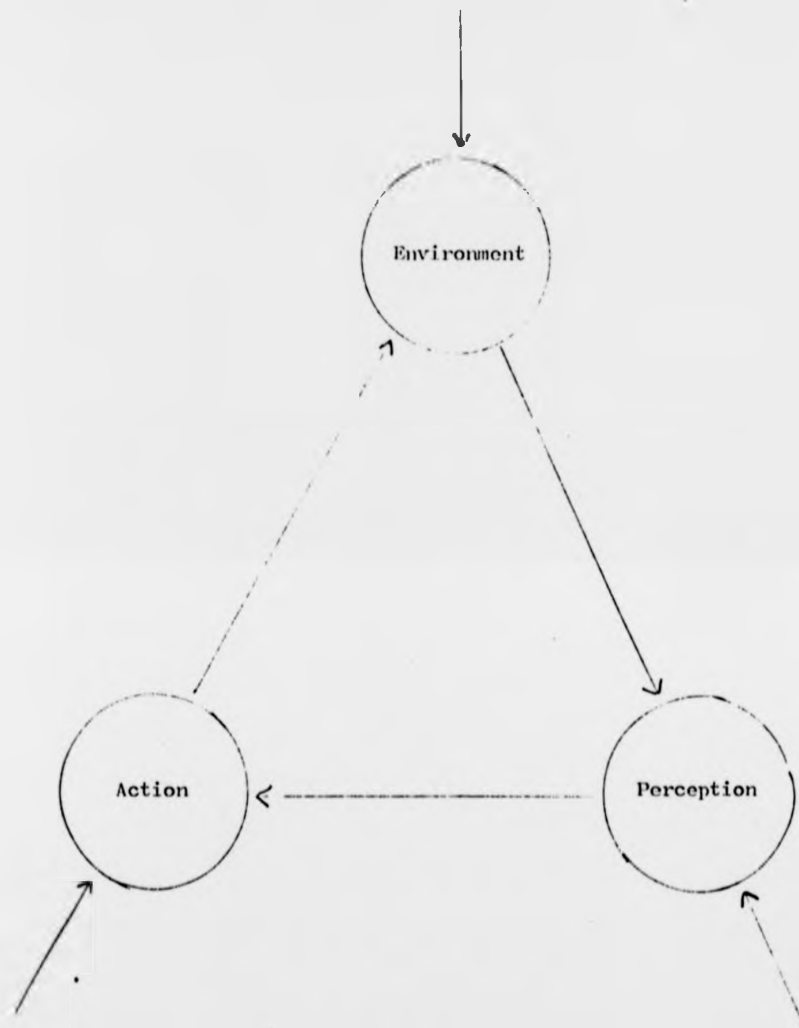


Figure 12.1 Turvey's coalition of action, perception and the environment; together these form one unit of behaviour. (Taken from Turvey, Shaw and Mace 1978, p.30)

Koslowki (1977) perception of dots of light experiments. When dots of light move about in a random fashion it is difficult for subjects to recognise or remember them. However, as soon as the dots of light begin to follow an action pattern such as when the lights are attached to the limbs and joints of actors walking, they are instantly recognised and remembered. But when the same patterns are presented static recognition again fails. There is further evidence, Newtonson (1976) to suggest that skilled actors perceive action quite differently from their unskilled counterparts.

One feature of Turvey's "model" is that "plans" and mental representations of actions and perceptions are regarded as unnecessary since in true Gibsonian fashion the environment presents all the information for action and perception. His one concession to mental processes is the "fine tuning" of co-ordinative structures. On this point he is appropriately silent. I would suggest that there is evidence that this "fine tuning" occurs during periods of covert rehearsal (as well as during actual practice). The experiments on reminiscence effects, such as Frith and Lang (1979), already mentioned support the role of mental processes in formulating appropriate actions. An image process would be an ideal candidate to accommodate such tuning. In the absence of physical stimulation from the environment images can be used to present possible environmental situations for actions to be performed in. These imaged consequences of action might then permit appropriate "co-ordinative structures" (or parts of movement) to be fashioned.

Images would seem to have a role in the organising and "tuning" of actions, which Turvey has yet to explain. While theorists such as

Turvey, who follow a Gibsonian perspective suggest that action and perception are intimately linked, this does not prevent one from postulating the existence of a separate motor production system. There is some evidence to suggest that perception and production are separate systems. For example, in language production young children are capable of perceiving and comprehending utterances long before they can produce utterances of their own. Of course, it could be argued that when young children are capable of perceiving and comprehending utterances they already "know" how to produce them themselves, but simply lack sufficient control of their vocal apparatus to be able to make the appropriate sequence of sounds. Children do indeed appear to spend some time "practising" controlling their vocal apparatus while experimenting with the different sounds that they can produce.

When one looks at the way in which adults acquire a second language we find that the same pattern of perception preceding production occurs. It is evident that people are able to perceive words and often comprehend them in a spoken foreign language before they can correctly produce those words themselves. These observations suggest, quite strongly, that language production follows language perception. Similar arguments apply to action production and perception. In skill acquisition the first hurdle to be overcome by the learner is to identify appropriate units of action. The "chunking" of actions during a process of skill acquisition is a primary factor in improving performance. Recent suggestions by Newell and Rosenbloom (1980) put forward to explain why improvements with practice follow a log-log linear law (Shoddy 1926), Crossman (1956), rely heavily on an assumption that "units" of skill are perceived differently during practice. Further

evidence for the independence of perception and production mechanisms comes from the various training methods used. Demonstration and verbal instruction in training are often most efficient when placed early in a training period, prior to any actual practice. One explanation of mental practice is that it allows images, based on perceptions of actions, to be translated into appropriate units of response. The superiority of visual cues in aiding MP also suggests that some perceptual processing must occur independently of action production. Of course it could be argued that mere recognition is a less demanding task than production in that production requires additional processing, but I would maintain that this is not simply further processing but a different processing system.

The concept of a motor programme (Pew 1966), Keele and Summers (1976), relates to a stored set of rules for producing actions. In Schmidt's (1975, 1976) "schema" theory of motor control, separate production and perception systems were suggested (see Figure 12.2). The "recall schema" is used to produce a particular motor act. Given the desired outcome of the motor act and the initial conditions, the recall schema generates a set of rules which specify a particular motor act. This is very much like the notion of a motor programme but there is little detail as to what information the schema contains. The recognition schema is used to predict the sensory outcomes of a motor act, and can be used to compare the expected sensory outcomes with the subsequent actual outcomes for error. This schema is based on perceptual information from past motor acts and is very similar to Adams (1971) "perceptual trace". The "perceptual trace" is supposed by Adams to be an image (not necessarily a conscious one) of the proprioceptive visual and other sensory consequences of motor acts.

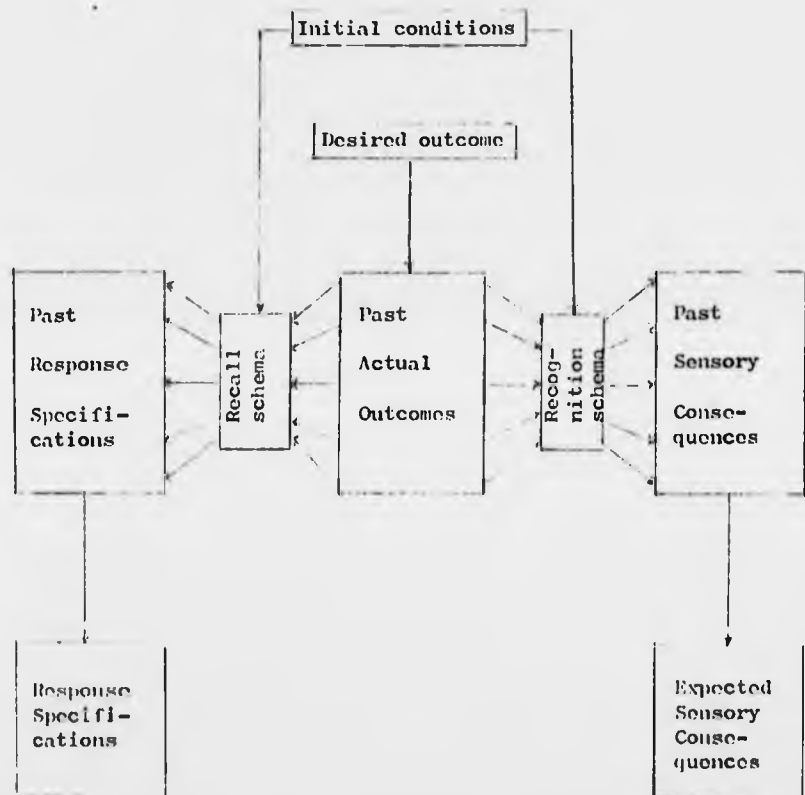


Figure 12.2 Schmidt's recall and recognition schema; taken from Schmidt, 1976, p.48

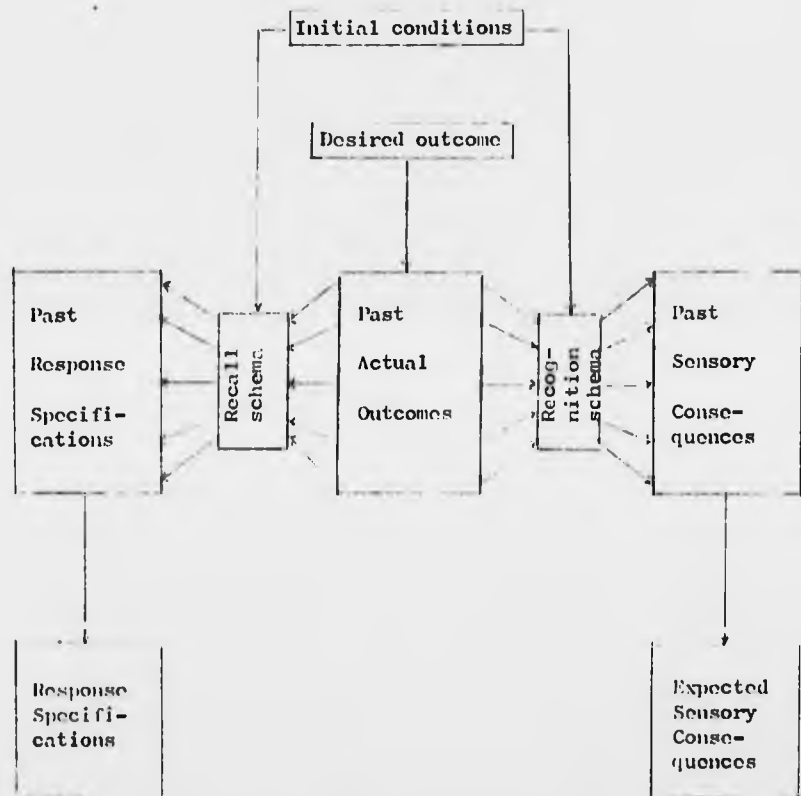


Figure 12.2 Schmidt's recall and recognition schema; taken from Schmidt 1976 p.48

Consequently there is strong support for the existence of separate production and perceptual mechanism in motor control and in other cognitive acts. Two different systems for modelling cognitive mechanisms have been developed, which might reflect the different processes of production and perception, (Anderson 1980).

"Production systems" are one way in which "procedural knowledge" might be represented in artificial intelligence, Newell and Simon (1972), Newell (1973), Rychener and Newell (1978). Briefly, procedural knowledge refers to that information required by a mechanism to enable a particular end-state to be achieved given a particular initial state. This is the exact specification of Schmidt's recall schema. The production system is a set of specified rules which represent the procedures needed to be carried out by the mechanism in order that the desired end state might be achieved. Each production rule has a condition and an action (IF, THEN) statement. Moreover the production system uses these rules as a test for a particular configuration of events which allows the system to be, to some extent, adaptive. Furthermore it permits sequences of behaviour to be "chunked" into particular rule systems. An example of a production system for fastening two steel plates together with a nut and bolt might be as in Table 12.1. Obviously other instructions or rules could be used to arrive at this same solution to this problem, but the modelling of a production system allows these solutions to be specified in a manner which represents the procedural knowledge used to perform the task.

The recognition schema, or perceptual processing mechanisms are not adequately modelled by such production systems. Instead,

Production		Explanation
P.1		
IF	the goal is to fasten two plates and the two plates have aligning holes and there is a bolt which passes through both holes and there is a nut to match the bolt.	This production provides a solution to the main problem of fastening two plates and provides a sub-goal of using a nut and bolt.
THEN	the sub-goal is to fasten the two plates with a nut and bolt.	
P.2		
IF	the sub-goal is to fasten two bolts with a nut and bolt and the bolt passes through both holes and the nut and bolt both rotate	This production puts the bolt through the holes and provides a sub-goal to hold the bolt while the nut is fastened.
THEN	the sub-goal is to hold the bolt firm and rotate the nut in a clockwise direction.	
P.3		
IF	the sub-goal is to hold the bolt firm and the nut does not rotate and the nut is flush to the plate	This production recognises when the nut and bolt are tight and the two plates are fastened.
THEN	the two plates are fastened.	

Table 12.1 A set of productions for fastening two plates together

according to Anderson (1980), "schemas", "scripts", or "frames" have been used to model perceptual processing, such as pattern recognition. Bobrow and Winograd (1977), Minsky (1975) and Schank and Abelson (1979) describe script and frame theories, while Rumelhart and Ortony (1977) describe schema theory. The three do have differences but in general they all present a system for representing "declarative" rather than "procedural" knowledge. Declarative knowledge refers to what we know, knowing that a certain object has certain features (such as a face having two eyes, two ears, a nose and a mouth), knowing that tightening a bolt requires more force to be applied towards the final stages, or that bolts are circular in diameter while nuts are often hexagonal, these are all examples of declarative knowledge. Schemata, then, are a framework which enable inferences to be made about the world and objects in it and how these are influenced by different contexts and different goals (or purposes). In the production system for fastening two plates with a bolt a schema or frame would allow knowledge about fastening plates together, nuts and bolts and screwing actions to be represented by a separate mechanism.

Production systems and schema theories might then be taken as separate theories of perceptual, recognition process and production, procedural processes. It seems that imagery of linear positioning movements involves the recognition mechanism and not the production mechanism. A strict separation between the two mechanisms is, however, untenable, since motor acts involve both recognition and production mechanisms. It seems that Turvey's notion of a "coalition" in which action, perception and an environmental niche interact is the correct unit of analysis for any one piece of behaviour, but that further

explanation of the cognitive mechanisms involved is still desirable.

Gallistel (1980) proposes that the last stage of perceptual processing and the first stage of motor production processes are one and the same. This is one solution to the problem of imitation, since it explains how perceiving a movement enables cognitive processes to formulate the commands that produce a corresponding movement via an oscillatory mechanism. Gallistel suggests that actions are represented by a set of six signals, one signal each to specify the period, amplitude, phase, while the plane of oscillation is specified by three signals relating to up/down, side to side, back and front. An oscillator is a neural circuit or neuron, whose electrical activity varies rhythmically in the absence or independently of any rhythm in the signals impinging on it; a unit of behaviour which is controlled by such a neural circuit or neuron is also called an oscillatory action, e.g. walking. Gallistel uses a wide range of behavioural, neurological and physiological data to arrive at a Fourier model for representing any movement. This is indeed a powerful model of action, but while it is capable of accounting for the similarities of action perception and production it ignores the irregularities. Gallistel's model is one possible concrete example of what an action schema might be. In this model a considerable weight is given to the representation of spatial parameters. Gallistel suggests that the "tuning" process mentioned by Turvey is concerned with relating "neuromuscular space" to "body code space". Body code space is that space around the body while neuromuscular space refers to the direction of movement produced by a given pattern of neuromuscular activity. For example body code space refers to movement in the sagittal plane, the horizontal plane and the transverse plane while neuromuscular space refers to the

movement of, say, the fingers to the palm. Wickens (1939) conditioned subjects to withdraw their finger then rotated the hand through 180° . In the conditioning period subjects moved their finger tips upwards and then with the hand rotated would have moved their finger tips downwards, if the conditioning had affected "neuromuscular-space" representation. Instead, all but one of the subjects made a translation through "body-space" and moved the finger-tips upwards. Consequently they had re-channelled muscular-space into body-space and it is this re-channelling or transformation between neuromuscular-space and body-space which occurs during the "tuning" of movements.

This is exactly the kind of function which imagery of the type discussed in this thesis might accomplish. In imagining a linear positioning movement subjects may be using the spatial information in the environment to imagine where the movement would start, where it might end and in what direction it will be. They are then able to use this spatial information in the form of an image, as a template upon which to map the appropriate "neuromuscular space" commands. In Experiment VIII where subjects were instructed to imagine a lever pressing task it might be the case that in such a task the "body-space" representation has little informational content for the neuromuscular-space representation, therefore maintaining an image of body-space does not affect neuromuscular-space. The spatial nature of motor control is emphasised in the parameters of Gallistel's model, while the experiments I have performed emphasise the spatial processing capabilities of mental imagery for certain motor acts. It seems reasonable to assume that images enable representations of body-space (i.e. the positions of ourselves and our limbs relative to objects in the world), to be aligned with representations of neuromuscular space (i.e. the positions of our

limbs relative to the positions of our musculature). Spatial representations might be topological (Deutsch 1960) or Euclidean. Piaget and Inhelder (1956) have devoted a book to the development of spatial representations and suggest that children start with a topological representational system and then develop an ability to represent Euclidean space and perform mental operations on that representation. Evidence from animal experiments, Tinkelpaugh (1932), Maier (1929) and others suggest that Euclidean space is represented. Recent work by O'Keefe and Nadel (1978) suggests that the hippocampus operates on Euclidean space. The work of Shepherd and his colleagues, on mental transformations is an excellent example of imagery being used to transform Euclidean spatial representations.

To sum up, I would suggest that there is strong evidence to support a notion of actions being dependent upon spatial representation for their control. Such a control system could, as Gallistel has suggested, make use of an oscillator mechanism to achieve motor output. The control parameter for the motor production mechanism can be captured by a Fourier model. This Fourier model specifies the amplitude, periodicity, phase and plane of oscillation. At least three parameters of this model (those governing the plane of oscillation) are directly responsible for spatial information. The process of relating body-space to neuromuscular space is responsible for the tuning of motor acts. Imagery of motor acts may well function as a template for the equating of body-space and neuromuscular-space. The experimental evidence I have found points to this function of mental imagery in motor control.

Mental practice is able to bring about the "tuning" of coordinative structures by using an image process to relate the two

representational states of "body-space" and "neuromuscular space". Assuming that skilled actions are represented as combinations of simple movements oriented with respect to body-space there must be a stage of processing which translates this code into the appropriate neuromuscular activity. One role of practice seems to be to develop the appropriate tunings of the neural circuitry to accommodate distortion between body-space and neuromuscular-space. If images of motor acts can provide a template of the body-space representation in the absence of such information in the environment, then MP may make use of this representation to assimilate the appropriate neuromuscular spatial representation. Thus new acts can be synthesised out of existing motor acts by the tuning of new co-ordinative structures and this tuning can be aided by MP.

12.3. Future Directions

The importance of cognitive processes, such as imagery, in skills is becoming increasingly more obvious. Recent trends within motor-skills and cognitive science suggest that more collaboration is inevitable. Newell and Rosenbloom (1980) have recently re-discovered the log-log linear learning law or power law of practice (see Snoddy, 1926; Fitts, 1964) and applied it to a variety of perceptual-motor, cognitive and industrial skills. Their interpretation of this effect draws heavily upon the role of planning, organisation and chunking in skills.

The part played by imagery in skill acquisition and retention is still barely understood. Further investigations need to be carried out to establish the limitations of imagery to function in skills. The

most immediate course of investigation might be to attempt to replicate Natadze's (1960) findings of imagery in weight lifting. Future research should make use of the procedures established here to investigate the possibility of image processes operating on non-spatial information. It seems that children and probably adults can anticipate weight information and produce motor performances on the basis of their anticipations.

The role of different instructions, relating "experience" and "picture" could be further investigated. Natadze hypothesises that it is the experiential effects of images which influence performance rather than the pictorial information contained in the image. This is interesting since it suggests that there may be circumstances under which subjects could use MP to rehearse other than the spatial aspects of a task.

On a more applied note there are a number of ways in which imagery might function in skill acquisition and retention. It has already been noted that MP provides an effective means of enhancing learning. In view of the present experiments it seems that imagery enhances the memory trace. It would be worthwhile to identify those skills which have a predominant spatial requirement since the effectiveness of MP might be increased if subjects were only instructed to imagine the spatial properties of the task. Other practice methods, such as actual practice or verbal learning, might then be applied to the appropriate non-spatial task components. It might be useful to include imagery instruction, emphasising the spatial properties of the task, at regular intervals to maintain an acceptable performance level. There are situations under which it is impossible to practice the complete

skill, except in a test performance (such as emergency measures). In these situations some improvements might be gained from imagery in organising and planning the required performance.

The varieties of tasks on which subjects have been tested for imagery effects needs extending, not in terms of the different types of motor tasks but across all kinds of skilled actions ranging from, say, weight lifting to mental arithmetic. The present investigations have merely highlighted the potential for investigating covert rehearsal strategies. To this end any claims about the function of MP and imagery of motor acts are as yet restricted to linear positioning tests and lever pressing tasks. However, these two tasks do contain two basic elements of all motor acts, space and force. Perhaps it is the temporal or rhythmic properties of motor acts which should next be systematically investigated for possible MP strategies. A task such as learning a particular rhythm of motor output, say in a tapping task in which the spatial components are varied independently of the temporal aspects of the task, might provide a suitable means for investigating the relative importance and efficiency of spatial and temporal rehearsal strategies.

A further dimension along which future investigations might proceed is the amount of practice prior to MP. In the review of MP in Chapter Two it was suggested that MP was most effective following a relatively small amount of actual practice. It may well be the case that the type of MP changes as a function of prior training. Pow (1966) suggested that skill changes as a function of the amount of practice from visual to kinesthetic dependence. However, Long (1976) notes that in skilled keyboard operations visual feedback plays an important

role in maintaining a high standard of performance even in well practised tasks. It would be interesting, therefore, to investigate if any changes occur in the type of MP subjects engage in as a function of the amount of prior actual practice. One might predict, on the basis of Pew's (1966) hypothesis that while visual/spatial imagery might be used in early stages of skill, force or some type of kinesthetic imagery might be more common in the later stages of skill.

To date, MP has only been considered during training or skill acquisition procedures. It offers great potential as a method of skill retention, or retraining. The effects of MP on the retention of skills over long periods, or on the refreshing of old skills has not been considered. A theoretical distinction was made earlier between images generated from long-term-memory and those which facilitate the retention of previously presented stimuli, such as "visualisations" of the Phillips and Christie (1977, a,b) sort. It is not clear if images generated from long-term memory should be subjected to the same kind of interference effects as has been found for the present series of experiments.

In a similar theme one might propose, following from Fuchs' (1962) progression/regression hypothesis of skill, that the same sequence of rehearsal strategies which had been effective during skill acquisition would be equally effective during skill retention. It then becomes of interest to know if the particular form of MP which was most effective prior to a skilled performance is capable of preventing skill loss in all aspects of the skill or in just a specific component of the skill. The use of MP as a method of providing refresher training offers great potential in terms of time and cost, if it can be determined what particular forms of MP are best suited to retaining which parts of the skill.

Continuing in the same vein, of MP as an aid to retraining schedules, the spacing of MP during the retention period may well affect the outcome of MP on skill retention. If Fuchs' hypothesis is found to hold for all or certain skills, then the placing of MP during the refresher course will also determine the type of MP used. More generally, in cases where the loss function for a particular skill is unknown it might be possible to mentally rehearse, by imagining performing the complete task, at regular intervals. In such circumstances MP may prevent or at least slow-down any skill-loss.

One feature of this research has been the transfer (albeit negative) effects, from one linear positioning movement to another, by means of imagery instructions. The possibility that imagery of actions might facilitate positive or negative transfer between tasks has not been considered other than in Experiment I. It might be the case that imagining performing a novel task may interact with the current repertoire of skills and experiences a subject possesses. It is not clear whether imagining a task, on which a subject has no previous experience, will have the same dependence on past experience as actual task performance has. For example assuming that certain parts of the skill of driving a motor-bike with gears on the left which follow a "one down - three up" format (as is the case with Japanese motor-bikes) will have a negative transfer effect on driving a British motor-bike which has gears on the right and follows a "one up - three down" format. Now there is reason to assume that the negative transfer effects observed in actual practice would be present in imaginary practice. The mapping of positive and negative transfer effects from actual practice to imaginary practice would provide further investigation of the equivalence of images and actions, together with a prescription

for the most suitable practice methods.

In clinical settings patients are sometimes faced with having to learn to use damaged or unused limbs or even a prosthetic device. It is often reported that patients "disown" the limb in question and refuse to even look at it. If patients were encouraged to imagine moving the limb this may speed up the first stages of skill acquisition by including that limb in the planning and organising motor acts. In addition it may help them overcome any phobias which they might have developed about the use of the limb. Of course the reverse phenomenon, of the "phantom limb" in which amputated limbs are imagined to exist, might also be related to the same process of imagery, although not under conscious control, in that the imagery is not voluntary.

Finally a theoretical note about measures of error in positioning experiments. There is some debate at present about what is the appropriate dependent variable for positive experiments, AE, CE, VE. It is suggested that CE and VE are the most useful since these separately reflect perceptual and memory parameters of movement, Laubs (1973).

If one takes a particular VE score one cannot fully appreciate what the subject's performance was really like. A high VE could be arrived at in many ways, such as a compounding of error in one direction over each trial. If one regresses a subject's raw error score against the recall trial then the resulting regression statistics fully describe a subject's performance over trials. The intercept (α) value can be taken as a measure of any bias in much the same way that CE is used.

Whilst the slope co-efficient reflects how the performance progressed over trials. The standard error of the residuals can then be taken as a measure of the variance on each trial from this overall trend (reflected by the β value).

To conclude, this thesis presents a thorough investigation of imagery in a linear positioning task and describes a potentially powerful means of investigating such processes. While the main body of the thesis is largely empirical, the theoretical considerations of MP and motor skills are developed in the vein of cognitive psychology. The underlying process involved in MP appears to be imagery which in the case of a linear positioning task appears to be a spatial process. The implications of this for theories of motor skills is such that a procedure for "tuning" or assimilating "body-space" with "neuromuscular-space" can be suggested which might make use of images of the spatial parameters of the movement with respect to other environmental objects. This image provides a template from which the neuromuscular-space parameters can be derived. In motor acts with low or little movement involved then the role of body-space representations and the potential of spatial imagery is drastically reduced. The importance of spatial representations for the control and organisation of movements is still arguable but this thesis suggests that cognitive processes such as imagery are confined to higher aspects of motor control. The possibility that images of motor acts have a functional role in skill has been established in the case of linear-positioning tasks. Future investigations using the techniques established here may distinguish between images from long-term memory and images in "working memory" retained from previous stimuli. Further investigations may lead to the identification

of non-spatial forms of imagery for other motor acts, but in every-day life it seems that the most important feature of motor acts is the frame of space in which they are to be executed and what values should be ascribed to the parameters of angle of orientation, amplitude, and direction of movement.

BIBLIOGRAPHY

- ADAMS, J.A. (1971) A Closed loop theory of motor learning. Journal of Motor Behaviour, 3: 111-150
- ADAMS, J.A. and DIJKSTRA, S. (1966) Short term memory for motor responses. Journal of Experimental Psychology, 71: 314-318
- ADAMS, J.A., GOPHER, D. and LINTERN, G. (1977) Effects of visual and proprioceptive feedback on motor learning. Journal of Motor Behaviour, 9: 11-22
- ALLPORT, D.A. (1980) Attention and Performance. In G. Claxton (ed.) Cognitive Psychology: New Directions. London: Routledge and Kegan Paul.
- AMMONS, R.B. (1958) Le mouvement. In G.H. Steward and R.W. Seward (Eds.) Current Psychological Issues. New York: Holt
- ANDERSON, J.R. (1972) FRAN: A simulation of free recall. In G.H. Bower (Ed.) The psychology of learning and motivation. Vol.5 New York: Academic Press
- ANDERSON, J.R. (1978) Arguments concerning representations for mental imagery. Psychological Review, 85: 249-277
- ANDERSON, J.R. (1979) Further arguments concerning representations for mental imagery: a response to Hayes-Roth and Pylyshyn. Psychological Review, 86: 395-406
- ANDERSON, J.R. (1980) Cognitive Psychology and its Implications. San Francisco: W.H. Freeman
- ANDERSON, J.R. and BOWER, G.H. (1973) Human Associative Memory. New York. Winston and Sons
- ANGELL, J.R. (1910) Methods for determination of mental imagery. Psychological Monographs, 13: 61-107
- ANNETT, J. (1959) Learning a Pressure under conditions of immediate and delayed knowledge of results. Quarterly Journal of Experimental Psychology, XI, 1: 3-15
- ANNETT, J. (1969) Feedback and Human Behaviour. Harmondsworth, Penguin
- ANTIKHUIS, J.S., ANTIKHUIS, J.S. and SINGER, J.L. (1964) Eye-movements accompanying daydreaming, visual imagery, and thought suppression. Journal of Abnormal and Social Psychology, 69: 244-252
- BADDELEY, A.D. (1976) The psychology of Human Memory. Harper and Row: New York
- BADDELEY, A.D. (1981) The concept of working memory: A view of its current state and probable future developments. Cognition, 10: 17-23

- BADDELEY, A.D. and HITCH, G.J. (1974) Working memory. In G.A. Bower (ed.) The Psychology of Learning and Motivation, Vol.8. New York, Academic Press
- BADDELEY, A.D. and Lieberman, K. (1980) Spatial working memory. In R. Nickerson (ed.) Attention and Performance VIII. Hillsdale, N.J., Erlbaum
- BAIN, A. (1855) The senses and the intellect. London: Parker
- BANKS, W.P. and FLORA, J. (1977) Semantic and perceptual processes in symbolic comparisons. Journal of Experimental Psychology: Human Perception and Performance, 3: 278-290
- BAYLOR, G.W. (1972) A Treatise on the Mind's Eye: An Empirical investigation of Visual Mental Imagery. (Ph.D.Thesis, Carnegie-Mellon University Ann Arbor, Mich. University Microfilms No. 72-12, 699
- BERNSTEIN, N. (1966) The Co-ordination and Regulation of Movements. New York: Pergamon Press
- BETTS, G.H. (1909) The Distribution and Functions of Mental Imagery. Teachers' College, Columbia University
- BILODEAU, E.A. and BILODEAU, I. McD. (Eds.) (1969) Principles of Skill Acquisition. New York, Academic Press
- BOBROW, D.G. and WINOGRAD, T. (1977) An overview of KRL, a knowledge representation language. Cognitive Science, 1: 3-46
- BOWER, G.H. (1970) Organizational factors in memory. Cognitive Psychology, 1: 18-46
- BOWER, G.H. (1972) Mental imagery and associative learning. In L. Gregg (Ed.) Cognition in Learning and Memory. New York: Wiley
- BROOKS, L.R. (1967) The suppression of visualization in reading. Quarterly Journal of Experimental Psychology, 19: 289-299
- BROOKS, L.R. (1968) Spatial and Verbal components of the act of recall. Canadian Journal of Psychology, 22: 349-368
- BRUGELSKI, B.R. (1971) The definition of the image. In S. Segal (ed.), Imagery: Current Cognitive Approaches. New York: Academic Press
- BYRNE, R. (1981) Mental Cookery: An illustration of fact retrieval from plans. Quarterly Journal of Experimental Psychology, 33A: 31-37
- CARMICHAEL, L.L., HOGAN, H.P. and WALTERS, A.A. (1932) An experimental study of the effect of language on the reproduction of visually perceived form. Journal of Experimental Psychology, 15: 73-86
- CHATFIELD, C. (1975) Statistics for technology, London: Chapman Hall
- CHEW, R.A. (1976) Verbal, visual and kinaesthetic error feedback in the learning of a simple motor task. Research Quarterly, 47: 254-259

- CLARK, L.V. (1960) Effect of Mental Practice on the development of a certain motor skill. Research Quarterly, 31: 560-569
- CLAXTON, G. (Ed.) (1980) Cognitive Psychology; New directions. London, Routledge and Kegan Paul
- COOPER, L.A. (1975) Mental rotation of random two-dimensional shapes. Cognitive Psychology, 7: 20-43
- COOPER, L.A. (1976) Demonstration of a mental analog of an external rotation. Perception and Psychophysics, 19: 296-302
- COOPER, L.A. and PODGORNÝ, P. (1976) Mental transformations and visual comparison processes: Effects of complexity and similarity. Journal of Experimental Psychology: Human perception and Performance, 2: 505-514
- COOPER, L.A. and SHEPARD, R.N. (1973a) Chronometric Studies of the rotation of mental images. In W.G. Chase (Ed.) Visual information processing. New York: Academic Press
- COOPER, L.A. and SHEPARD, R.N. (1973b) The time to prepare for a rotated stimulus. Memory and Cognition, 1: 246-250
- COOPER, L.A. and SHEPARD, R.N. (1975) Mental transformations in the identification of left and right hands. Journal of Experimental Psychology: Human Perception and Performance, 10: 48-56
- COOPER, L.A. and SHEPARD, R.N. (1978) Transformations on Representations of Objects in Space. In E.C. Carterette and M.P. Friedman (Eds.) Handbook of Perception, Vol. VIII: Perceptual Coding. New York: Academic Press
- CORBIN, C.B. (1967a) Effects of mental practice on skill development after controlled practice. Research Quarterly, 38: 534-538
- CORBIN, C.B. (1967b) The effect of covert rehearsal on the development of a complex motor skill. The Journal of General Psychology, 76: 143-150
- CORBIN, C.B. (1972) Mental Practice. In W.P. Morgan (Ed.) Ergonomic Aids and Muscular Performance. New York: Academic Press
- CRAFT, J.L. and HENDRICH, J.V. (1971) Short term retention of simple motor responses. Journal of Experimental Psychology, 87: 297-302
- CRAIK, F.I.M. and LOCKHART, R.S. (1972) Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11: 671-684
- CRAIK, F.I.M. and WATKINS, M.J. (1973) The role of rehearsal in short-term memory. Journal of Verbal Learning and Verbal Behavior, 12: 599-607
- CRASKE, B. (1980) Kinaesthetic Fusion and registered arm length. Proceedings of the Experimental Psychology Society: Meeting at Exeter

- CROSSMAN, E.R.F.W. (1956) The measurement of perceptual load in manual operations. Unpublished Ph.D. Thesis, University of Birmingham
- CUTTING, J.E. and KOSLOWSKI, L.T. (1977) Recognizing friends by their walk: Gait perception without familiarity cues. Bulletin of the Psychonomic Society, 9: 353-356
- DEUTSCH, J.A. (1960) The structural basis of behavior. Chicago: Univ. of Chicago Press
- DURNDELL, A.J. and WETHERICK, N.E. (1975) Reported imagery and social desirability. Perceptual and motor skills, 41: 987-992
- DURNDELL, A.J. and WETHERICK, N.E. (1976) The relation of reported imagery to cognitive performance. British Journal of Psychology, 67: 501-506
- FERNALD, M.R. (1912) The diagnosis of mental imagery. Psychology Monographs No. 58
- FINKE, R.A. (1979) The functional equivalence of mental images and errors of movement. Cognitive Psychology, 11: 235-264
- FINKE, R.A. (1980) Levels of equivalence in imagery and perception. Psychology Review, 87: 113-132
- FINKE, R.A. and SCHMIDT, M.J. (1977) Orientation - specific color aftereffects following imagination. Journal of Experimental Psychology: Human perception and performance, 3: 599-606
- FINKE, R.A. and SCHMIDT, M.J. (1978) The quantitative measures of pattern representation in images using orientation-specific color after effects. Perception and Psychophysics, 23: 515-520
- FISHBURN, G. (1980) The Assimilation of movement items in memory. Paper presented to B.S.S.P. Conference, Sheffield
- FITTS, P.M. (1964) Perceptual motor skill learning. In A.W. Melton (ed.). Categories of human learning. New York: Academic Press
- FLEISHMAN, E.A. (1967) Performance assessment based on an empirically derived task taxonomy. Human Factors, 9: 1017-1032
- FLEISHMAN, E.A. (1978) Relating Individual differences to the dimensions of human tasks. Ergonomics, 21, 2: 1007-1019
- FOWLER, C.A. and TURVEY, M.T. (1978) Skill Acquisition: An event approach with special reference to searching for the optimum of a function of several variables. In: G.E. Stelmach (ed.) Information Processing in motor control and learning. New York: Academic Press
- FRITH, C.D. and LANG, R.J. (1979) Learning and reminiscence as a function of target predictability in a two dimensional tracking task. Quarterly Journal of Experimental Psychology, 31: 103-110

- FUCHS, A.H. (1962) The progression-regression hypotheses in perceptual-motor skill learning. Journal of Experimental Psychology, 63: 177-182
- GALLISTEL, C.R. (1980) The organization of Action: A new Synthesis. Hillsdale, New Jersey: Lawrence Erlbaum Associates
- GALTON, F. (1883) Inquiries into Human Faculty. London: Macmillan
- GENTILE, A.M. (1972) A working model of skill acquisition with applications to teaching. Quest, 17: 3-23
- GILHOOLY, K.J. and LOGIE, R.H. (1980a) Age-of-acquisition, imagery, concreteness, familiarity, and ambiguity measures for 1,944 words. Behavior Research Methods and Instrumentation, 12: 395-427
- GILHOOLY, K.J. and LOGIE, R.H. (1980b) Meaning-dependent ratings of imagery, age of acquisition, familiarity, and concreteness for 387 ambiguous words. Behavior Research Methods and Instrumentation, 12: 428-450
- GLUCKSBERG, S. and DANKS, J.H. (1975) Experimental Psycholinguistics: An introduction. Hillsdale New Jersey: Lawrence Erlbaum Associates
- GORDON, R. (1949) An investigation into some of the factors that favour the formation of stereotyped images. British Journal of Psychology, 39: 156-167
- HALL, G.R. (in Press) Imagery for movement. Journal of Human Movement Studies
- HARVEY, N. and GREER, K. (1980) Action: the mechanisms of motor control. In G. Claxton, (ed.) Cognitive psychology: New directions. London: Routledge and Kegan Paul
- HEBB, D.O. (1949) The organisation of behavior. New York: Wiley
- HEBB, D.O. (1968) Concerning Imagery. Psychological Review, 75: 466-477
- HERMLIN, B. and O'CONNOR, N. (1975) Location and distance estimates by blind and sighted children. Quarterly Journal of Experimental Psychology, 27: 295-301
- HINTON, G. (1979) Some demonstrations of the effects of structural descriptions in mental imagery. Cognitive Science, 3: 231-250
- HINTON, G. (1981) A distributed computational model of motor coordination. Proceedings of the Experimental Psychology Society, meeting at Oxford, 2-3 July
- HITCH, G.J. (1980) Developing the concept of working memory. In G. Claxton (Ed.) Cognitive Psychology: New directions. London: Routledge and Kegan Paul
- HOCKEY, R. (1979) Stress and the cognitive components of skilled performance. In V. Hamilton and D.M. Warburton (eds.) Human Stress and cognition an information processing approach. London: Wiley

- HOLDING, D.H. (1965) Principles of training. New York: Pergamon
- HOWARTH, C.I. (1978) Strategies in the control of movement. In G. Underwood (ed.) Strategies in Information Processing. London: Academic Press
- HUSBAND, R.W. (1931) Comparative behavior on different types of mazes. Journal of General Psychology, 5: 234-244
- JACOBSON, E. (1932) Electrophysiology of mental activities. American Journal of Psychology, 44: 677-694
- JAMES, W. (1890) Principles of psychology, Vols. I and II. New York: Holt, Rinehart and Winston
- JOHANSSON, G. (1973) Visual perception of biological motion and a model for its analysis. Perception and psychophysics, 14: 201-211
- JOHNSON, D.M. (1939) Confidence and speed in the two-category judgement. Archives of Psychology, N.Y. No. 241
- JOHNSON, P. (1980) The relative weightings of visual and non visual coding in a simple motor learning task. Journal of Motor Behavior, 12: 281-291
- KAHNEMAN, D. (1973) Attention and Effort; Englewood Cliffs, N.J.: Prentice-Hall
- KANT, I. (1929) Critique of Pure Reason. (trans. N.Kemp-Smith). London: Macmillan
- KEELE, S.W. and SUMMERS, J.J. (1976) The structure of motor programs. In G.E. Stelmach (ed.) Motor control: Issues and trends. New York: Academic Press
- KELSO, J.A.S. and FREKANY, C.A. (1978) Coding processes in pre-selected and constrained movements: Effects of vision. Acta Psychologica, 42: 145-161
- KELSO, J.A.S., HOLT, K.G., KUGLER, P.N. and TURVEY, M.T. (1980). On the concept of coordinative structures as dissipative structures: II. Empirical lines of convergency. In G.E. Stelmach and J. Requin (eds.) Tutorials in motor behavior. Amsterdam: North-Holland Publishing Co.
- KELSO, J.A.S. and STELMACH, G.E. (1976) Central and peripheral mechanisms in motor control. In G.E. Stelmach (ed.) Motor Control: Issues and trends. New York: Academic Press
- KELSO, J.A.S. and WALLACE, S.A. (1978) Conscious mechanisms in movement. In G.E. Stelmach (ed.) Information Processing in Motor Control and Learning. New York: Academic Press
- KERST, S.M. and HOWARD, J.H.J. (1977) Mental comparisons for ordered information in abstract and concrete dimensions. Memory and Cognition, 5: 227-234

- KIOL, R.M. and ROENKER, D.L. (1980) Bilateral transfer as a function of mental imagery. Journal of Motor Behavior, 12: 197-205
- KINTSCH, W. (1974) The representation of meaning in memory. Hillsdale, N.J.: Lawrence Erlbaum Associates
- KNAPP, B. (1967) Skill in sport: The attainment of proficiency. London: Routledge and Kegan Paul
- KOLERS, P.A. and SMYTHE, W.E. (1979) Images, symbols and skills. Canadian Journal of Psychology, 33: 3, 158-184
- KOSSLYN, S.M. (1973) Scanning visual images: some structural implications. Perception and Psychophysics, 14: 90-94
- KOSSLYN, S.M. (1975) Information representation in visual images. Cognitive Psychology, 7: 341-370
- KOSSLYN, S.M. (1976) Can imagery be distinguished from other forms of internal representation? Evidence from studies of information retrieval time. Memory and Cognition, 4: 291-297
- KOSSLYN, S.M. (1978) Measuring the visual angle of the mind's eye. Cognitive Psychology, 10: 356-389
- KOSSLYN, S.M. (1980) Image and Mind. Harvard University Press
- KOSSLYN, S.M., BALL, T.M. and REISER, B.J. (1978) Visual images preserve metric spatial information: Evidence from studies of image scanning. Journal of Experimental Psychology: Human Perception and Performance, 4: 47-60
- KOSSLYN, S.M., PINKER, S., SMITH, G.E. and SCHWARTZ, S.P. (1979) On the demystification of mental imagery. The Behavioral and Brain Sciences, 2: 535-581
- KUGLER, P.N., KELSO, J.A.S. and TURVEY, M.T. (1980) On the concept of coordinative structures as dissipative structures: I. Theoretical line. In G.E. Stelmach and J. Requin (eds.), Tutorials in motor behavior. Amsterdam: North-Holland Publishing Co.
- LAABS, G.J. (1973) Retention characteristics of different reproduction cues in motor short-term memory. Journal of Experimental Psychology, 100: 168-177
- LAABS, G.J. and SIMMONS, R.W. (1981) Motor Memory. In D.H. Holding (ed.) Human Skills. New York: Wiley and Son
- LASHLEY, K.S. (1951) The problem of serial order behavior. In L.A. Joffress (ed.) Cerebral Mechanisms of Behavior. New York: Wiley
- LIBERMAN, A.M., COOPER, F.S., SHANKWEILER, D.P. and STUDEERT-KENEDY, M. (1957) Perception of the speech code. Psychological Review, 74: 431-461

- LONG, J.B. (1976) Effects of delayed irregular feedback on unskilled and skilled keying performance. Ergonomics, 19: 183-202
- MACCORQUODALE, K. and MEEHL, P.E. (1948) On a distinction between hypothetical constructs and intervening variables. Psychological Review, 55: 97-119
- MCBRIDE, E.R. and ROTHSTEIN, A.L. (1979) Mental and physical practice and the learning of open and closed skills. Perceptual and motor Skills, 49: 359-365
- MAIER, N.R.F. (1929) Reasoning in white rats. Comparative Psychology Monographs, 6: No.29
- MARR, D. (1975) Analysing natural images: A computational theory of texture vision. M.I.T. AI Memo, 334
- MILLAR, S. (1978) Aspects of memory for information from touch and movement. In: G. Gordon (ed.) Active touch. Oxford: Pergamon
- MILLER, R.B. (1962) "Analysis and specification of behavior in training". In R. Glaser (ed.) Training research and education. Pittsburgh U.S.A. University of Pittsburgh Press
- MINAS, S. (1978) Mental practice of a complex perceptual - motor skill. Journal of human movement studies, 4: 102-107
- MINSKY, M. (1975) A framework for representing knowledge. In P.H. Winston (ed.) The Psychology of Computer Vision. New York: McGraw-Hill
- MORRIS, P.E. and REID, L.R. (1970) Repeated use of mnemonic imagery. Psychonomic Science, 20: 337-8
- MORRIS, P.E. and STEVENS, R.S. (1974) Linking images and free recall. Journal of Verbal Learning and Verbal Behavior, 13: 310-315
- MORRISETT, L.N. Jr. (1956) The role of implicit practice in learning. Unpublished doctoral dissertation, Yale University
- MORTON, J. (1969) Interaction of information in word recognition. Psychological Review, 76: 165-178
- MOYER, R.S. (1973) Comparing objects in memory: evidence suggesting an internal psychophysics. Perception and Psychophysics, 13: 180-184
- NATADZE, R. (1960) Emergence of a set on the basis of imaginal situations. British Journal of Psychology, 51: 237-245
- NEISSER, U. (1967) Cognitive Psychology. New York: Appleton-Century-Crofts
- NEISSER, U. (1970) Visual imagery as process and experience. In J.S. Antrobus (ed.) Cognition and Affect. Boston: Little, Brown
- NEISSER, U. (1972) Changing conceptions of imagery. In P.W. Sheehan (ed.) The Function and Nature of Imagery. New York: Academic Press

- NEISSER, U. (1976) Cognition and Reality San Francisco: W.H. Freeman and Co.
- NEISSER, U. (1978) Images, Anticipation and Schemata. In C.W. Savage (ed.) Minnesota studies in the philosophy of science, 9. Perception and Cognition. Issues in the foundations of psychology. Minnesota: Minnesota Univ. Press
- NEWELL, A. (1973) Production Systems: Models of control structures. In W.G. Chase (ed.) Visual Information Processing. New York: Academic Press
- NEWELL, A. and ROSENBLOOM, P.S. (1980) Mechanisms of skill acquisition and the law of practice. In J.R. Anderson (ed.) Cognitive skills and their acquisition. Hillsdale, N.J.: Erlbaum
- NEWELL, A. and SIMON, H.A. (1972) Human Problem Solving. Englewood Cliffs, N.J.: Prentice-Hall
- NEWTSON, D. (1976) Foundations of attribution: The perception of ongoing behavior. In J. Harvey, N. Ickes and R. Kidd (eds.) New directions in attribution research. Pontomac, Md: Lawrence Erlbaum Associates
- NORMAN, D.A. (1976) Perception, Memory and Mental Processes. In L.G. Nilsson (ed.) Perspectives on memory research New York: Lawrence Erlbaum Associates
- O'KEEFE, J. and NADEL, L. (1978) The hippocampus as a cognitive map Clarendon Press: London
- ORNE, M.T. (1962) On the social Psychology of the psychological experiment. American Psychologist, 17: 776-783
- ORNSTEIN, R.E. (1977) The Psychology of Consciousness Harcourt Brace Jovanovich: New York
- PAIVIO, A. (1971) Imagery and verbal processes. New York: Holt
- PAIVIO, A. (1975a) Coding distinctions and repetition effects in memory. In G.H. Bower (ed.) The psychology of Learning and motivation (Vol.9) New York: Academic Press
- PAIVIO, A. (1975b) Neomentatism. Canadian Journal of Psychology, 29: 263-291
- PAIVIO, A. (1975c) Perceptual comparisons through the mind's eye. Memory and Cognition, 3: 635-647
- PAIVIO, A. (1977) Images, propositions and knowledge. In J.M. Nicholas (ed.) Images, Perception and Knowledge. The Western Ontario series in the Philosophy of Science. Dordrecht: Reidel
- PAIVIO, A. (1978) The Relationship between Verbal and Perceptual Codes. In E.G. Carterette and M.P. Friedman (eds.) Handbook of Perception Vol.VIII: Perceptual Coding London: Academic Press
- PAIVIO, A. and BEGG, I. (1974) Pictures and Words in visual search. Memory and Cognition, 2: 515-521

- PAIVIO, A., YUILLE, J.D. and MADDIGAN, S.A. (1968) Concreteness, imagery and meaningfulness values for 925 nouns. Journal of Experimental Psychology: Monograph Supplement, 76: 1-25
- PATRICK, J.P. (1971) The effect of interpolated motor activities in short-term motor memory. Journal of Motor Behavior, 3: 39-48
- PENFIELD, W. and ROBERTS, L. (1959) Speech and Brain Mechanisms. Princeton: Princeton Univ. Press
- PEPPER, R.L. and HERMAN, L.M. (1970) Decay and interference effects in short-term retention of a discrete motor act. Journal of Experimental Psychology 83, Monograph Supplement No. 2
- PERKY, C.W. (1910) An Experimental Study of Imagination. American Journal of Psychology, 21: 422-452
- PERRY, H.M. (1939) The relative efficiency of actual and imaginary practice in five selected tasks. Archives of Psychology, 34: 5-75
- PEW, R.W. (1966) Acquisition of hierarchical control over the temporal organisation of a skill. Journal of Experimental Psychology, 71: 764-771
- PHILLIPS, W.A. and CHRISTIE, D.F.M. (1977a) Components of Visual Memory. Quarterly Journal of Experimental Psychology, 29: 117-133
- PHILLIPS, W.A. and CHRISTIE, D.F.M. (1977b) Interference with visualization. Quarterly Journal of Experimental Psychology, 29: 637-650
- PIAGET, J. and INHILDER, B. (1956) The Child's Conception of Space. London: Routledge and Kegan Paul
- PIAGET, J. and INHILDER, B. (1974) The Child's Construction of Quantities: Conservation and atomism. London: Routledge and Kegan Paul
- POSNER, M.I. (1973) Coordination of internal codes. In W.G. Chase (ed.) Visual information Processing. New York: Academic Press
- POSNER, M.I. (1978) Chronometric explanations of Mind. Hillsdale, N.J.: Lawrence Erlbaum Associates
- POSNER, M.I., BOIES, S.J., EICHELMAN, W.H. and TAYLOR, R.L. (1969) Retention of visual and name codes of single letters. Journal of Experimental Psychology Monograph, 79: 1 pt 2
- POSNER, M.I. and MITCHELL, R.F. (1967) Chronometric analysis of classification. Psychological Review, 74: 392-409
- POWELL, G.E. (1973) Negative and positive mental practice in motor skill acquisition. Perceptual Motor Skills, 37: 312
- PYLYSHYN, Z.W. (1973) What the mind's eye tells the mind's brain: a critique of mental imagery. Psychological Bulletin, 80: 1-24
- PYLYSHYN, Z.W. (1978) Imagery and Artificial Intelligence. In: W. Savage (ed.) Perception and Cognition: Issues in the Foundations of Psychology. Minneapolis: Univ. of Minnesota Press

- PYLYSHYN, Z.W. (1980) Computation and cognition: issues in the foundation of cognitive science. The Behavioral and Brain Sciences, 3: 111-169
- RAWLINGS, E.I., RAWLINGS, I.L., CHEN, S.S. and YILK, M.D. (1972) The Facilitating effects of mental rehearsal in the acquisition of rotary pursuit tracking. Psychonomic Science, 26: 71-73
- RAWLINGS, E.I. and RAWLINGS, I.L. (1974) Rotary pursuit tracking following mental rehearsal as a function of voluntary control of visual imagery. Perceptual and motor skills, 38: 302
- RICHARDSON, A. (1967a) Mental Practice: A review and discussion, Part I Research Quarterly, 38: 95-107
- RICHARDSON, A. (1967b) Mental Practice: A review and discussion, Part II. Research Quarterly, 38: 263-272
- RICHARDSON, A. (1969) Mental Imagery. New York: Springer
- RICHARDSON, A. (1972) Voluntary Control of the memory image. In P. W. Sheehan (ed.) The nature and function of imagery. New York: Academic Press
- RICHARDSON, A. and START, K.B. (1964) Imagery and Mental Practice. Proceedings XVII International Congress on Psychology, Washington 1963. North Holland Publishing Co. Amsterdam
- RICHARDSON, J.T.E. (1980) Mental Imagery and Human Memory. London: Macmillan
- ROSH, E. (1975) Cognitive representation of semantic categories. Journal of Experimental Psychology: General, 104, 192-233
- ROSENFELD, J.B. (1967) Information processing: encoding and decoding. Unpublished doctoral dissertation, Indiana Univ.
- ROSENTHAL, R. (1967) Covert communication in the psychological experiment. Psychological Bulletin, 67: 356-367
- RUMELHART, D.E. and ORTONY, A. (1977) The representation of knowledge in memory. In R.C. Anderson, R.J. Spiro, and W.E. Montague (eds.) Schooling and the acquisition of knowledge. Hillsdale, N.J.: Lawrence Erlbaum Associates
- RUSSELL, D.G. (1976) Spatial location cues and movement production. In G.E. Stelmach (ed.) Motor Control: Issues and trends. New York: Academic Press
- RYCHENER, M.D. and NEWELL, A. (1978) An instructible production system: Basic design issues. In D.A. Waterson and F. Hayes-Roth (eds.) Pattern-directed inference systems. New York: Academic Press
- SACKETT, R.S. (1934) The influence of symbolic rehearsal upon the retention of a maze habit. Journal of General Psychology, 10: 376-398
- SACKETT, R.S. (1935) The relationship between amount of symbolic rehearsal and retention of a maze habit. Journal of General Psychology, 13: 113-128

- SAGE, G.H. (1977) Introduction to Motor Behavior: A Neuropsychological approach, 2nd edition. London: Addison Wesley
- SCHANK, R.C. and ABELSON, R. (1979) Scripts, Plans, Goals and Understanding Hillsdale, N.J.: Lawrence Erlbaum Associates
- SCHMIDT, R.A. (1975) A Schema theory of discrete motor skill learning. Psychological Review, 82: 225-260
- SCHMIDT, R.A. (1976) The schema as a solution to some persistent problems in motor learning theory. In G.E. Stelmach (ed.) Motor control: Issues and trends. New York: Academic Press
- SCHOER, D., BALZANO, G. and SMITH, E.E. (1978) Selective interference between imagery and perception: Is it modality specific or relation specific. Bulletin of the Psychonomic Society, 12: 419-422
- SEGAL, S.J. (1971) Processing of the stimulus in imagery and perception. In S.J. Segal (ed.) Imagery: Current cognitive Approaches New York: Academic Press
- SEGAL, S.J. (1972) Assimilation of a stimulus in the construction of an image: The Perky effect revisited. In P.W. Sheehan (ed.) The function and nature of imagery New York: Academic Press
- SEGAL, S.J. and MUSELLA, V. (1970) Influence of imaged pictures and sounds on detection of visual and auditory signals. Journal of Experimental Psychology, 83: 458-464
- SEKULER, R. (1974) Spatial Vision. Annual Review of Psychology, 25: 195-232
- SHEEHAN, P.W. (1967) A shortened form of Betts' Questionnaire upon mental imagery. Journal of Clinical Psychology, 23: 386-389
- SHEPARD, R.N. and METZLER, J. (1971) Mental rotation of three-dimensional objects. Science, 171: 701-703
- SHICK, J. (1970) Effects of mental practice on selected volleyball skills for college women. Research Quarterly, 41: 88-94
- SIMON, H.A. (1972) What is visual imagery? An information processing interpretation. In: L.W. Gregg (ed.) Cognition in Learning and Memory. New York: Wiley
- SIMON, H.A. (1974) How big is a chunk? Science, 183: 482-488
- SIOMAN, A. (1978) The computer revolution in philosophy: Philosophy, science and models of mind. Sussex: Harvester Press Ltd.
- SMITH, L.E. and HARRISON, J.S. (1962) Comparison of the effects of visual, motor, mental and guided practice upon speed and accuracy of performing a simple eye-hand co-ordination task. Research Quarterly, 33: 299-307
- SMYTH, M.M. (1975) The role of mental practice in skill acquisition. Journal of Motor Behavior, 7: 199-206

- SNODDY, G.S. (1926) Learning and stability. Journal of Applied Psychology, 10: 1-36
- START, K.B. (1960) Relationship between intelligence and the effect of mental practice on the performance of a motor skill. Research Quarterly, 31: 644-649
- START, K.B. (1964) Kinaesthesia and mental practice. Research Quarterly, 35: 316-320
- START, K.B. and RICHARDSON, A. (1964) Imagery and Mental Practice. British Journal of Educational Psychology, 34: 280-284
- STEDBINGS, R.J. (1968) A comparison of the effects of physical and mental practice in learning a motor skill. Research Quarterly, 39: 714-720
- STEINER, G. (1981) On the nature of visual imagery, another chance for the selective interference paradigm. Report No. 6 Institut für Psychologie, der Universität Basel, Switzerland
- STELMACH, G.E. and WALSH, M.F. (1973) The temporal placement of interpolated movements in short-term-memory. Journal of Motor Behavior, 5: 165-173
- SUMMERS, J.J. (1977) Adjustment to redundancy in reaction time: A comparison of three learning methods. Acta Psychologica, 41: 205-223
- SUMMERS, J.J. and SHARP, C.A. (1979) Bilateral effects of concurrent verbal and spatial rehearsal on complex motor sequencing. Neuropsychologia, 17: 331-343
- SURBURG, P.R. (1968) Audio, visual and audio-visual instruction with mental practice in developing the forehand tennis drive. Research Quarterly, 39: 728-734
- TINKELPAUGH, O.L. (1932) Multiple delayed reactions with chimpanzees and monkeys. Journal of Comparative Psychology, 13: 207-243
- TITCHNER, E.B. (1909) Lectures on the experimental psychology of thought processes. New York: Macmillan
- TULVING, E. and DONALDSON, W. (eds.) (1975) Organization of Memory. New York: Academic Press
- TURVEY, M.T. (1977) Preliminaries to a theory of action with reference to vision. In R. Shaw and J. Bransford (eds.), Perceiving, Acting and Knowing. Hillsdale, N.J.: Lawrence Erlbaum Associates
- TURVEY, M.T. and CARELLO, C. (1981) Cognition: The view from ecological realism. Cognition, 10: 313-321
- TURVEY, M.T. and SHAW, R. (1979) The primacy of perceiving: An ecological reformulation of perception for understanding memory. In L.G. Nilsson (ed.), Perspectives on memory research: Essays in honor of Uppsala University's 500th Anniversary. Hillsdale, N.J.: Lawrence Erlbaum Associates

- TURVEY, M.T., SHAW, R. and MACE, W. (1978) Issues in the theory of action: Degrees of freedom, co-ordinative structures and coalitions. In J. Requin (ed.) Attention and Performance, VII. Hillsdale N.J. Lawrence Erlbaum Associates
- TURVEY, M.T., SHAW, R.F., REED, E.S. and MACE, W.M. (1981) Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn (1981). Cognition, 9: 237-305
- TVERSKY, B. (1969) Pictorial and verbal encoding in a short-term memory task. Perception and Psychophysics, 6: 225-233
- TWINING, W.H. (1949) Mental practice and physical practice in learning a motor skill. Research Quarterly, 20: 432-435
- ULICH, E. (1967) Some experiments on the function of mental training in the acquisition of motor skills. Ergonomics, 10: 411-419
- WALLACH, H. and AVERBACH, E. (1955) On memory modalities. American Journal of Psychology, 68: 249-257
- WALSH, W.D., RUSSELL, D.G. and CRASSINI, B. (1981) Interference effects in recalling movements. British Journal of Psychology, 72: 287-298
- WARDEN, C.J. (1924) The relative modes of attack in the mastery of a Stylus maze. Journal of Experimental Psychology, 7: 243-275
- WASHBURN, M.F. (1916) Movement and Mental Imagery. Boston: Houghton Mifflin Co.
- WATSON, J.B. (1913) Psychology as the behaviorist views it. Psychological Review, 20: 158-177
- WATSON, J.B. (1928) The Ways of Behaviorism. New York: W.W. Norton
- WEIMER, W.B. (1977) A conceptual framework for cognitive psychology: Motor theories of the mind. In R. Shaw and J. Bransford (eds.) Perceiving acting and knowing: Towards an ecological psychology. Hillsdale, New Jersey: Lawrence, Erlbaum Associates
- WELCH, R.B. (1978) Perceptual modification: Adapting to altered sensory environments. New York: Academic Press
- WICKENS, D.D. (1939) A study of voluntary and involuntary finger conditioning. Journal of Experimental Psychology, 25: 127-140
- WILLIAMS, R.L. (1976) N.C.P.E.A.M. Proceedings, 73, 43
- WOODWORTH, R.S. (1899) The accuracy of voluntary movement. Psychological Review, Monograph Supplement, Vol.3, No.2: 1-114
- WOODWORTH, R.S. (1938) Experimental Psychology. New York: Holt
- WOODWORTH, R.S. and SCHLOSBERG, H. (1955) Experimental Psychology 3rd ed. London: Methuen

APPENDIX A

Summary of Mental Practice Research

Abbreviations:

MP	= Mental Practice.
AP	= Actual Practice.
NP	= No Practice.
AMP	= Actual Practice followed by Mental Practice.
MAP	= Mental Practice followed by Actual Practice.
OBS	= Observational learning.

STUDY	COMPARISON	TASK	PRIOR TRAINING	CUES DURING MP	OUTCOME OF COMPARISON	DEPENDENT VARIABLE
Clark 1960	MP v AP	Basketball	Written instructions Demonstration 25 Actual Shots	Written Work Sheets	No significant differences	No. of successful shots
Corbin 1967 (a)	MP v AP	Juggling	5 trials of 30 actual tosses	Written Work Sheets	AP > MP	No. of successful shots
	MP v NP	"	"	"	MP > NP	"
Corbin 1967 (b)	AP v MP	"	"	"	AP > NP	"
	MP v AP	Juggling	30 actual tosses but on a less complex version of the task	Written Work Sheets	AP > MP	No. of successful tosses.
	MP v NP	"	"	"	No significant differences	"
	AP v NP	"	"	"	AP > NP	"
Kelsey 1961	AMP v AP	"	"	"	No significant differences	"
	AMP v NP	"	"	"	AMP > NP	"
	MP v AP	Sit-ups	5 mins actual sit-ups	Written instructions	AP > MP	No. of sit-ups
	MP v NP	"	"	"	No significant differences	"
McBride & Rothstein 1979	NP v AP	"	"	"	AP > NP	"
	MP v AP	Table tennis	Written instructions Demonstration 3 Actual trials	Written instructions	No significant differences	No. of successful shots
	MP v NP	"	"	"	"	"
	MP v NP	"	"	"	"	"
Minas 1979	MP v AP	Ball throwing	2 trials	Lights	MP > AP	No. of Balls in bin
	MP v NP	"	"	"	MP > NP	"
	MP v NP	"	2 Actual trials	Apparatus	No significant differences	"
	MP v AP	"	"	"	"	"

STUDY	COMPARISON	TASK	PRIOR TRAINING	CUES DURING MP	OUTCOME OF COMPARISON	DEPENDENT VARIABLE
Perry 1939	MP v AP	Three hole tapping	2 trials (30 secs. each)	Apparatus	No significant differences	No. of holes tapped
	MP v NP	"	"	"	"	"
	AP v NP	"	"	"	"	"
	MP v AP	Card sorting	2 trials (30 secs. each)	Apparatus & stimulus card	AP > NP	No. of cards sorted
	MP v NP	"	"	"	AP > MP	"
	AP v NP	"	"	"	MP > NP	"
	MP v AP	Peg Board	2 trials (30 secs. each)	Apparatus & stimulus	AP > NP	No. of pegs in holes
	MP v NP	"	"	"	No significant difference	"
	AP v NP	"	"	"	MP > NP	"
	MP v AP	Symbol Digit substitution	2 trials (30 secs. each)	Apparatus & stimulus	AP > NP	No. of substitutions made
	MP v NP	"	"	"	AP > MP	"
	AP v NP	"	"	"	MP > NP	"
Rawlings & Rawlings 1974	MP v AP	Mirror Drawing	2 trials (30 secs. each)	Apparatus & stimulus	MP > AP	No. of tracings done
	MP v NP	"	"	"	MP > NP	"
	NP v AP	"	"	"	AP > NP	"
	MP v NP	Pursuit rotor	25 actual trials	Apparatus	MP > NP	Time on target
	MP v AP	"	"	"	No significant differences	"
	NP v AP	"	"	"	AP > NP	"
	MP v NP	"	"	"	MP > NP	"
	AP v NP	"	"	None	MP > NP	"
	MP v NP	"	"	"	AP > NP	"
	AP v NP	"	"	"	AP > NP	"
	MP v AP	"	"	"	AP > MP	"
	NP v MP	Maze	2 actual trials	"	MP > NP	Errors/speed
Sackett 1935	NP v MP	"	"	"	No significant difference	"
Sackett 1934	MP v NP	"	"	"	ence	"
	MP v NP	"	"	Draw	MP > NP	"
	MP v MP	"	"	"	No significant difference	"

STUDY	COMPARISON	TASK	PRIOR TRAINING	CUES DURING MP	OUTCOME OF COMPARISON	DEPENDENT VARIABLE
Smith & Harrison 1962	MP v NP	Peg Board	Actual practice 1 min. + written instructions	Think (none)	MP > NP	Errors/speed
	MP v NP	"	"	Move eyes	MP > NP	"
	MP v NP	"	"	Move eyes in opposite order	MP > NP	"
	MP v NP	"	"	Guided round	No significant differences	"
	MP v AP	"	"	Peg Board	MP > AP	"
	MP v AP	"	"	Nothing	MP > AP	"
	MP v AP	"	"	Move eyes around board	MP > AP	"
	MP v AP	"	"	Move eyes in opposite order	No significant differences	"
	MP v AP	"	"	Guided around peg Board.	"	"
	MP v MP	"	"	Move eyes	"	"
Smyth 1975	AP v MP	Pursuit rotor	Written explanation	None	AP > MP	Accuracy Time on target
	MP v NP	"	"	"	No significant differences	"
	AP v NP	"	"	"	AP > NP	"
	AMP v NP	"	"	"	AMP > NP	"
	AMP v AP	"	"	"	No significant differences	"
	AMP v MP	"	"	"	AMP > MP	"
	AP v MP	Mirror drawing	"	"	AP > MP	"
	AP v NP	"	"	"	AP > NP	"
	MP v NP	"	"	"	MP > NP	"
	MP v AP	Tapping key/lights	10 trials	Action	AP > MP	"
Summer 1977	MP v NP	"	"	"	No significant differences	"

STUDY	COMPARISON		TASK	PRIOR TRAINING		CUES DURING MP		OUTCOME OF COMPARISON		DEPENDENT VARIABLE	
	MP v NP	MP v NP		27 trials	100 trials	Watch Others	Explain	No significant differences	MP > NP	Accuracy	Accuracy
Stebbins 1968	MP v NP	MP v NP	Tennis	"	"	Watch Others	Explain	No significant differences	MP > NP	"	"
	MP v NP	MP v NP	Ball throwing	"	"	Watch Others	Explain	No significant differences	MP > NP	"	"
	MP v AP	MP v AP	"	"	"	"	"	"	"	"	"
	MAP v AP	MAP v AP	"	"	"	"	"	"	"	"	"
	AMP v AP	AMP v AP	"	"	"	"	"	"	"	"	"
	MAP v NP	MAP v NP	"	"	"	"	"	MAP > NP	"	"	"
	AMP v NP	AMP v NP	"	"	"	"	"	AMP > NP	"	"	"
	MAP v MP	MAP v MP	"	"	"	"	"	MAP > MP	"	"	"
	AMP v MP	AMP v MP	"	"	"	"	"	AMP > MP	"	"	"
	MAP v AMP	MAP v AMP	"	"	"	"	"	No significant differences	"	"	"
Twining 1949	MP v NP	MP v NP	Ring toss	210 throws	"	Target present	"	MP > NP	"	"	"
	MP v AP	MP v AP	"	"	"	"	"	No significant differences	"	"	"
	AP v NP	AP v NP	"	"	"	"	"	AP > NP	"	"	"
Ulich 1967 Experiment 1	AP v MP	AP v MP	Finger test	4 trials of 5 mins each.	"	None	"	AP > MP	"	Speed/accuracy	"
	AP v NP	AP v NP	"	"	"	"	"	AP > NP	"	"	"
	MP v NP	MP v NP	"	"	"	"	"	MP > NP	"	"	"
	OBS v NP	OBS v NP	"	"	"	"	"	No significant differences	"	"	"
	OBS v MP	OBS v MP	"	"	"	"	"	MP > OBS	"	"	"
	OBS v AP	OBS v AP	"	"	"	"	"	AP > OBS	"	"	"
	AMP v AP	AMP v AP	"	"	"	"	"	No significant differences	"	"	"
	AMP v MP	AMP v MP	"	"	"	"	"	AMP > MP	"	"	"
	AMP v OBS	AMP v OBS	"	"	"	"	"	AMP > OBS	"	"	"
	AMP v NP	AMP v NP	"	"	"	"	"	AMP > NP	"	"	"
	AP v NP	AP v NP	Typing	15 trials	"	"	"	AP > NP	"	"	"
	AP v MP	AP v MP	"	"	"	"	"	AP > MP	"	"	"
	AP v MP	AP v MP	"	"	"	"	"	AP > MP	"	"	"

STUDY	COMPARISON	TASK	PRIOR TRAINING	CUES DURING MP	OUTCOME OF COMPARISON	DEPENDENT VARIABLE
Experiment 3	MP v NP	Typing	15 trials	None	MP > NP	Speed/accuracy
	MP v OBS	"	"	"	MP > OBS	"
	AP v OBS	"	"	"	AP > OBS	"
	OBS v NP	"	"	"	OBS > NP	"
	MAP v NP	"	"	"	MAP > NP	"
	MAP v OBS	"	"	"	MAP > OBS	"
	MAP v MP	"	"	"	MAP > MP	"
	MAP v AP	"	"	"	AP > MAP	"
	AP v NP	Rivetting	4 trials of 5 ms.each	"	AP > NP	"
	AP v OBS	"	"	"	AP > OBS	"
	MP v NP	"	"	"	MP > NP	"
	MP v OBS	"	"	"	No significant differences	"
	MP v AMP	"	"	"	AMP > MP	"
	AMP v NP	"	"	"	AMP > NP	"
	AMP v AP	"	"	"	AMP > AP	"

APPENDIX B

CLASSIFICATION OF TASKS : based on Morrisett (1956)

TASK	Score out of a total of 15		
	Symbolic	Perceptual	Motor
Basketball	8	13*	10
Juggling	6	12	13*
Three Hole tapping	13*	3	8
Pursuit Rotor	3	11*	9
Table tennis	6	12*	11
Ball throwing	5	6	13*
Tennis	11	14*	12
Mirror drawing	7	13*	9
Key tapping	13*	10	7
Ring toss	4	8	10*
Finger dexterity	10	5	13*
Typing	13	6	14*
Pegboard	9	5	13*
Rivetting	5	12*	11
Card sorting	6	15*	7
Symbol/digit substitution	12*	10	4
Sit-ups	3	2	15*
Maze learning	11*	10	6

* indicates into which category this particular task was classified.

Note: Correlation between judges on each category, was measured by Kendals Coefficient of Concordance (w)

Symbolic: (w) = $0.732 \chi^2_{17}$ = 29.577, pr < .05
 Perceptual: (w) = $0.712 \chi^2_{17}$ = 29.098, pr < .05
 Symbolic: (w) = $0.705 \chi^2_{17}$ = 28.916, pr < .05.

APPENDIX C

EXPERIMENT I

Subject		Conditions							
		NIM30	NAM30	CB30	SIM30	NIM60	NAM60	CB60	SIM60
1	C.E.	4.50	4.55	-0.30	0.25	-5.80	-3.85	0.90	0.30
	V.E	0.71	2.1 1/4	2.16	0.49	1.08	1.23	0.62	0.30
2	C.E.	3.20	3.65	-0.70	-0.10	-7.20	-3.45	0.10	0.25
	V.E.	1.14	3.00	1.25	0.32	0.40	1.45	1.10	0.20
3	C.E.	7.20	5.00	0.00	-0.40	-4.10	-4.10	1.25	0.30
	V.E.	2.49	1.33	1.56	0.39	0.78	3.89	1.75	0.40
4	C.E.	2.40	3.20	3.20	0.05	-3.00	-5.40	1.45	-0.10
	V.E.	3.12	2.80	1.30	0.60	1.00	2.06	1.05	0.30
5	C.E.	3.20	5.90	-2.60	0.15	-3.40	-4.75	-1.75	0.05
	V.E.	0.79	2.23	1.07	0.42	1.20	2.25	1.38	0.50
6	C.E.	4.70	6.40	-2.80	-0.10	-5.60	-5.40	-2.38	0.00
	V.E.	1.16	2.12	1.06	0.52	1.36	2.01	2.78	0.20

Table C.1. Experiment I. Constant error (C.E.) and variable error (V.E.) for each subject and each condition; error is measured in CMS. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials.

Trials		Conditions							
		NIM30	NAM30	CB30	SIM30	NIM60	NAM60	CB60	SIM60
1	\bar{x}	4.00	6.33	0.50	-0.42	-4.17	-6.50	-0.67	0.08
	s.e.	0.63	3.00	3.08	0.66	2.23	1.05	1.99	0.20
2.	\bar{x}	4.80	6.17	0.83	-0.50	-4.33	-3.67	0.83	0.10
	s.e.	1.80	1.50	2.64	0.55	2.16	1.21	1.97	0.22
3	\bar{x}	4.00	4.33	1.00	0.00	-4.33	-5.00	0.75	-0.08
	s.e.	3.40	2.50	2.97	0.45	1.51	2.19	1.70	0.37
4	\bar{x}	4.30	5.25	-0.67	-0.08	-4.67	-3.58	0.33	0.16
	s.e.	2.90	2.60	2.73	0.20	1.97	1.74	1.25	0.25
5.	\bar{x}	4.80	4.92	-0.50	-0.08	-4.17	-3.25	0.58	0.16
	s.e.	2.90	1.40	2.26	0.49	2.04	0.88	1.62	0.68
6	\bar{x}	4.80	3.92	-1.30	0.00	-5.33	-3.75	-1.08	0.08
	s.e.	2.90	2.80	2.42	0.32	1.97	2.09	2.59	0.20
7	\bar{x}	4.00	3.80	-1.25	0.00	-4.67	-4.92	0.41	0.08
	s.e.	2.24	3.18	2.32	0.32	1.97	2.25	1.88	0.20
8	\bar{x}	3.00	3.67	-1.17	0.25	-4.67	-4.33	0.00	0.16
	s.e.	0.89	2.80	1.72	0.61	2.25	2.50	1.67	0.25
9	\bar{x}	4.30	4.17	-0.92	0.33	-5.33	-4.08	-0.33	0.41
	s.e.	2.07	2.90	2.20	0.41	1.86	1.83	2.27	0.37
10	\bar{x}	4.20	4.50	-1.50	0.25	-5.17	-4.67	0.41	0.16
	s.e.	1.17	2.70	2.07	0.27	2.04	2.42	2.22	0.25

Table C.2. Experiment I: Mean error \bar{x} and standard error (s.e.) per recall trial in each condition; error measured in CMS. (6 subjects per cell).

APPENDIX D

EXPERIMENT II

Subjects		NAM	NIM	V	M	NIMV	NIMM	CB
1	CE	5.90	2.50	1.70	2.40	-4.45	2.50	-0.80
	VE	1.89	0.45	1.01	0.64	1.62	0.85	0.11
2	CE	6.20	5.50	0.95	1.60	-0.20	6.60	1.50
	VE	1.56	0.65	0.92	0.14	0.96	1.07	0.65
3	CE	3.30	9.40	-1.58	-1.00	-2.10	6.65	-1.60
	VE	2.66	0.44	0.73	0.39	0.96	0.60	0.99
4	CE	6.75	8.30	1.30	-2.10	2.30	4.50	1.65
	VE	1.06	0.61	1.41	2.69	1.46	1.25	1.15
5	CE	7.60	6.40	-1.85	2.05	-2.70	5.60	2.35
	VE	2.04	0.46	0.70	1.67	1.21	0.64	0.80
6	CE	5.70	5.10	-1.95	1.55	1.00	4.25	2.00
	VE	2.41	0.69	1.12	1.73	0.79	0.56	0.15

Table D.1. Experiment II: Constant error (C.E.) and variable error (V.E.), for each subject in each condition, error is measured in cms.. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed after 10 recall trials.

Trials	CONDITIONS						
	NAM	NIM	V	M	NIMV	NIMM	CB
1 \bar{x}	6.70	7.00	0.00	0.67	-1.08	4.83	0.83
s.e.	2.25	2.76	1.40	1.63	2.33	2.48	1.60
2 \bar{x}	6.90	6.80	-0.70	0.42	-1.83	5.00	0.33
s.e.	2.01	2.32	1.40	1.02	1.94	1.67	1.75
3 \bar{x}	6.25	6.50	0.10	0.67	-1.33	4.67	1.33
s.e.	2.32	2.66	2.75	1.66	2.34	1.63	1.75
4 \bar{x}	5.50	6.00	-0.30	0.58	-0.83	4.83	1.25
s.e.	2.07	2.53	1.75	2.20	2.99	1.17	1.33
5 \bar{x}	5.00	5.80	-0.5	1.42	-1.08	5.00	1.25
s.e.	1.79	1.83	2.28	1.56	3.32	2.00	1.84
6 \bar{x}	4.80	5.80	-0.30	1.33	-1.58	5.50	1.25
s.e.	2.77	2.48	1.41	2.66	2.06	1.38	1.97
7 \bar{x}	6.08	6.20	-0.20	1.33	-1.17	5.75	0.50
s.e.	1.86	2.79	2.30	2.71	2.21	1.67	2.07
8 \bar{x}	6.67	6.30	-0.30	0.17	-1.67	4.83	0.75
s.e.	1.94	2.73	2.70	2.29	2.14	1.83	1.67
9 \bar{x}	5.75	5.80	-0.20	0.75	-1.00	4.75	0.58
s.e.	1.41	2.64	2.10	2.21	2.97	2.04	1.91
10 \bar{x}	5.58	5.70	-0.25	0.25	-1.50	5.00	0.58
s.e.	0.92	2.58	1.70	3.66	2.28	2.19	2.27

Table D.2. Experiment II : mean error (\bar{x}) and standard error (s.e.) per recall trial; Error is measured in CMS (6 subjects per cell).

APPENDIX E

EXPERIMENT III

Subject	Conditions							
	NAM60	NAM30	NIM60	NIM30	NIMV60	NIMV30	NIMM60	NIMM30
1 CE	4.45	-5.50	4.50	-5.50	2.20	0.00	7.55	-4.00
	1.89	1.35	1.18	0.53	1.55	1.15	1.95	0.94
2 CE	5.40	-7.60	6.25	-6.55	-1.30	-3.40	4.60	-4.20
	1.51	1.12	1.59	0.50	0.77	0.97	0.97	1.14
3. CE	3.70	-7.40	6.25	-4.80	0.80	1.20	7.10	-4.70
	0.82	2.63	1.01	0.42	0.48	1.14	1.10	0.54
4 CE	4.10	-7.20	4.65	-5.00	1.80	1.80	5.25	-5.95
	1.29	1.35	0.82	0.67	1.03	1.14	0.89	1.50
5 CE	5.80	-4.20	5.65	-5.55	-2.35	1.20	5.20	-5.75
	1.48	0.74	0.97	0.69	1.06	0.88	1.11	1.21
6 CE	6.60	-3.80	4.35	-5.50	0.00	-1.70	4.50	-6.05
	1.15	0.79	1.08	0.71	1.25	0.57	0.94	1.42

Table E.1.: Experiment III : Constant Error (C.E.) and variable error (V.E.) for each subject in each condition, error is measured in CMS. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials.

Trials	Conditions							
	NAM60	NAM30	NIM60	NIM30	NIMV60	NIMV30	NIMM60	NIMM30
1. \bar{x}	4.30	-5.30	5.40	-6.00	0.00	-0.50	5.75	-5.00
s.e.	2.42	1.50	1.30	0.89	1.27	1.05	1.99	2.28
2. \bar{x}	4.20	-5.30	4.70	-5.50	1.00	-0.20	5.60	-5.20
s.e.	1.33	2.73	0.60	0.84	3.03	0.98	1.80	1.72
3. \bar{x}	4.70	-6.00	4.50	-5.20	1.00	-0.30	4.80	-4.60
s.e.	0.82	1.55	0.55	0.75	3.03	1.86	1.33	0.80
4. \bar{x}	5.30	-6.50	4.80	-5.50	0.30	-1.00	6.00	-5.10
s.e.	1.60	2.88	1.21	0.84	1.47	2.53	1.67	0.80
5. \bar{x}	5.30	-7.00	5.30	-5.30	-0.25	-0.70	6.00	-5.30
s.e.	0.76	3.03	1.89	1.03	1.41	3.08	1.79	1.50
6. \bar{x}	5.70	-5.70	5.30	-5.50	0.33	0.50	6.00	-5.25
s.e.	0.82	1.63	1.78	0.55	1.99	2.17	1.58	1.60
7. \bar{x}	5.80	-5.20	5.42	-5.30	0.17	0.50	5.70	-5.50
s.e.	1.78	1.72	1.56	0.82	2.23	2.51	1.40	1.61
8. \bar{x}	5.20	-6.50	5.40	-5.50	-0.08	-0.50	5.75	-4.40
s.e.	1.94	2.66	1.69	1.05	1.15	3.27	1.89	0.92
9. \bar{x}	5.30	-6.30	5.80	-5.60	0.00	0.50	5.75	-5.10
s.e.	2.73	1.51	0.99	0.49	2.34	2.59	2.36	1.11
10. \bar{x}	4.50	-5.70	6.10	-5.40	-0.25	0.20	5.70	-5.30
s.e.	1.87	1.51	1.43	0.92	2.14	1.94	1.75	1.21

Table E.2. Experiment III : Mean error (\bar{x}) and standard error (S.E.) per recall trial; error is measured in CMS. (6 subjects per cell)

APPENDIX F

EXPERIMENT IV

Subject		Conditions					
		Verb R	Vis R	Motor R	Verb NR	Vis NR	Motor NR
1	CE	5.70	0.50	6.25	10.20	0.40	5.40
	VE	0.48	0.97	0.86	0.79	1.08	1.43
2	CE	5.80	1.30	4.40	4.80	1.80	4.20
	VE	1.03	0.54	0.66	0.63	1.03	0.42
3	CE	5.20	0.95	4.68	5.70	-2.10	4.40
	VE	0.79	0.37	0.56	0.48	0.99	1.35
4	CE	5.00	0.20	4.40	5.70	0.10	4.90
	VE	0.41	0.79	0.84	0.68	1.00	0.88
5	CE	4.40	0.10	5.20	8.00	-1.20	8.20
	VE	0.70	0.57	0.42	1.16	2.30	0.92
6	CE	5.10	-0.70	4.60	6.00	-0.80	7.10
	VE	0.88	0.68	0.52	0.67	0.79	1.20

Table F.1. Experiment IV : Constant error (C.E.) and variable error (V.E.) for each subject in each condition; error is measured in CMS, and each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials.

Trials	Conditions					
	Verb R	Vis R	Motor R	Verb NR	Vis NR	Motor NR
1 \bar{x}	4.90	0.17	4.80	6.50	-1.00	4.50
s.e.	1.28	1.33	0.75	1.97	2.10	1.87
2 \bar{x}	4.90	0.17	4.30	6.33	-0.30	4.70
s.e.	0.66	1.17	0.52	2.42	1.97	2.50
3 \bar{x}	4.80	0.17	4.50	6.83	-0.60	5.80
s.e.	0.75	1.17	0.55	2.32	1.84	2.14
4 \bar{x}	5.00	0.50	4.80	6.67	-0.50	6.17
s.e.	0.89	1.05	0.76	2.25	1.64	1.94
5 \bar{x}	5.30	0.67	4.90	6.50	0.33	6.00
s.e.	0.52	0.82	1.11	2.07	1.51	1.67
6 \bar{x}	5.80	0.58	5.10	7.17	-1.17	6.00
s.e.	0.75	0.49	1.20	2.37	2.48	2.00
7 \bar{x}	5.80	0.42	5.00	7.00	-0.33	6.17
s.e.	0.75	0.92	0.71	2.00	1.97	1.83
8 \bar{x}	5.50	0.33	5.80	6.67	-0.17	6.00
s.e.	1.05	0.82	0.76	2.25	1.47	1.55
9 \bar{x}	5.00	0.25	5.10	6.67	-0.17	5.67
s.e.	0.63	1.08	1.43	1.97	0.75	1.21
10 \bar{x}	4.80	0.67	5.00	7.00	0.67	6.00
s.e.	0.75	0.52	0.89	1.67	2.16	1.55

Table F.2. Experiment IV; mean error (\bar{x}) and standard error (s.e.) per recall trial in each condition; error is measured in CMS. (6 subjects per cell).

APPENDIX G

EXPERIMENT V

Subjects		Conditions					
		VS	AS	MS	VNS	ANS	MNS
1	CE	1.00	2.00	1.20	9.30	8.10	3.90
	VE	0.60	1.60	0.90	1.90	1.50	0.70
2	CE	0.80	1.40	1.70	12.80	7.60	6.80
	VE	0.80	0.40	0.90	0.90	1.60	1.00
3	CE	-0.10	1.60	1.70	1.90	6.60	11.50
	VE	0.90	0.90	0.80	0.30	1.00	0.90
4	CE	0.90	1.40	2.30	6.10	6.40	7.10
	VE	0.60	0.60	1.00	1.00	1.80	0.80
5	CE	0.40	1.70	3.60	2.10	6.90	6.70
	VE	0.50	0.60	0.90	0.70	1.50	0.60
6	CE	0.40	2.00	3.90	12.30	7.25	8.40
	VE	0.70	1.00	1.50	1.50	1.20	0.50

Table G.1. Experiment V : Constant error (C.E.) and variable error (V.E.) for each subject and each condition, error is measured in CMS. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials.

Trials		Conditions					
		VS	AS	MS	VNS	ANS	MNS
1	\bar{x}	1.17	3.43	2.33	6.50	6.17	7.83
	s.e.	0.75	1.50	1.63	4.04	1.72	2.32
2	\bar{x}	1.00	1.75	2.17	7.00	6.5	7.33
	s.e.	0.63	1.04	1.60	4.60	1.38	2.42
3	\bar{x}	0.67	1.42	3.33	8.17	7.0	7.50
	s.e.	0.52	0.58	1.51	4.88	1.27	3.02
4	\bar{x}	0.67	1.67	2.33	7.67	8.25	7.67
	s.e.	0.98	0.52	1.51	5.72	1.33	3.20
5	\bar{x}	0.58	1.50	2.17	7.83	7.17	7.17
	s.e.	0.66	0.63	1.17	5.19	1.81	2.48
6	\bar{x}	0.42	1.67	2.00	8.17	7.17	7.83
	s.e.	0.66	0.61	1.10	5.19	4.37	3.06
7	\bar{x}	0.50	1.08	2.58	7.17	6.67	7.25
	s.e.	0.55	0.20	2.58	4.88	1.51	2.06
8	\bar{x}	0.00	1.00	3.50	7.33	7.33	7.08
	s.e.	0.89	0.55	1.97	5.54	1.21	2.15
9	\bar{x}	0.58	1.58	2.58	7.50	6.25	7.16
	s.e.	0.49	0.49	1.02	4.85	1.08	2.34
10	\bar{x}	0.50	1.67	1.83	6.83	6.92	6.92
	s.e.	0.55	0.75	1.47	4.40	2.01	2.62

Table G.2 Experiment V: mean error (\bar{x}) and standard error (s.e.) per recall trial, in each condition, error is measured in CMS (6 subjects per cell).

APPENDIX H
EXPERIMENT VI

Subjects		VS	AS	MS	VNS	ANS	MNS
1	CE	-0.20	-21.10	-2.70	3.90	7.10	7.80
	VE	2.00	3.20	3.50	1.10	1.00	1.10
2	CE	-0.30	-0.30	-0.80	3.90	5.40	4.40
	VE	2.10	3.70	3.30	0.90	1.20	0.50
3	CE	-4.40	0.60	-2.90	5.80	3.90	5.20
	VE	0.80	0.80	1.70	1.70	0.30	0.80
4	CE	-3.00	7.40	-1.45	12.70	5.30	4.90
	VE	2.90	2.10	2.70	1.20	0.50	0.60
5	CE	0.30	6.50	0.30	5.90	5.70	6.50
	VE	0.80	4.20	2.60	1.00	0.80	0.80
6	CE	-3.60	0.20	2.20	6.40	4.90	5.90
	VE	4.10	0.90	1.50	0.50	0.60	1.20

Table H.2. Experiment VI: Constant error (C.E.) and variable error (V.E.) for each subject and each condition, error is measured in CMS. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials.

Trials		Conditions					
		VS	AS	MS	VNS	ANS	MNS
1.	\bar{x}	-1.67	-3.83	0.33	6.00	5.50	5.67
	s.e.	2.94	11.99	1.03	3.16	0.84	1.21
2	\bar{x}	-1.92	- 3.00	-0.33	6.17	5.50	6.17
	s.e.	3.23	10.95	2.50	3.19	1.22	1.60
3	\bar{x}	-1.92	- 2.50	0.66	6.50	5.67	6.17
	s.e.	3.35	10.56	1.97	3.33	1.03	2.32
4	\bar{x}	-2.92	- 2.00	-0.92	6.58	5.17	5.67
	s.e.	3.60	10.06	3.26	3.20	1.17	1.51
5	\bar{x}	-1.08	- 1.67	-1.08	6.50	5.00	5.83
	s.e.	2.78	9.73	2.50	3.39	1.67	1.47
6	\bar{x}	-2.00	-1.33	-2.67	5.83	5.17	5.83
	s.e.	4.22	10.05	3.39	3.76	1.60	1.47
7	\bar{x}	-0.67	0.17	-0.83	5.83	5.33	5.50'
	s.e.	3.08	10.15	5.12	3.37	1.80	1.38
8	\bar{x}	-0.67	0.33	-2.67	6.50	5.33	5.67
	s.e.	2.73	10.31	2.80	3.27	1.03	1.21
9	\bar{x}	-0.08	1.00	-0.17	7.17	5.50	5.33
	s.e.	2.01	10.77	3.43	3.43	1.05	1.37
10.	\bar{x}	-2.00	4.00	-1.33	7.17	5.67	6.00
	s.e.	3.74	11.15	3.67	3.92	1.21	1.26

Table H.2. Experiment VI: mean error (\bar{x}) and standard error (s.e.) per recall trial, error is measured in CMS. (6 subjects per cell).

APPENDIX I

EXPERIMENT VII

Subjects		Conditions					
		VS	AS	MS	VNS	ANS	MNS
1	CE	-6.70	5.60	-3.50	0.69	0.68	-1.20
	VE	2.06	1.35	2.51	0.59	0.56	0.63
2	CE	6.20	4.95	6.70	0.20	-0.75	1.40
	VE	1.93	1.21	1.57	0.82	0.68	0.97
3	CE	6.60	5.85	-4.70	-0.40	0.80	1.00
	VE	1.96	1.80	0.82	0.97	0.79	0.47
4	CE	-4.30	7.80	-5.10	-1.40	0.20	0.30
	VE	3.16	1.62	1.73	0.52	1.03	0.67
5	CE	5.30	-3.60	3.50	-0.10	-0.10	-1.30
	VE	2.00	2.37	2.37	0.57	0.88	0.48
6	CE	6.40	-6.80	-5.40	0.60	0.70	1.20
	VE	1.90	1.75	1.58	0.70	0.67	0.42

Table I.1. Experiment VII : constant error (C.E.) and variable error (V.E.) for each subject and each condition. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials (error is measured in CMS).

Trials	Conditions					
	VS	AS	MS	VNS	ANS	MNS
1 \bar{x}	2.00	3.83	-0.50	0.33	-0.17	0.67
s.e.	5.29	5.08	4.81	1.21	1.17	1.37
2 \bar{x}	0.00	3.00	-1.17	0.75	-0.25	0.33
s.e.	7.48	4.94	4.71	-0.25	0.88	1.03
3 \bar{x}	1.67	3.50	-0.67	1.08	-0.08	0.17
s.e.	7.06	6.53	4.46	-0.17	1.02	1.72
4 \bar{x}	3.00	1.83	-0.67	1.17	0.25	0.00
s.e.	4.94	5.64	5.68	-0.80	1.33	2.10
5 \bar{x}	2.00	1.50	-1.50	1.26	0.42	0.00
s.e.	6.96	6.12	4.68	0.33	0.92	1.10
6 \bar{x}	3.33	1.50	-2.17	0.82	0.33	0.17
s.e.	5.16	5.54	5.08	0.48	0.52	0.98
7 \bar{x}	2.33	1.16	-1.33	-0.42	0.83	-0.50
s.e.	6.65	6.52	5.54	1.36	0.98	1.38
8 \bar{x}	1.67	1.42	-1.50	0.17	0.17	0.17
s.e.	7.12	7.76	5.54	0.75	0.98	0.98
9 \bar{x}	1.83	2.75	-2.50	-0.17	0.33	0.17
s.e.	5.67	5.47	7.09	0.75	0.82	1.47
10 \bar{x}	1.16	2.50	-2.17	0.00	0.33	0.17
s.e.	7.60	7.31	6.64	0.63	0.82	0.98

Table I.2. Experiment VII: Mean error (\bar{x}) and standard error (S.E.) per recall trial, error is measured in CMS (6 subjects per cell).

Trials		Conditions					
		VS	AS	MS	VNS	ANS	MNS
1	\bar{x}	2.00	3.83	-0.50	0.33	-0.17	0.67
	s.e.	5.29	5.08	4.81	1.21	1.17	1.37
2	\bar{x}	0.00	3.00	-1.17	0.75	-0.25	0.33
	s.e.	7.48	4.94	4.71	-0.25	0.88	1.03
3	\bar{x}	1.67	3.50	-0.67	1.08	-0.08	0.17
	s.e.	7.06	6.53	4.46	-0.17	1.02	1.72
4	\bar{x}	3.00	1.83	-0.67	1.17	0.25	0.00
	s.e.	4.94	5.64	5.68	-0.80	1.33	2.10
5	\bar{x}	2.00	1.50	-1.50	1.26	0.42	0.00
	s.e.	6.96	6.12	4.68	0.33	0.92	1.10
6	\bar{x}	3.33	1.50	-2.17	0.82	0.33	0.17
	s.e.	5.16	5.54	5.08	0.48	0.52	0.98
7	\bar{x}	2.33	1.16	-1.33	-0.42	0.83	-0.50
	s.e.	6.65	6.52	5.54	1.36	0.98	1.38
8	\bar{x}	1.67	1.42	-1.50	0.17	0.17	0.17
	s.e.	7.12	7.76	5.54	0.75	0.98	0.98
9	\bar{x}	1.83	2.75	-2.50	-0.17	0.33	0.17
	s.e.	5.67	5.47	7.09	0.75	0.82	1.47
10	\bar{x}	1.16	2.50	-2.17	0.00	0.33	0.17
	s.e.	7.60	7.31	6.64	0.63	0.82	0.98

Table I.2. Experiment VII: Mean error (\bar{x}) and standard error (S.E.) per recall trial, error is measured in CMS (6 subjects per cell).

APPENDIX J

EXPERIMENT VIII

Subjects		Conditions		
		30I'	30I	CB
1	CE	7.3	0.70	0.50
	VE	2.87	1.34	0.71
2	CE	5.20	-0.10	0.40
	VE	1.87	1.54	0.52
3	CE	6.00	0.40	-0.70
	VE	0.94	1.17	0.48
4	CE	5.90	0.20	0.00
	VE	1.73	0.79	0.47
5	CE	5.20	1.60	0.20
	VE	1.23	0.52	0.42
6	CE	5.60	0.70	0.90
	VE	1.26	0.67	0.88

Table J.1. Experiment VIII : constant error (C.E.) and variable error (V.E.) for each subject in each condition. Each subject appears in only one experimental condition. C.E. and V.E. are collapsed over 10 recall trials (error is measured in Kps).

Trials		Conditions		
		30 P	30 I	C.B.
1	\bar{x}	6.83	1.17	0.33
	s.e.	2.71	0.98	1.03
2	\bar{x}	6.17	0.50	-0.17
	s.e.	1.17	1.52	0.41
3	\bar{x}	6.00	0.00	-0.17
	s.e.	0.63	1.41	0.41
4	\bar{x}	6.67	0.33	0.33
	s.e.	1.03	1.63	0.82
5	\bar{x}	6.67	0.40	0.17
	s.e.	1.03	1.52	0.98
6	\bar{x}	6.67	0.33	0.17
	s.e.	2.07	1.21	0.98
7	\bar{x}	6.5	0.67	0.33
	s.e.	2.66	0.52	0.82
8	\bar{x}	4.80	0.33	0.33
	s.e.	1.48	1.03	0.52
9	\bar{x}	4.33	0.83	0.17
	s.e.	0.82	0.98	0.75
10	\bar{x}	4.00	1.17	0.50
	s.e.	1.55	0.41	0.84

Table J.2. Experiment VIII : mean error (\bar{x}) and standard error (s.e.) per recall trial in each condition; error is measured in Kaps. (6 subjects per call).