

Original citation:

Watson, D. G. and Blagrove, E. (2012). Tagging multiple emotional stimuli: Negative valence has little benefit. *Journal of Experimental Psychology: Human Perception and Performance*, 38(3), pp. 785-803

Permanent WRAP url:

<http://wrap.warwick.ac.uk/47953>

Copyright and reuse:

The Warwick Research Archive Portal (WRAP) makes the work of researchers of the University of Warwick available open access under the following conditions. Copyright © and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners. To the extent reasonable and practicable the material made available in WRAP has been checked for eligibility before being made available.

Copies of full items can be used for personal research or study, educational, or not-for-profit purposes without prior permission or charge. Provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

Publisher's statement:

'This article may not exactly replicate the final version published in the APA journal. It is not the copy of record.'

©2012 American Psychological Association

A note on versions:

The version presented here may differ from the published version or, version of record, if you wish to cite this item you are advised to consult the publisher's version. Please see the 'permanent WRAP url' above for details on accessing the published version and note that access may require a subscription.

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

warwick**publications**wrap
highlight your research

<http://go.warwick.ac.uk/lib-publications>

Tagging multiple emotional stimuli: Negative valence has little benefit

Derrick G. Watson

and

Elisabeth Blagrove

University of Warwick, UK

Address for correspondence:

Derrick G. Watson

Department of Psychology

University of Warwick

Coventry CV4 7AL

UK

Telephone: +44 (0)2476 522763

Email: d.g.watson@warwick.ac.uk

Keywords: visual enumeration, emotion, face processing, expression, attentional capture

Abstract

Six experiments examined the influence of emotional valence on the tagging and enumeration of multiple targets. Experiments 1, 5 and 6 found that there was no difference in the efficiency of tagging/enumerating multiple negative or positive stimuli. Experiment 2 showed that, when neutral-expression face distractors were present, enumerating negative targets was faster overall, but was only more efficient for small numbers of targets. Experiments 3 and 4 determined that this negative target advantage was most likely caused by increased attentional guidance to negative valenced stimuli and was not based on simple visual feature differences. The findings suggest that a multiple target negative stimulus advantage will only occur under conditions of attentional competition, and for relatively small numbers of targets. The results are discussed in relation to theories of multiple and single item processing, threat priority mechanisms, and the types of representations that support different attentional tasks.

Introduction

We are all familiar with the classic spaghetti western scene; our lone hero walks into a saloon, only to be faced with a number of menacing villains amongst a crowd of innocent bystanders. Within the blink of an eye, our hero draws his gun and dispatches his enemies with apparent ease, leaving the bystanders unharmed. Although entertaining in the movies, the real world equivalent of this type of situation takes on a wholly more somber and serious tone, and leaves us with questions concerning our visual and attentional abilities in such dramatic contexts. For example, is it really that easy for us to discern multiple threats from a visually-rich environment?

The main purpose of the current study is to examine the behavior and efficiency of the attentional system when people have to process multiple negative stimuli. Given that the limitations in visual attentional capacity are well-documented, the ability to prioritize the most important information at any given time would be highly adaptive. For example, even when we struggle to find a complex target in a cluttered scene (see Wolfe, 1998, for an overview) or when we miss important information presented during an eye blink (e.g., Cole, Kentridge & Heywood, 2004; O'Regan, Rensink & Clark, 1999; Rensink, 2000; Simons, 1996; Simons & Levin, 1997, 1998), the need to identify behaviorally relevant stimuli remains.

Consistent with this general goal, previous work has shown that observers are able to prioritize newly appearing information at the expense of other items already in the field (e.g., Yantis & Hillstrom, 1994; Watson & Humphreys, 1997). However, prioritizing the processing of stimuli need not rely on the appearance of new stimuli, or on changes over time, but can be based on the content within a scene. For example, according to guided search theory (Wolfe, 1994; Wolfe, Cave & Franzel, 1989), stimuli which differ from their

neighbors tend to attract attention (i.e. the bottom-up component). At the same time, attention can be biased towards stimuli that match the features of a desired target (i.e. the top-down intentional component). With respect to the present work, a substantial body of research has shown that negative stimuli appear to be able to take priority over more neutral stimuli (Blanchette, 2006; Eastwood, Smilek & Merikle, 2001; Lipp, Derakshan, Waters & Logies, 2004). Effectively, the properties of the negative stimulus appear to act as a salient feature allowing it to attract or guide attention.

The negative superiority effect

With relevance to the present work, the growing evidence showing that humans are more efficient at detecting negative stimuli than positive stimuli (Blanchette, 2006) or faces that show a negative emotional expression compared with a positive expression (Eastwood, Smilek & Merikle, 2001; Fox et al., 2000) points towards biological preparedness (Seligman, 1971) or dedicated fear processing mechanisms (LeDoux, 1996, 1998; Öhman & Mineka, 2001). For example, Eastwood and colleagues (2001) demonstrated in a visual search experiment that a negative target face presented amongst neutral faces could be detected more efficiently (i.e. more rapidly, and with a shallower search slope) than a positive face (see also Fox et al., 2000; Hansen & Hansen, 1988; Hampton et al., 1989). Furthermore, some authors have argued that negative expressions can be detected preattentively, again suggesting that emotional valence might act in the same way as a salient low-level feature in some situations (Öhman, Lundqvist & Esteves, 2001). This negative advantage not only applies to object processing but is also apparent with word stimuli. For example, the valence of negative words versus neutral words was detected more easily than positive words versus neutral words even under subliminal presentation conditions (Nasrallah, Carmel & Lavie, 2009).

To date, a number of attentional paradigms have demonstrated the behavioral importance of negatively valenced or threatening stimuli, by either the enhanced ability of these stimuli to guide attention to themselves (i.e. in visual search, e.g., Eastwood et al., 2001; Fox et al, 2000), or their ability to hold attention, once captured (i.e. in flanker and cueing tasks, for examples see, Fenske & Eastwood, 2003; Horstman, Borgstedt & Heumann, 2006; Fox, Russo, Bowles & Dutton, 2001; Georgiou et al., 2005). Negative facial stimuli have also been shown to influence early visual processes. In this instance, a fearful face resulted in an increase in contrast sensitivity, an effect which was further multiplied by the allocation of attention to that location (Phelps, Ling & Carrasco, 2006). Overall, the findings from these types of studies have been taken to suggest that the visual system is adapted to prioritize the processing of threat or negative stimuli from our environment (but see also Brosch, Sander, Pourtois & Scherer, 2008; Most et al., 2007; Zeelenberg, Wagenmakers & Rotteveel, 2006 for a contrasting view). Clearly such prioritization would be adaptive, because early detection of potential threats or negative stimuli would lend a valuable survival advantage by allowing those stimuli to be avoided or responded to at the expense of less important information. However, given that some studies have also shown that negatively valenced faces can hold attention, leading to a ‘disengagement deficit’ from such stimuli (e.g., Fox, Russo, Bowles & Dutton, 2001), maintaining our attention on a negative or potentially threatening stimulus might come at a cost. In other words, other potentially important information may be missed, or at least, our attention to it could be delayed.

Processing multiple stimuli

The vast majority of visual search studies have focused on examining the detection of a single target presented among a varying number of distractors. However, some studies have considered the efficiency of processing and tagging multiple items using visual enumeration methodologies. Typically in such tasks, people are asked to enumerate (count) how many

items are present in a display. The results show that participants perform rapidly and accurately up to approximately four items ($< 100\text{ms}$ per item), however beyond this limit, their rate of enumeration drops dramatically ($\sim 250\text{-}350\text{ms/item}$), error rates increase (e.g., Gallistel & Gelman, 1993; Mandler & Shebo, 1982; Trick & Pylyshyn, 1993, 1994) and a greater reliance is placed on overt attentional processes (eye movements; Simon & Vaishnavi, 1996; Watson, Maylor & Bruce, 2007). This leads to a bilinear enumeration function with a flex point at around three to four items. The rapid and efficient enumeration of small numerosities is often referred to as *subitizing* (Kaufman, Lord, Reese & Volkman, 1949), and at larger numerosities, as *counting*.

One theory to account for the efficient enumeration/tagging of small numbers of items is based on the idea that the visual system contains a limited number of pointers (called FINSTs for FINgers of INSTantiation) which can be attached to objects (Pylyshyn, 1989, 2000, 2001). According to the FINST theory, subitizing occurs because the visual system can rapidly tag a small number of items (possibly in parallel, but see Olivers & Watson, 2008; Egeth, Leonard & Palomares, 2008) and the number of ‘bound’ tags then indicates the number of items in the display (Trick & Pylyshyn, 1993, 1994). However, as the number of tags is limited to approximately four, beyond four items, additional processes are needed causing a slowing in enumeration rate. Although appearance of new objects tend to capture FINSTs automatically (Pylyshyn, 2001), top-down goals can also be used to control which objects are tagged; for example, tagging can be restricted to the objects of a particular color (Trick & Pylyshyn, 1993; Maylor, Allen & Bruce, 2007). Thus, the FINST system represents a flexible mechanism adapted to tagging multiple items for further processing, such as, enumeration or tracking over space and time.

Processing multiple emotional stimuli

The studies considered above show that, in some situations, negative stimuli can attract, guide and possibly hold attention. That said, they have typically only considered instances in which a single negative target has to be detected or processed. However, in the real world, we might be faced with multiple negative stimuli, *each* of which requires rapid and efficient processing with priority. Accordingly, it would be adaptive if they could *all* be prioritized over more neutral, less behaviorally-relevant stimuli in the field. To date, this facet of valenced-based attentional processing has not been addressed. However, recent work (outside the emotion processing literature) has shown that finding a single target can be detected efficiently or in a spatially parallel manner does not necessarily mean that multiple targets of the same type can be tagged with similar efficiency.

Watson, Maylor, Allen and Bruce (2007) measured both visual search and enumeration performance for detecting or enumerating a color defined target disc(s) among distractor discs of a different color. The main finding was that, as the target-distractor similarity increased (based on their distance in CIE 1976 u^*v^* color space), subitization was found only for the largest of color differences, whereas single target detection remained efficient for all but the smallest differences. This showed that multiple targets could not be tagged efficiently (subitized), even though they supported efficient visual search. Thus, the detection advantage of a single negative target over a positive target need not generalize to situations in which multiple targets have to be detected, tagged or processed. In other words, in the same visual context, detecting a *single* threat might be efficient, but detecting *multiple* threats might not be.

Purpose of the present work

The main purpose of the present work was to determine the efficiency of processing multiple facial stimuli, displaying either a positive or a negative expression. As in previous work with simple geometric shapes and letters, this was achieved by asking participants to

enumerate how many stimuli were present, and examining the resulting enumeration function to determine the rate of processing multiple items. Because numerosity 4 is typically taken to be the point at which subitizing processes break down, following previous work (Trick & Pylyshyn, 1993, 1994; Watson et al., 2007), we calculated subitizing slopes using the numerosity range of one to three items and the counting range from five items upwards. We also excluded the largest numerosity (either eight or nine targets) in order to avoid possible end effects, when participants know there can be no additional items to check for (e.g., Trick & Pylyshyn, 1993, 1994; Watson et al., 2007). In addition, for clarity across experiments, we refer to the range of small numerosities (one to three items) as the *subitizing range* and the larger range of numerosities (above five items) as the *counting range*, even though in some experiments there was no difference in processing rates between these two ranges.

Experiments 1, 5 and 6 examined enumeration of positive, negative and neutral expression schematic and photo-realistic faces presented in isolation. Experiment 2 considered the effect of attentional competition, in which positive or negative faces had to be enumerated among neutral expression distractors. Experiments 3 and 4 examined attentional capture by, and disengagement from valenced faces and the enumeration of simple valence-defining features presented outside of a face context. Overall, the findings suggest little effect of either positive or negative valence on multiple item tagging except in conditions of attentional competition; where there was an advantage for tagging a small number of negatively valenced stimuli.

Experiment 1: Enumeration of positive and negative valenced schematic faces

Experiment 1 examined the enumeration of faces which showed either a negative or a positive expression. Predicting the results in these tasks is less than straightforward, based on previous research in which the processing of only one target was necessary. For example, in visual search tasks in which only a single target has to be detected (e.g., Eastwood et al.,

2001; Fox et al., 2000), the impact of additional negative targets cannot be assessed. Similarly, the impact of re-allocating attention to additional targets also remains undetermined. Accordingly, there are several possibilities: (i) negative targets might show a shallower enumeration function than positive targets, because they attract or guide attention more efficiently than positive targets, (ii) negative targets might show a steeper enumeration function because, they are more difficult to disengage from once attended, and (iii) if subitizing and counting rely on different processes, then enumeration performance for negative and positive targets might differ in the subitizing range compared with the counting range. Indeed, in the domain of color differences, Watson, Maylor, Allen and Bruce (2007) showed that increasing the similarity between targets and distractors had a selective influence on the subitizing range of numerosities (reducing subitizing rates), but had little impact beyond the subitizing range. Conversely, preventing eye movements only influences performance beyond the subitizing range (Simon & Vaishnavi, 1996; Watson, Maylor & Bruce, 2007). Thus, it is possible that any influence of valence could be selectively expressed within either the subitizing or counting range of numerosities. If negatively-valenced targets hold attention, then this could have the effect of abolishing subitizing, leading to even small numerosities being enumerated serially (and resulting in a linear rather than a bilinear enumeration function across the whole range of numerosities).

Method

Participants

Twenty four undergraduate students (10 male), aged 18 to 24 years from the University of Warwick volunteered to take part. All had self-reported normal or corrected-to-normal visual acuity.

Stimuli and apparatus

Stimuli were presented and responses recorded by a custom-written computer program, running on a Pentium-based PC attached to a 17 inch Sony CRT monitor at a resolution of 1024 x 768 pixels. The monitor was placed at eye level and viewed from a distance of approximately 60cm, although no mechanical means were used to restrict head movements. Individual stimuli consisted of positive or negative schematic faces as used in previous work (Eastwood et al., 2001; Blagrove & Watson, 2010), approximately 13 mm in diameter, presented in white (RGB value 200, 200, 200) against the black (RGB value 0, 0, 0) background of the monitor. Each search display was generated by randomly placing one to nine faces into the cells of an invisible 6 x 6 matrix, with a center-to-center stimulus spacing of 90 pixels (30 mm). Individual stimulus positions were also jittered by ± 15 pixels (5 mm) in order to avoid collinear arrangements of adjacent stimuli. Within a single display, all the stimuli were of either a positive valence or a negative valence (see Figure 1 for example displays).

Design and procedure

Each trial began with a blank screen (500ms), followed by a white central fixation dot (2mm x 2mm) for 1000ms, then by the enumeration display (consisting of between one and nine positively or negatively valenced face stimuli). Participants were requested to press the space bar as soon as they determined how many items were present on the screen, whilst maintaining accuracy. The display was replaced with the prompt 'press 1 to 9' presented at the display center and participants were then required to press the numeric key on the number pad, corresponding to their answer. RTs were measured from the onset of the enumeration display until the press of the space bar (for previous examples of the use of this type of procedure, see Atkinson, Campbell & Francis, 1976; Svenson & Sjöberg, 1983; Trick & Enns, 1997; Watson, Maylor, Allen & Bruce, 2007; Watson, Maylor & Manson, 2002; Watson & Humphreys, 1999). Following the response, incorrect responses were signaled by

the presentation of the word ‘Incorrect’ at the display center for 1000ms. The next trial began automatically.

The experiment used a fully within participants 2 (target valence: positive or negative) x 9 (numerosity) design. Each block contained 72 trials (eight replications per numerosity) and participants completed four blocks (i.e. two blocks of negative targets and two blocks of positive targets) to give 288 trials per participant (16 trials per cell). Blocks were presented in an ABAB order, which was counterbalanced across participants.

Results

As in previous work, we evaluated performance in terms of RTs across the subitizing (one to three items) and counting ranges (five to eight items), enumeration slopes, and deviations from linearity. In addition, bilinear modeling was used to determine the subitizing span. In this, and in all subsequent experiments the largest numerosity (here, nine) was excluded from analyses to avoid the possibility of an *end effect* (Mandler & Shebo, 1982; Trick & Pylyshyn, 1993; 1994). This can occur when participants are observed to respond more quickly to the largest numerosity, and is due to them being more confident in this particular response (i.e. on trials where they know that they have found all the possible targets compared with trials on which fewer than the maximum possible number of targets are present).

Reaction times

Overall RTs. Anticipatory RTs of less than 100 ms were discarded and treated as errors (four out of 6912 trials). For each participant, values above or below 2.5 standard deviations from their individual cell means were also discarded (143 trials). Mean correct RTs were then calculated for each cell of the design, individually for each participant (overall means are shown in Figure 2).

The data were analyzed with a 2 (valence) x 8 (numerosity) within-subjects ANOVA. This revealed that RTs increased as numerosity increased, $F(7,161) = 503.04$, $MSE = 46662.81$, $p < .001$, although neither the main effect of valence, nor the valence x numerosity interaction approached significance, both $F_s < 1$.

Enumeration slopes. As in previous enumeration studies, the rate of enumerating targets (the enumeration slope) was calculated for each participant, for both subitizing (one to three) and counting (five to eight) ranges of numerosities for each target valence. For positive targets, this revealed subitizing and counting rates of 50.7 and 354.0 ms/item respectively and for negative targets, 50.2 and 371.8 ms/item. A 2 (valence: positive or negative) x 2 (range: subitizing /counting) ANOVA revealed a significant main effect of range, $F(1,23) = 358.87$, $MSE = 6528.49$, $p < .001$. Neither the main effect of valence nor the valence x range interaction approached significance, both $F_s < 1$.

Deviations from linearity. Consistent with previous research (Trick & Pylyshyn, 1993; Watson, Maylor & Manson, 2002), the mean correct RTs for each numerosity (one to eight items) were tested for deviations from linearity, for each participant individually. If participants were able to subitize small numerosities, then departures from linearity would be obtained because of the bilinear nature of the subitizing-counting function. In contrast, if there was no difference between enumerating small and large numerosities, then the enumeration function should be linear. This analysis revealed significant deviations from linearity (all $F_s > 4.31$, $p_s < .001$) for all participants (24 out of 24), when enumerating positive targets, and for 23 out of 24 participants when enumerating negative targets (all $F_s > 3.34$, $p_s < .001$).

RT Modeling. We determined the subitizing span by fitting a bilinear function to each participant's RTs (see Watson, Maylor & Bruce, 2005a, b, for use of a similar procedure). This function is defined by four free parameters; two enumeration slopes (b_1 , b_2) and two

intercept values (a_1 , a_2) for each segment of the bilinear function (i.e. corresponding to subitizing and counting). Before optimization, the free parameters were initialized with the slope and intercept values corresponding to the subitization (numerosities one to three) and counting functions (numerosities five to eight) of the enumeration function for that participant. This procedure has the effect of reducing the likelihood that the model will settle on unrealistic solutions caused by local minima. The subitizing span is then given by the point on the x-axis corresponding to the flex point of the bilinear function (i.e., where the two functions intercept).

The bilinear model provided a good fit to the data (median R^2 values of 0.851 and 0.861, for positive and negative targets respectively {footnote 1}), and resulted in mean flex points of 3.47 (SD=0.49) for positive, and 3.57 (SD=0.54) for negative targets, $t(23)=1.03$, $p=.316$. The resulting best fit subitizing and counting slopes (parameters b_1 , b_2) were 40.2 and 380.3 ms/item for positive targets, and 46.2 and 394.1 ms/item for negative targets. A 2 (valence: positive or negative) x 2 (range: subitizing/counting) revealed a significant main effect of range, $F(1,23) = 671.78$, $MSE = 4227.11$, $p<.001$. However, neither the main effect of valence, nor the valence x numerosity interaction proved significant, both $F_s<1.63$, $p_s>.214$.

As a more robust test for subitizing than determining deviation from linearity alone, we also assessed whether the bilinear model provided a significantly better fit to the data than a simple linear model {footnote 2}. This analysis revealed that a bilinear model provided a significantly better fit than a linear model for all participants, for both positive and negative targets, all $F_s > 3.5$, all $p_s < .05$.

Errors

As shown in Table 1, mean percentage error rates over the complete set of trials were low overall (<3%) and were analyzed with a 2 (valence: positive or negative) x 8

(numerosity) within-subjects ANOVA. This revealed a significant main effect of numerosity, $F(7,161) = 13.74$, $MSE = 17.69$, $p < .001$, and a significant numerosity x valence interaction, $F(7,161) = 2.68$, $MSE = 16.39$, $p < .05$, but no effect of valence, $F < 1$. The interaction appears to arise primarily as a result of a non-systematic increase in the error rate for numerosity six with positive targets. Considering the subitizing range alone, no main effects or their interaction approached significance, all F s < 1.51 , all p s $> .09$. For the counting range, errors increased with numerosity, $F(3,69) = 7.89$, $MSE = 29.09$, $p < .001$ and there was also a significant valence x numerosity interaction, $F(3,69) = 3.30$, $MSE = 26.74$, $p < .001$. However, the main effect of valence was not statistically reliable, $F < 1$. Overall, the error data did not suggest the presence of a systematic speed/accuracy trade-off.

Discussion

Experiment 1 examined the influence of positive and negative valence on visual enumeration. Two main findings emerged. First, there was no evidence for any valence-based differences in performance for processing multiple negative stimuli, when compared with positive stimuli. This was true for both enumeration rates and overall RTs. Second, there was a clear distinction between the subitizing and counting rates, but no effect of valence on subitizing span. Furthermore, enumeration performance was comparable to previous studies which used abstract stimuli without emotional valence (e.g., letters of the alphabet, colored discs etc). For example, the subitizing spans (~3.5 items), subitizing rates (50ms/item) and counting rates (~380-390ms/item) obtained here are very similar to those previously obtained with non-valenced stimuli {footnote 3}.

As discussed above, previous visual search studies (Eastwood et al., 2001; Fox et al., 2000; Blanchette, 2006; Lipp et al., 2004; Blagrove & Watson, 2010) have found that negatively valenced targets can attract/guide attention more efficiently than positive targets. Other studies (Fox et al., 2001, 2002; Georgiou et al., 2005; Fenske & Eastwood, 2003) have

shown that negative stimuli can hold onto attention, leading to a slowed disengagement of attention from such stimuli. On the basis of this past work, we might have expected that processing multiple stimuli (i.e. in the enumeration task here) might lead to faster enumeration rates for negative targets, potentially because they create a stronger signal for the attentional system. Alternatively, if it is more difficult to disengage attention from each of the negative stimuli, then this would result in a slower enumeration rate relative to positive stimuli. Such a disengagement deficit could act to abolish efficient/parallel subitization, leading to a linear enumeration function for negative targets compared with positive targets. Clearly this was not the case, with valence having no detectable effect on the processing of multiple items.

One possibility for the lack of valence-based effects could be that our valence manipulation was simply not strong enough. However this seems unlikely, given that many previous visual search experiments using highly similar stimuli have found a reliable negative target advantage (based both on overall RTs and on search slopes, e.g., Blagrove & Watson, 2010; Eastwood et al., 2001; Fox et al., 2000). Alternatively, it could be that enumerating targets in the absence of distractors can be based on an early representation, which encodes the locations, but not the features of objects (Found & Müller, 1996; Pylyshyn, 2001; Pylyshyn & Strom, 1988; Watson, Maylor & Bruce, 2005; Watson & Maylor, 2006). Furthermore, in the absence of distractors, feature or valence information is not required to perform the task effectively, and enumeration could theoretically proceed via object location information alone.

Experiment 2: Enumeration of positive and negative valenced schematic targets among neutral distractors

One possibility for the lack of a valence effect in Experiment 1, is that observers did not need to use valence-based information in order to enumerate the stimuli. In contrast,

when previous visual search studies have shown a negative superiority effect, the target has always either been defined as an odd-one-out (Eastwood et al., 2001; Fox et al., 2000; Öhman et al., 2001) or has been defined by a specific valence value (Blagrove & Watson, 2010; Williams et al., 2005; Williams, McGlone, Abbott & Mattingley, 2008). In both these cases, performing the task requires a shape- or valence-based distinction to be made within the stimulus set. Thus, valence-based effects might only arise when shape or valence information must be assessed in order to complete the task. Accordingly, to test this possibility and to extend our findings to conditions of attentional competition, in Experiment 2 the enumeration displays consisted of valenced targets presented among neutral face distractors. Now, as in previous visual search tasks, a shape / valence distinction must be made in order to find each of the targets.

Another possibility is that, participants might not have perceived our specific stimuli as possessing negative and positive valence, thus leading to equivalence in their enumeration. Accordingly in Experiment 2, we also ran an additional rating study to confirm that the stimuli were being perceived as differing in valence.

Method

Participants

Twenty four undergraduate students (12 male), aged 18 to 24 years from the University of Warwick volunteered to take part in the main enumeration experiment. All had self-reported normal or corrected-to-normal visual acuity. Twenty four different participants took part in a rating study and were obtained via opportunity sampling of undergraduate students at the University of Warwick.

Stimuli and apparatus

For the enumeration task, the stimuli and apparatus were identical to Experiment 1, except that each enumeration display now consisted of one to nine targets (all either positive

or negative valence) and 11 to 19 neutral face distractors respectively. As in Watson, Maylor, Allen & Bruce (2007; see also Watson, Maylor & Bruce, 2005a,b; Watson, Maylor & Manson, 2002), this presented a fixed total number of items (twenty) in every display (see Figure 3, for example displays). For the rating study, each schematic emotional face was rated on four scales designed to measure valence differences.

Design and procedure

For the enumeration task, the design and procedure were the same as Experiment 1. For the stimulus rating task, valence ratings were obtained using a procedure based on that developed by Lundqvist, Esteves and Öhman (1999; see also Lundqvist, Esteves & Öhman, 2004, Lundqvist & Öhman, 2005) in which each participant rated each stimulus on four 7-point scales labeled: Good-Bad, Kind-Cruel, Friendly-Unfriendly and Pleasant-Unpleasant. The stimuli were presented on a single piece of paper (stimulus order counterbalanced from top to bottom) with the four rating scales to the right of each stimulus picture. The stimuli were presented in white on a black background, and were of approximately the same size as those presented in the enumeration task.

Results

Enumeration task

Reaction times

Overall RTs. Anticipatory RTs of less than 100 ms were discarded and treated as errors (three out of 6912 trials), and values above or below 2.5 standard deviations from their cell mean for each participant were also discarded (73 trials). Mean correct RTs were calculated for each cell of the design individually for each participant, with overall means shown in Figure 4. A 2 (valence) x 8 (numerosity) ANOVA showed that RTs increased with numerosity, $F(7,161) = 187.46$, $MSE = 119577.09$, $p < .001$, and overall, were 512.3 ms shorter for negative targets than for positive targets, $F(1,23) = 44.28$, $MSE = 579483.66$,

$p < .001$. The target x numerosity interaction was also statistically reliable, $F(7,161) = 2.29$, $MSE = 37432.86$, $p < .05$.

Enumeration slopes. The rates of enumerating targets were calculated for the subitizing (one to three) and counting (five to eight) numerosity ranges for each target valence. A 2 (valence: positive or negative) x 2 (range: subitizing/counting) revealed a significant main effect of range, $F(1,23) = 13.36$, $MSE = 7354.83$, $p = .001$ but the main effect of valence did not approach significance, $F < 1$. The valence x numerosity interaction was significant, $F(1,23) = 8.10$, $MSE = 4673.72$, $p < .01$, indicating that positive and negative target enumeration rates differed as a function of numerosity. For positive targets, subitizing and counting rates were 364.2 and 260.6ms/item, respectively, and 303.0 and 278.8ms/item for negative targets. Subitizing slopes were shallower for negative targets (303.0ms/item) than for positive targets (364.2ms/item), $t(23) = 2.23$, $p < .05$, but the counting slopes for negative stimuli (278.8ms/item) did not differ from positive stimuli (260.6ms/item), $t(23) = .627$, $p = .537$.

Deviations from linearity and modeling. As in Experiment 1, we determined whether each participant's enumeration function deviated from linearity. However, in contrast to Experiment 1, with positive targets only one (out of 24) participant's enumeration slope showed a reliable deviation from linearity ($F = 2.9$, $p < .05$, all remaining slope deviations $Fs < 2.1$, $ps > .07$). For negative targets, four slopes out of 24 showed a deviation from linearity (all $Fs > 2.35$, $ps < .05$, remaining $Fs < 2.14$, $ps > 0.05$). In addition, we also tested whether a bilinear model was a significantly better fit to each participant's data than a linear model. This analysis showed that a bilinear fit was statistically better for only one participant, and then only for the negative targets, $F(2,99) = 3.83$, $p < .05$, all remaining $Fs < 2.5$, $ps > .09$.

Errors

As shown in Table 1, mean percentage error rates were greater on positive target trials than on negative target trials, $F(1,23) = 21.56$, $MSE = 89.85$, $p = .001$, and increased as numerosity increased, $F(7,161) = 33.63$, $MSE = 75.06$, $p < .001$. However, the valence x numerosity interaction did not approach significance, $F < 1$.

Stimulus valence rating task

Rating responses for each scale were scored from -3 (reflecting negative valence) to +3 (reflecting positive valence). The valence for each stimulus was then calculated by averaging the results over the four scales associated with that stimulus, for each participant individually. The overall averages were +2.40 (SD = 0.83) for the positive faces, -0.41 (SD = 1.01) for the neutral faces, and -1.30 (SD = 1.14) for the negative faces. A one-way within-subjects ANOVA revealed that valence ratings differed across stimuli, $F(2,46) = 89.24$, $MSE = 1.00$, $p < .001$; planned comparisons showed that the positively valenced face was, in fact, rated more as more positive than the neutral face, $t(23) = 9.25$, $p < .001$, with the negatively valenced face rated as more negative than the neutral face, $t(23) = 3.87$, $p = .001$.

Discussion

The main aim of Experiment 2 was to determine the efficiency of detecting, tagging and processing multiple valenced stimuli under conditions of attentional competition (i.e. when neutral distractors were also in the display). Unlike Experiment 1, participants would not be able to determine target numerosity without evaluating the visual features or valence of the target stimuli. The main findings were that: (i) overall, negative targets were enumerated approximately 500ms faster than positive targets, (ii) there was no clear subitizing-counting distinction, but (iii) the rate of enumeration for negative targets was greater than for positive targets, although only within the subitizing range (beyond the subitizing range there was no difference in enumeration rate). In terms of valence perception, our rating study showed robust differences between the positive, neutral and negative facial stimuli. Interestingly, the

rating data produced a larger difference between the negative and neutral stimuli than between the positive and neutral stimuli. Thus the negative face advantage for small numerosities does not appear to be due their being a larger difference between the negative and neutral stimuli than between the positive and neutral stimuli. The finding of robust target valence effect here, and the results of our rating study, further suggests that the lack of valence-based difference in Experiment 1 was not simply due to an insufficient difference in the perception or signaling of valence between our schematic face stimuli.

Experiment 3: Attention capture and disengagement from valenced faces

Experiment 2 showed that, in conditions of attentional competition, small numbers of negatively valenced stimuli were enumerated more efficiently than positive stimuli. This finding could arise because negatively valenced stimuli provide a stronger attentional signal than positive ones allowing attention to be sequentially allocated to them at a faster rate. Top-down knowledge of target valence might then be more effectively used to amplify (Wolfe, 1994) such negative signals, when compared with positively valenced signals. In this way, ‘setting’ (Folk, Remington & Wright, 1994; Folk, Remington & Johnston, 1992; Folk & Anderson, 2010) the attentional system to search for negative stimuli might be more effective than setting it to search for positive stimuli (see also Williams et al., 2005; cf. Blagrove & Watson, 2010; Williams et al., 2008).

Alternatively, the valence-based difference in Experiment 2 might have arisen due to more automatic processes related to attentional processing. The first possibility is that each negative stimulus might capture attention in a more effective manner than the positive stimuli; leading to a faster rate of enumeration for the negative targets. The second possibility is that although in previous work (Fox et al., 2001; Georgiou et al., 2005) negative faces have shown a selective disengagement deficit, in enumeration tasks the reverse might hold and

positive faces might be less easily disengaged from. This would lead to a slower reallocation of attention and hence, enumeration of positive stimuli.

The aim of Experiment 3 was to explore these possibilities further. This was achieved by presenting similar displays to those of Experiment 2, but asking participants to enumerate *neutral* faces presented among either positive or negative valenced distractors. If the advantage for enumerating negative stimuli amongst neutral distractors (Experiment 2) was because top-down attentional settings could boost the salience of negative stimuli more effectively than positive stimuli, there should now be little difference in enumerating neutral distractors amongst either positive or negative valenced distractors. This is because top-down knowledge could be used to set the attentional system for target neutral faces, and thus, neither positive nor negative stimuli should receive top-down activation (Wolfe, 1994). In contrast, if negative faces capture attention automatically, then enumeration of neutral expression targets should be less efficient in the presence of negative distractors than positive distractors, as negative faces would compete strongly with the neutral faces for attention. Finally, if positive faces tend to hold onto attention once engaged, then performance should be worse in the presence of positive distractors, than when negative distractors are present.

Method

Participants

Twenty four undergraduate students (six male), aged 18 to 26 years from the University of Warwick participated for course credit or payment of £5. All had self-reported normal or corrected-to-normal visual acuity.

Stimuli and apparatus

Stimuli and apparatus were identical to Experiment 2, except that each enumeration display now consisted of one to nine neutral targets and 11 to 19 (all either positively or negatively valenced faces) distractors respectively.

Design and procedure

The design and procedure were the same as Experiment 2.

Results

Reaction times

Overall RTs. Anticipatory RTs of less than 100 ms were discarded and treated as errors (two out of 6912 trials), and values above or below 2.5 standard deviations from their cell mean for each participant were also discarded (106 trials). Mean correct RTs were calculated for each cell of the design individually for each participant, with overall means shown in Figure 5. A 2 (distractor valence: positive or negative) x 8 (numerosity) ANOVA showed that RTs increased with numerosity, $F(7,161) = 103.07$, $MSE = 157093.81$, $p < .001$, and were 230ms faster overall with negative distractors, $F(1,23) = 7.54$, $MSE = 674766.39$, $p < .05$. However, the numerosity x distractor valence interaction did not approach significance, $F < 1$.

Enumeration slopes. The rates of enumerating targets were calculated for the subitizing (one to three) and counting (five to eight) numerosity ranges for each target valence. With positive valenced distractors, this revealed subitizing and counting rates of 262.0 and 216.4 ms/item, respectively, and of 240.6 and 200.6 ms/item for negative distractors. However, a 2 (distractor valence: positive or negative) and 2 (range: subitizing/counting) indicated that no main effects or their interaction approached significance, all $F_s < 1.74$, $p_s > .289$.

Deviations from linearity and modeling. One participant showed a deviation from linearity in their enumeration slope with positively valenced distractors, $F(6,108) = 2.31$, $p < .05$, all remaining $F_s < 1.94$, $p_s > .08$. With negatively valenced distractors, two participants showed a deviation from linearity, $F > 2.2$, $p < .05$, all remaining $F_s < 2.15$, $p_s > .05$. A bilinear model was a better fit than a linear model in the case of one enumeration function with

negatively valenced distractors only, $F(2,120) = 4.24, p < .05$; all remaining F s < 3.05 , all p s > 0.05 .

Errors

The overall error rate was 7.5% and mean error rates, as a function of condition and numerosity, are shown in Table 1. A 2 (valence: positive or negative) \times 8 (numerosity) within-subjects ANOVA showed that error rates increased as numerosity increased, $F(7,161) = 23.18, MSE = 48.05, p < .001$, and errors were greater overall in the positive distractor condition (7.36% vs. 5.79%), $F(1,23) = 7.12, MSE = 32.91, p < .05$. However, of most importance, the distractor valence \times numerosity interaction did not approach significance, $F(7,161) = 1.45, MSE = 35.06, p = .188$.

Discussion

The main aim of Experiment 3 was to determine whether the negative face enumeration advantage for small numerosities observed in Experiment 2 was due to top-down effects, or differences in the automatic processing of positive and negative valenced faces. The results were relatively clear. As in Experiment 2, there was a lack of a strong subitizing-counting slope distinction. However, of most interest, enumeration rates were statistically equivalent for counting neutral targets among either positive or negative valenced distractors. Moreover, this equivalence held over both the subitizing and counting range of numerosities.

If negative faces had captured attention automatically with each enumeration step, then enumerating neutral expression faces among negative distractors should have been less efficient than enumerating neutral faces among positive distractors. If positive stimuli had held onto attention, then the opposite should have been found. Instead, the data support the view that the negative target enumeration rate advantage for small numerosities in Experiment 2, was most likely due to participants being able to use top-down processes to boost the signals of the negatively valenced target faces more than the positive face targets.

This would have given negative stimuli a relative advantage and could arise if the negative stimuli produce a more salient feature signal than the positive stimuli. In turn, this would allow attention to be ‘set’ (Folk, Remington & Wright, 1994) for the detection of those salient feature signals. Note however, that the results suggest that any difference in salience between negative and positive faces appears to be relatively weak, and might be considered insufficient to cause automatic attention capture. This is consistent with our findings, as in the present context, adopting an attentional set for neutral stimuli appears to have overridden any potential differences between interference from positive and negative distractors on enumeration rates.

That said, although enumeration rates were statistically equivalent with negative and positive distractors, overall RTs were shorter for neutral targets with negative distractors than with positive distractors. This difference might have arisen if neutral targets were initially less discriminable (i.e. immediately after display onset) from positive distractors than from negative distractors, which then caused a delay in the onset of enumeration processes. Another possibility is that at display onset, a single positive distractor captured and held onto attention, again causing a delay in further processing. However, for this account to hold, we must assume that following this initial “hold”, no other positive distractors were able to hold onto attention (otherwise, enumeration rates would also have been reduced which was not found). Finally, the presence of negative distractors might have led to an increase in overall arousal levels (e.g., Dimburg & Öhman, 1996), driving an earlier application of enumeration processes or faster response initiation. Irrespective of this issue, the main finding from Experiment 3 was that enumeration rates were not affected by distractor valence, suggesting that multiple negative targets in Experiment 2 did not capture attention automatically, nor multiple positive distractors hold onto attention, both of which would have led to differences in enumeration rates.

Experiment 4: Enumeration of simple features

Taken together, findings from Experiments 2 and 3 suggest that negatively valenced stimuli provide a unique (or more discriminable) attentional signal that can be used by top-down processes to enhance the detection of those stimuli. However, it is possible that the observed negative target advantage might arise because of processing differences in the efficiency of detecting the differentiating feature between negative and positive faces (i.e., orientation of the curved mouth). For example, it might be that a downwards pointing curve (u-shaped) is more easily detected among horizontal lines than an upward pointing curve (n-shaped). According to this view, simple visual feature differences, unrelated to stimulus valence, could account for the results of Experiment 2. If this is the case, then the same findings should emerge even when those shapes are presented outside of a face context. To this end, in Experiment 4 participants enumerated n-shaped or u-shaped curves presented among horizontal line distractors. In addition to the enumeration task, we also ran an additional rating study to determine whether the mouth features presented in isolation would differ in perceived valence.

Method

Participants

Twenty four undergraduate students (six male), aged 18 to 34 years from the University of Warwick participated for course credit or payment of £5. All had self-reported normal or corrected-to-normal visual acuity. Twenty-five different participants volunteered to take part in the rating study and were obtained via opportunity sampling of undergraduate students at the University of Warwick.

Stimuli and apparatus

The stimuli were the same as those used in Experiment 2, except that the facial outline and eyes were deleted to leave just the mouth feature remaining. Thus, the individual stimuli

consisted of n-shaped or u-shaped curved targets presented among horizontal line distractors (see Figure 6).

Design and procedure

The design and procedure for both the enumeration task and the rating study were the same as Experiment 2. However importantly, the stimuli were not described in either valenced-based or facial feature terms. Participants were told to search for the upward pointing curve or the downward pointing curve among horizontal distractors.

Results

Enumeration task

Overall RTs. Anticipatory RTs of less than 100ms were discarded and treated as errors (one out of 6912 trials). For each participant, values above or below 2.5 standard deviations from their individual cell means were discarded (138 trials). Mean correct RTs were then calculated for each cell of the design, for each participant individually (overall means are shown in Figure 7).

The data were analyzed with a 2 (target: n-shaped curve or u-shaped curve) x 8 (numerosity) within-subjects ANOVA. This revealed that RTs increased as numerosity increased, $F(7,161) = 251.46$, $MSE = 88235.72$, $p < .001$. However, neither the main effect of target, $F(1,23) = 1.68$, $MSE = 58871.81$, $p = .208$, nor the target x numerosity interaction, ($F < 1$), approached significance.

Enumeration slopes. Enumeration slopes were calculated for each participant, for the subitizing (one to three) and counting (five to eight) ranges of numerosities for each target valence. This revealed subitizing and counting rates of 120.9 and 332.0 ms/item for downward pointing curves, and 133.4 and 336.9 ms/item for upward pointing curves.

A 2 (target: n- or u-shaped) x 2 (range: subitizing / counting) ANOVA revealed a significant main effect of range, $F(1,23) = 69.74$, $MSE = 14787.25$, $p < .001$. However, neither

the main effect of target, nor the target x range interaction approached significance (both $F_s < 1$).

Deviations from linearity. Deviations from linearity for the RT-numerosity function were calculated in the same way as in Experiment 1, over the range of 1 to 8 items. The number of participants (out of 24) whose enumeration functions revealed significant deviations from linearity were: 14 for u-shaped curve targets (all $F_s > 2.32$, $p_s < .05$) and 13 for n-shaped curve targets (all $F_s > 2.33$, $p_s < .05$).

RT Modeling. We determined the subitizing span by fitting a bilinear function to each participant's RTs and determining the flex point. The bilinear model provided a good fit to the data, with median R^2 values of 0.718 and 0.750 for downward and upward pointing targets respectively. The resulting mean flex points were, 3.32 (SD = 1.25) and 3.70 (SD = 1.23), for enumerating u- and n-shaped curves respectively and did not differ, $t(23) = 1.36$, $p = .187$.

The resulting mean best fit subitizing and counting slopes (parameters b1, b2) were 96.3 and 350.1 ms/item for u-shaped targets, and 120.3 and 363.8 ms/item for n-shaped targets. A 2 (target: u- or n-shaped) x 2 (range: subitizing / counting) revealed a significant main effect of range, $F(1,23) = 135.13$, $MSE = 10979.91$, $p < .001$. However, neither the main effect of target, $F(1,23) = 1.42$, $MSE = 6020.36$, $p = .246$ nor the range x target interaction, $F < 1$ approached significance. We also determined whether the bilinear model provided a significantly better fit to the data than a simple linear model. For u-shaped targets, a bilinear fit was better for 13 of the 24 participants, all $F_s > 3.53$, $p_s < .05$, and for n-shaped targets the bilinear fit was better for 17 participants, all $F_s > 3.53$, $p_s < .05$.

Errors

As shown in Table 1, mean percentage error rates were low overall ($< 2.6\%$). A 2 (target: u- or n-shaped) x 8 (numerosity, 1 to 8) within-subjects ANOVA revealed that error

rate increased as numerosity increased, $F(7,161) = 13.17$, $MSE = 15.83$, $p < .001$. However, neither the main effect of target nor the target x numerosity interaction approached significance, both $F_s < 1$.

Stimulus valence rating task

Valence ratings were analyzed in the same way as in Experiment 2. The u-shaped curved was rated highest (i.e. most positively) with an average valence rating of +2.38 (SD = 0.65), followed by the horizontal line, -0.47 (SD = 0.88) and the n-shaped curved, -1.15 (SD = 0.95). A one-way within-subjects ANOVA revealed that valence ratings differed across the stimuli, $F(2,48) = 106.7$, $MSE = .822$, $p < .001$; with planned comparisons showing that the u-shaped curve was rated more positively than the horizontal line, $t(24) = 12.37$, $p < .001$, and the n-shaped stimuli more negatively than the horizontal line, $t(24) = 2.58$, $p < .05$.

Discussion

Experiment 4 assessed whether the enumeration benefit for negative faces found in Experiment 2 was driven by simple visual differences, rather than by differences in stimulus valence. This was achieved by measuring performance for enumerating the valence-defining mouth feature from the face stimuli (presented in Experiment 2) when presented outside a facial context.

If simple u-versus n-shaped visual feature differences account for the negative face enumeration benefit, then enumerating n-shaped curves among horizontal distractors should have been more efficient than enumerating u-shaped curves. The results showed that this was not the case, with enumeration efficiency for the n- and u-shaped curves being statistically equivalent. Furthermore, there was actually a numerical trend for the n-shaped targets (which were present in the negative valenced faces of Experiment 2) to be enumerated less, rather than more, efficiently than the u-shaped targets (which were present in the positive faces of Experiment 2). Thus, these findings support the view that the negatively valenced

enumeration benefit found in Experiment 2 was driven by valence-based differences, rather than via differences in visual features between n- and u-shaped curves.

Interestingly, although there was no difference between enumerating the n- and u-shaped curve targets, there was a difference in their valence ratings. Participants reliably rated the u-shaped curve as more positive than the horizontal line, and the n-shaped curve as more negative. This dissociation between visual tagging performance and valence ratings might reflect differing degrees of top-down interpretation. When rating the stimuli, observers might have developed a context for the simple shapes in order to make sense of them, and this might have led to a difference in valence being reported. For example, with some thought, it would be easy to imagine that the n-shaped curve represented a sad mouth and a u-shaped curve a happy mouth. Nonetheless, the finding that the enumeration rates for u- and n-shaped targets did not differ suggests that any valence-based differences in isolated curves were insufficient to drive attentional allocation. Thus, in terms of target detection, the curves needed to be embedded within a facial context to be effective in guiding attention (see also Tipples, Atkinson and Young, 2002, for examples of when simple features need a face context in order to drive a processing advantage).

Experiment 5: Enumeration without distractors but with a valence-based judgment

Experiments 1 and 2 suggest that small numbers of negative valenced faces can be detected/enumerated more efficiently than positively valenced faces, but that this only holds under conditions of attentional competition, for example, when neutral distractors are present in the field (Experiment 2). If there are no other stimuli competing with the targets for selection, then the enumeration of positive and negative valenced stimuli did not differ (Experiment 1).

However, another difference between Experiments 1 and 2 is that, in Experiment 1, participants did not need to evaluate or process the valence of the stimuli because items could be enumerated without needing to process their expression. In other words, participants could in effect perform the task by enumerating the number of ‘blobs’ on the screen. In contrast in Experiment 2, participants had to enumerate only positive or negative stimuli presented among neutral distractors, which required that they made a stimulus valence judgment. It follows that valence-based differences might emerge even in conditions of low attentional competition (i.e., when distractors are absent) if the valence of the targets have to be consciously processed.

Another account of why enumerating negative and positive expression faces in Experiment 1 was equally efficient, might be because *any* relatively strong valence-based signals (whether positive or negative) are equally effective at guiding attention (i.e., a general emotionality effect; Martin, Williams & Clark, 1991). Supporting this possibility, several recent studies have found processing advantages for both positive and negative stimuli with pictorial (Brosch et al., 2008; Most et al., 2007) and word stimuli (Zeelenberg, Wagenmakers & Rotteveel, 2006) compared with neutral items. However, Experiment 1 could not assess this possibility because the enumeration of neutral valence faces was not measured. If valence per se is important for capturing or guiding attention effectively, then we might expect faces with positive and negative expressions to be enumerated more efficiently than those with neutral expression.

To test these possibilities, in Experiment 5, participants had to enumerate displays consisting of schematic faces with positive or neutral expressions in one block and negative or neutral faces in another block. Following the enumeration response, participants then indicated the valence of the stimuli that had been presented on that trial. This required a positive-neutral or negative-neutral valence judgment to be made on every trial in addition to

the enumeration task, similar to that in Experiment 2. If affective processing is important for obtaining valence-based effects, then we should now see a valence-based difference emerge even when no distractors are present. Similarly, if affective valence is generally, rather than specifically, effective in guiding attention, then faces with positive and negative expressions should be enumerated more efficiently than those with neutral expression.

Method

Participants

Twenty four undergraduate students (four male), aged 18 to 21 years from the University of Warwick participated for course credit or payment of £5. All had self-reported normal or corrected-to-normal visual acuity.

Stimuli and apparatus

The stimuli and apparatus were essentially the same as in Experiment 1, except that displays consisted of 1 to 8 items, which were all positive, all negative or all neutral expression faces.

Design and procedure

Each trial began with a blank screen (500ms), followed by a white central fixation dot (2mm x 2mm) for 1000ms, and then by the enumeration display consisting of between one and eight positively, neutral or negatively valenced faces. Participants determined how many items were present, and then pressed the space bar. The display was replaced with the prompt 'press 1 to 8' presented at the display center and participants were then required to press the numeric key corresponding to their answer. Following this, two adjacent faces were displayed at the screen center (14 mm apart, edge-to-edge). The face on the right was neutral and the face on the left face was either positive or negative depending on the block. The phrase 'Please enter emotion type' was displayed directly above the two faces, and participants pressed the left (left face) and right (right face) arrow keys to make their response. If

participants made an error on either the enumeration or the facial affect discrimination response, the word 'Incorrect' was then displayed for 1500ms in the centre of the screen.

The experiment used a fully within participants 3 (target valence: positive, neutral or negative) x 8 (numerosity) design. Each block contained 96 trials. A positive valence block consisted of eight replications of positive face trials and four replications of neutral face trials, for numerosities 1 to 8. A negative valence block was identical, with the replacement of the valenced face (i.e., positive faces were replaced by negative). This design ensured that, over the course of the experiment, participants saw an equal number of positive, negative and neutral face stimuli. Participants completed four blocks (i.e. two blocks of negative/neutral targets and two blocks of positive/neutral targets) to give a total of 16 trials per cell. Blocks were presented in an ABAB order, which was counterbalanced across participants.

Results

Reaction times

Overall RTs. Anticipatory RTs of less than 100 ms were discarded and treated as errors (four out of 9216 trials). For each participant, values above or below 2.5 standard deviations from their individual cell means were also discarded (192 trials). Mean correct RTs were then calculated for each cell of the design, individually for each participant (overall means are shown in Figure 8).

The data were analyzed with a 3 (valence: positive, negative or neutral) x 7 (numerosity) within-subjects ANOVA. This revealed that RTs increased as numerosity increased, $F(6,138) = 185.01$, $MSE = 122720.08$, $p < .001$. However, neither the main effect of valence ($F(2,46) = 1.02$, $MSE = 42479.36$, $p = .368$), nor the valence x numerosity interaction, $F(12,276) = 1.16$, $MSE = 13718.70$, $p = .316$, approached significance.

Enumeration slopes. Enumeration slopes were calculated for each participant, for the subitizing (one to three) and counting (five to seven) ranges of numerosities for each target

valence. This revealed subitizing and counting rates of 91.3 and 347.8 ms/item for positive targets, 71.4 and 346.7 ms/item for neutral targets, and 83.0 and 355.5 ms/item for negative targets.

A 3 (valence: positive, negative or neutral) x 2 (range: subitizing / counting) ANOVA revealed a significant main effect of range, $F(1,23) = 189.60$, $MSE = 13646.58$, $p < .001$. Neither the main effect of valence nor the valence x range interaction approached significance, both $F_s < 1$.

Deviations from linearity. Deviations from linearity for the RT-numerosity function were calculated in the same way as in Experiment 1, but over the range of 1 to 7 items. The number of participants (out of 24) whose enumeration functions revealed significant deviations from linearity were: 22 for negative targets (all $F_s > 3.06$, $p_s < .005$), 22 for neutral targets (all $F_s > 2.77$, $p_s < .05$), and 21 for positive targets (all $F_s > 3.82$, $p_s < .05$).

RT Modeling. As in Experiment 1, we determined the subitizing span by fitting a bilinear function to each participant's RTs and determining the flex point. The bilinear model provided a good fit to the data with median R^2 values of 0.738, 0.733, and 0.711 for positive, neutral and negative targets respectively. The resulting flex points were, 3.92 (SD = 0.99), 3.52 (SD = 0.81), and 3.90 (SD = 0.75), for enumerating positive, neutral and negative faces respectively and did not differ, $F(2,46) = 1.98$, $MSE = 0.627$, $p = .150$.

The resulting best fit subitizing and counting slopes (parameters b1, b2) were 84.4 and 396.8 ms/item for positive targets, 59.8 and 394.1 for neutral targets, and 83.0 and 396.8 ms/item for negative targets. A 3 (valence: positive, neutral or negative) x 2 (range: subitizing / counting) revealed a significant main effect of range, $F(1,23) = 178.23$, $MSE = 20701.88$, $p < .001$. However, neither the main effect of valence, nor the range x valence interaction, approached significance, both $F_s < 1$. We also determined whether the bilinear model provided a significantly better fit to the data than a simple linear model. For negative targets, a bilinear

fit was better than a linear fit for 23 of the 24 participants, all $F_s > 4.04$, $p_s < .05$, for neutral targets, 22 participants, all $F_s > 4.39$, $p_s < .05$, and for positive targets 21 participants, all $F_s > 5.01$, all $p_s < .05$.

Errors

Visual enumeration

As shown in Table 1, mean percentage error rates were low overall (1.9%) and were analyzed with a 3 (valence: positive, neutral or negative) x 7 (numerosity) within-subjects ANOVA. This revealed that errors increased as numerosity increased, $F(6,138) = 10.45$, $MSE = 8.56$, $p < .001$. However, neither the main effect of valence, nor the valence x numerosity interaction approached significance, both $F_s < 1$.

Face discrimination

Mean percentage error rates were low overall (1.84%) and were not analyzed further.

Discussion

A number of findings emerged. First, as in Experiment 1, there was a clear subitizing-counting distinction with small numerosities (up to approximately three or four items) being enumerated at a much faster rate than larger numerosities. Second, despite participants making valence discriminations on every trial, the results were essentially the same as in Experiment 1. That is, the enumeration of negatively and positively valenced face stimuli was equivalent for both small and large numerosities. Third, it is possible that any behaviorally-relevant emotional expression (whether positive or negative) might be used to guide attention efficiently (Brosch et al., 2008; Most et al., 2007; Zeelenberg, Wagenmakers & Rotteveel, 2006). According to this view, the efficiency of enumerating either positively or negatively affective faces should be equivalent, but *both* should be more efficient than the enumeration of neutral expression faces. By including neutral faces in the present experiment, this

possibility can be ruled out. All three expressions (positive, neutral and negative) produced essentially the same pattern of performance and statistically, were indistinguishable.

Experiment 6: Enumeration of photo-realistic faces

The findings so far suggest that there is no difference in the efficiency of enumerating negative or positive expression faces, unless distractors, competing for attentional resources, are also present. However, it is possible that the emotional signals presented by the schematic stimuli used thus far, are simply insufficient to generate a valenced-based difference when they are presented without other distracting items. It could be that more realistic faces, which perhaps contain a greater range of and/or more subtle affective cues would show a difference between the enumeration rates of positive and negative stimuli. Accordingly in Experiment 6, we repeated Experiment 5 but used photographic faces rather than schematic stimuli.

However, the use of photographic faces is not without problems. For example, using photographic faces sometimes results in the inclusion of unwanted artifacts (see Purcell, Stewart, & Skov, 1996; see also Blagrove & Watson, 2010, for consideration of the advantages and disadvantages of schematic versus realistic faces). However, to address these issues as effectively as possible, we chose three stimuli from the NimStim (Tottenham, et al., 2002) data set. Here, photographs of a female were selected, showing a positive, neutral and negative expression without introducing artifactual differences such as open/closed mouths or substantial perceptual differences in facial area. We also cropped the stimuli to remove any additional differences related to surface area, hair position etc. As in the earlier experiments, we ran an additional rating task to verify whether there was a robust difference in perceived valence across the three images used.

Method

Participants

Twenty four undergraduate students (six male), aged 18 to 28 years from the University of Warwick participated for course credit or payment of £5. All had self-reported normal or corrected-to-normal visual acuity. Twenty-six different participants volunteered to take part in the rating study and were obtained via opportunity sampling of undergraduate students at the University of Warwick.

Stimuli and apparatus

The stimuli and apparatus were essentially the same as in Experiment 5, except that that the displays consisted of photographic images. The images comprised of one female face from the NimStim (Tottenham et al., 2002) library showing three different expressions, happy, neutral and angry (image codes: 03F_NE_O, 03F_AN_O, and 03F_HA_O, respectively). These stimuli were chosen because the teeth were visible in all expressions, and there were no obvious color or shape artifacts. Each face was then cropped with an oval mask to obscure hair and outer facial features. The size of each stimulus was 22mm in height by 16mm wide.

Design and procedure

For the enumeration task, the design and procedure were identical to Experiment 5. The valence rating task followed the procedures used in the previous experiments.

Results

Enumeration task

Reaction times

RTs. Anticipatory RTs of less than 100 ms were discarded and treated as errors (three out of 9216 trials) and RTs on error trials were also discarded. Of the remaining data, for the RT analyses, values above or below 2.5 standard deviations from each participant's individual cell means were also removed (200 trials). Mean correct RTs were then calculated

for each cell of the design, individually for each participant (overall means are shown in Figure 9).

The data were analyzed with a 3 (valence: positive, neutral or negative) x 7 (numerosity) within-subjects ANOVA. This revealed that RTs increased as numerosity increased, $F(6,138) = 124.11$, $MSE = 143911.86$, $p < .001$. However, neither the main effect of valence, nor the valence x numerosity interaction were significant, both $F_s < 1$.

Enumeration slopes. Enumeration slopes were calculated for each participant, for the subitizing (one to three) and counting (five to seven) ranges of numerosities for each target valence. This showed subitizing and counting rates of 63.5 and 341.1 ms/item for positive targets, 72.8 and 310.2 ms/item for neutral targets, and 61.0 and 315.4 ms/item for negative targets. A 3 (valence: positive, negative or neutral) x 2 (range: subitizing / counting) ANOVA revealed a significant main effect of range, $F(1,23) = 84.84$, $MSE = 27910.53$, $p < .001$. However, neither the main effect of valence, nor the valence x range interaction approached significance, both $F_s < 1$.

Deviations from linearity. Deviations from linearity for the RT-numerosity function were calculated in the same way as in Experiment 1, but over the range of one to seven items. The number of participants (out of 24) whose enumeration functions revealed significant deviations from linearity were: 16 for negative targets (all $F_s > 2.30$, $ps < .05$), 17 for neutral targets (all $F_s > 2.36$, $ps < .05$), and 19 for positive targets (all $F_s > 2.35$, $ps < .05$).

RT Modeling. As in Experiment 1, we determined the subitizing span by fitting a bilinear function to each participant's RTs and determining the flex point. The bilinear model provided a good fit to the data with median R^2 values of 0.639, 0.646, and 0.627 for positive, neutral and negative targets respectively. The resulting mean flex points were, 3.74 (SD = 0.87), 3.52 (SD = 0.81), and 3.51 (SD = 0.97), for enumerating positive, neutral and negative faces respectively and did not differ, $F < 1$.

The resulting best fit subitizing and counting slopes (parameters b_1 , b_2) were 49.6 and 374.4 ms/item for positive targets, 71.6 and 348.8 for neutral targets, and 56.8 and 346.3 ms/item for negative targets. A 3 (valence: positive, neutral or negative) x 2 (range: subitizing / counting) revealed a significant main effect of range, $F(1,23) = 105.27$, $MSE = 30205.14$, $p < .001$. However, neither the main effect of valence, $F < 1$, nor the range x valence interaction, $F(2,46) = 1.08$, $MSE = 6794.01$, $p = .349$, approached significance. We also determined whether the bilinear model provided a significantly better fit to the data than a simple linear model. For positive targets, a bilinear fit was better for 19 of the twenty four participants, all $F_s > 4.29$, $p_s < .05$. For neutral targets, the bilinear fit was better for 16 participants, all $F_s > 4.48$, $p < .05$ and for negative targets a bilinear fit was better for 19 participants, all $F_s > 3.49$, all $p_s < .05$.

Errors

Enumeration task. Errors from the complete data set are shown in Table 1, mean percentage error rates were low overall (<2.2%) and were analyzed with a 3 (valence: positive, neutral or negative) x 7 (numerosity) within-subjects ANOVA. This revealed a significant main effect of numerosity, $F(6,138) = 6.06$, $MSE = 10.31$, $p < .001$. However, neither the main effect of valence, nor the valence x numerosity interaction were significant, both $F_s < 1$.

Face discrimination task. The overall error rate for indicating the valence of the face stimuli was low (1.94%), and was not analyzed further.

Stimulus valence ratings

The overall valence rating averages were +2.20 (SD = 0.62) for the positive face, +0.39 (SD = 0.61) for the neutral face, and -1.86 (SD = 0.79) for the positive face. A one-way within-subjects ANOVA revealed that valence ratings differed across stimuli, $F(2,48) = 180.93$, $MSE = .594$, $p < .001$; planned comparisons showed that the positively valenced face

was rated as more positive than the neutral face, $t(25) = 9.55$, $p < .001$, and the negatively valenced face, more negatively than the neutral face, $t(25) = 10.63$, $p < .001$.

Discussion

Experiment 6 assessed whether differences in enumerating positive, neutral and negative valenced expressions would occur in the absence of distractors, when photo-realistic faces were used as the stimuli. It is possible that the schematic faces used previously simply lacked sufficient affective strength to enable valence-based effects to emerge. However, these results show that this was not the case. Essentially, the same pattern of results occurred with realistic photographic stimuli as occurred in Experiment 5, when schematic face stimuli were used. Specifically, there was evidence of a subitizing-counting distinction, with smaller numerosities being processed more quickly than the larger numerosities; however, overall RTs and enumeration rates were not influenced by stimulus valence. As in Experiment 5, participants made a positive-neutral or a negative-neutral valence discrimination on every trial, and so again, the lack of a valence-based effect cannot be attributed to the lack of a need to make a valence discrimination. Similarly, the valence rating study confirmed that there were clear differences in the perceived valence of the three different stimuli.

General Discussion

The main aim of this study was to determine the efficiency of tagging multiple valenced stimuli. Clearly from an ecologically adaptive point of view, the early detection of potential threats (here, indicated by negatively valenced facial stimuli) will convey numerous survival advantages (e.g. Öhman et al., 2001; Öhman & Mineka, 2001). Consistent with this, previous work has shown that a single negatively valenced stimulus appears to capture or guide attention more strongly than a positively valenced target (Eastwood et al., 2001; Fox et al., 2000; Blanchette, 2006; Lipp et al., 2004). Furthermore, once attended, it might be more difficult to disengage attention from a negative stimulus than from a positive stimulus (e.g.,

Fox et al., 2001, 2002; Georgiou et al., 2005; Fenske & Eastwood, 2003). However, in real world interactions, we are often faced with multiple threats or negative stimuli and so, we might argue that the negative superiority effect is only useful adaptively if it also holds under conditions when multiple items need to be processed with priority. In this study, we assessed the processing of multiple valenced stimuli using an enumeration paradigm in which participants had to determine how many target stimuli were present within a display. The enumeration task allows us to examine multiple tagging performance which is proposed to be based on parallel ‘subitizing’ mechanisms (up to approximately three to four items) and also in conditions in which a serial attentional mechanism must be used (beyond four items).

Summary of main findings

The main findings were that valence-based effects only emerged under conditions of attentional competition. That is, when all items in the display had to be processed and there were other distractor elements present. When no distractors were present (Experiments 1, 5 and 6), valence had no reliable effect on subitizing rates, counting rates, subitizing span or overall RTs. This finding held even if participants had to make a valence-based discrimination/judgment on every trial (Experiments 5 and 6) and when realistic photographic stimuli were used (Experiment 6). Furthermore, the patterns of results were very similar to previous enumeration findings with non-valenced stimuli. In contrast, when distractors were present (Experiment 2), negative target RTs were faster overall, and although there was no clear subitizing-counting distinction, nonetheless small numbers of negative targets were tagged and enumerated more efficiently than positively valenced targets. However, beyond the subitizing range, enumeration rates did not differ. Experiment 4 tested and ruled out the possibility that visual feature differences could account for the apparent negative expression face advantage found in Experiment 2. When the ‘valence-defining’ mouth features were presented outside of a facial context, then there was no difference in

enumeration efficiency across the different stimuli. Experiment 3 examined possible differences in top-down and automatic guidance between the negatively and positively valenced faces. In terms of enumeration rates, the results showed that participants were no worse at enumerating / tagging neutral valenced faces among negative distractors than among positive distractors.

Accounting for the findings

Why were there no valence-based effects in the absence of distractors? From previous research, in which a detection advantage has been shown for negative face targets (i.e. attention has been guided efficiently to or attracted by these stimuli), we might have expected negative targets to be enumerated more rapidly than positive ones. Alternatively, if negative facial stimuli hold attention, then enumerating negative targets might have been slower than enumerating positive targets. In contrast to both these predictions, Experiments 1, 5 and 6 showed that there were no reliable valence-based differences when enumerating targets presented in isolation.

One explanation for the absence of a disengagement deficit for negative targets within the subitizing range might be that, for small numerosities, the number of items does not exceed the number of available FINSTs (Trick & Pylyshyn, 1993, 1994). Therefore, in these instances, bound tags do not need to be disengaged from their stimuli, once assigned (although note that we also failed to find a disengagement deficit *beyond* the subitizing range). However, even if this were the case, it implies that negative stimuli are also unable to attract multiple FINSTs any more efficiently than positive stimuli, when everything in a display has to be tagged.

An alternative explanation is that, in the absence of distractors, enumeration can proceed via representations available within a ‘master map’ of locations (Treisman & Gelade, 1980; Found & Müller, 1996; Watson & Maylor, 2006) that encodes *where* items are but not

what they are or *what features* they contain. Indeed, a central tenet of FINST theory is that the indexes or tags are specifically spatial in nature (e.g., Pylyshyn, 2001). That is, they are proposed to tag or index items individuated at a preattentive level, and act as pointers to each object's location. A single focus of attention can then be moved around the objects which are currently bound to FINSTs, in order to allow further processing, such as object identification or evaluating the spatial relationships between other (potentially identical) objects. Consistent with this view, subitizing performance is not impaired by item color heterogeneity (Watson & Maylor, 2006; see also Puts & de Weert, 1997), suggesting that enumeration may operate on representations which do not carry feature information. Similarly, Watson, Maylor and Bruce (2005) provided further evidence that subitization processes were specialized for tagging the locations of individual objects. In this instance, when observers were asked to enumerate how many features (different colors or orientations) were in a display visual (and hence, responses could not be based on object location), enumeration was particularly slow and serial, and small numerosities could not be subitized.

Thus, the efficient subitization of valenced stimuli might arise simply because multiple tags or FINSTs can be assigned on the basis of a location map without involvement of feature (or in this case, valence) information. Note however, that even when participants had to also make a valence-based discrimination on every trial (Experiments 5 and 6), there was still no valence-based difference in tagging/enumerating either small or large numerosities. This shows that the valence-based effect found for enumerating targets among distractors (Experiment 2) is not merely due to the need to process valence in that task. Rather, it seems that the negative valence advantage arises only in conditions in which target signals must be separated from distractor signals within a single display (we return to this aspect below).

Although these accounts might explain why preattentive subitizing was not affected by valence, they do not provide an explanation for why enumeration beyond the counting range was unaffected by valence, even when distractors were present. Recall that previous work has shown that tagging small numbers of items (subitizing) requires or generates very few eye movements (Simon & Vaishnavi, 1996; Watson, Maylor & Bruce, 2007), indicating that subitizing can be a spatially parallel process. However, beyond the subitizing range, there is approximately one eye movement per additional item. This suggests that it is likely that participants serially attended to individual stimuli beyond the subitizing range. One might expect that such serial processing would entail, or provide, opportunity for the processing of individual stimulus features or valence (indeed, counting rates were around 360ms/item, which would allow plenty of time for stimulus processing). In this case, we might have expected an effect of stimulus valence (even without the inclusion of a specific valence judgment task), because enumeration would not have proceeded on the basis of a rapid and parallel assignment of FINSTs within a feature-neutral master map. It follows that we might have expected to find an effect of valence within the counting range.

One explanation for this unexpected finding can be based on the role of eye movements in enumeration discussed above. Watson, Maylor and Bruce (2005a) proposed that the need to make eye movements for accurate counting could explain why the enumeration rates of older adults were no slower than the rates of young participants. According to generalized slowing theory, older adults' responses can be a linear transformation of young adults' responses (Cerella, 1990; Cerella, Poon, & Williams, 1980; Salthouse, 1985). Based on this, the difference between older and young adults enumerating rates should have been greater within the slower, more difficult counting range than within the subitizing range – which they were not. By contrast, in a visual search task, where performance was less dependent on eye movements, older adults' search rates were slowed

when task difficulty increased. Similarly, increasing target-distractor similarity had a selective effect on the subitizing range of numerosities, but no effect within the counting range (Watson, Maylor, Allen & Bruce, 2007). Watson, Maylor and Bruce, (2005a, see also Watson, Maylor & Bruce, 2005b; Watson, Maylor, Allen & Bruce, 2007) proposed that the relatively slow and noisy eye movements needed for accurate counting acted to mask or wash out the smaller attentional-based deficits resulting from old age (or the increased difficulty as target-distractor similarity increased).

Applied to the current findings, it is possible that the requirement to make eye movements when enumerating beyond the subitizing range had the effect of masking, or washing out, any smaller attention-based differences between processing negative and positive stimuli. It follows that any beneficial attentional effects, due to negative valence, may not emerge when slower and potentially noisier processes are required to successfully perform a visual task.

The influence of distractors

When neutral distractors were present in the display, an effect of valence did emerge. Small numbers of negative targets were enumerated more efficiently, and responses were approximately 500ms faster overall. Based on the above discussion, this is what we might expect if targets could no longer be enumerated on the basis of activity solely within a feature-neutral master map. Instead, tagging the targets must entail separating them from the distractors on the basis of their features and/or valence. In these conditions of attentional competition, valence is now more likely to be able to exert an influence. One way in which the required selective tagging could take place is by positively biasing the features or valence of the target items (Wolfe, Cave & Franzel, 1989; Wolfe, 1994), or by inhibiting the features/valence of the distractors (Treisman & Sato, 1990; Watson & Humphreys, 1998) to increase the salience of the relevant target items within a master map. These enhanced master

map locations could then be tagged/subitized, although this selective biasing might incur an overall RT increase (for further discussion related to the selective enumeration of colors, see Watson & Maylor, 2006; see also Found & Müller, 1996). The more efficient tagging of negative, compared with positive, targets indicates that negative targets provide a stronger signal to support multiple selective tagging, or that their signal can be more easily enhanced than positive targets. Either way, it suggests that the representation of (at least a small number of) multiple negative targets is stronger, or can be better strengthened, than the representations of multiple positive targets.

This suggestion also meshes with previous work, in which observers had to count how many upward or downward pointing curves were present in displays where groups of three upward or downward curves were arranged to form multiple face-like stimuli (Eastwood, Smilek & Merikle, 2003). Here, it was found that counting the number of target curves was slower in displays in which the triplets of curves formed negative faces, compared with when they formed positive faces. Eastwood et al. concluded that negative faces captured attention at a ‘global level’, impairing the detection of individual features within them. At first glance, this result seems incompatible with our absence of valence-based effects in Experiment 1. However, note that in Eastwood et al., (2003), the task required the identification and discrimination of shapes within the display. Thus, in contrast to Experiment 1, their counting task could not be performed on the basis of excitation within a feature-neutral master-map of locations. It would seem that whenever stimuli need to be separated for the attentional allocation to targets, then the visual system becomes sensitive to valence-based properties within the display. In contrast, when tasks can be performed on the basis of simple object presence alone, valence appears to have little effect on attentional deployment. Note also, that the mere processing of valence per se appears to have little effect on performance. Even when a stimulus valence decision had to be made on every trial (Experiments 5 and 6), we still

obtained no effect of valence for enumerating multiple items when no distractors were present.

Even though we have found that the multiple tagging/subitizing of negative targets was more efficient than that of positive targets, nonetheless it was still relatively inefficient when compared with subitizing in the absence of distractors. It was also considerably less efficient than subitizing of color-defined stimuli (Trick & Pylyshyn, 1993; Watson, Maylor, Allen & Bruce, 2007). Furthermore, there was little evidence of a distinct subitizing-counting difference in the enumeration slopes. Indeed numerically, counting rates were more efficient than subitizing rates (although, note that error rates did increase substantially more with numerosity in the *counting* range compared with the *subitizing* range). Thus, if negative valence does act to provide a unique attentional signal, then is it considerably weaker than the signals provided by (perhaps) more primitive features such as color and shape.

Consistent with this ‘weak signal’ hypothesis is the finding that tagging/enumerating neutral targets was not differentially influenced by the presence of negative compared with positive distractors. If the valence-based signals were stronger for negative stimuli, then we would have expected greater interference by negative distractors than by positive distractors – which was not the case (Experiment 3). Instead, the data are consistent with the proposal that negative stimuli provide more salient (or more discriminable) signals than positive stimuli which can be better boosted by top-down influences. In this way, searching for multiple negative targets (adopting a ‘negative attentional set’; Folk, Remington, & Johnston, 1992), can improve the efficiency of tagging these threats, but adopting an alternative search goal neutralizes any differential effect of positive versus negative stimuli. Beyond the subitizing range, in the presence of distractors, performance was again equivalent for both sets of valenced targets, which is consistent with the earlier described eye movement-based wash out effect (Watson, Maylor & Bruce, 2005a).

Despite the relatively weak effects of valence on enumeration rates, negative targets were still processed approximately 500 ms faster overall, and showed an advantage, even when distractors were present. This difference may reflect an initial advantage in terms of the onset of enumeration processes. Alternatively, it might reflect the more efficient parallel grouping and rejection of distractors (Duncan & Humphreys, 1989; Horstmann, Scharlau & Ansorge, 2006), or biasing of target features (Wolfe, Cave & Franzel, 1989; Wolfe, 1994), in order to enhance the salience of target items (see earlier).

Summary

This paper started with a light-hearted example of successfully detecting multiple hostile stimuli in our environment. Previous work has shown that a single negatively valenced stimulus can be detected more efficiently than a positive stimulus. Here, we have shown that multiple negative stimuli also enjoy an overall selection advantage, and the rate of processing small numbers of negative stimuli can be somewhat faster than that of positive stimuli. However, beyond around three or four items, and in conditions of low attentional competition (i.e. absence of distractors), there appears to be no negative superiority effect. It would seem that whenever a task can be performed on the basis of object presence alone, valence might have little impact on attentional processing. Further exploring of the conditions under which negative stimuli do not demonstrate a selection advantage, and the limits of any such advantage, will be valuable goals for future research.

Footnotes

¹ The R^2 values reported here are somewhat smaller than those reported by Watson, Maylor and Bruce (2005). This is because they fitted the bilinear model using the participant cell means of the correct RT data, whereas here, we fit the data using the individual correct RTs. For comparison with previous work, when the RTs were fit using the participants' mean RTs, the median R^2 values were .980 and .984 for positive and negative targets respectively.

² This method provides a more robust test than those used previously because a departure from linearity, whilst inconsistent with a linear function, does not necessarily mean that a bilinear function is more appropriate. For example, a deviation from linearity could arise from a number of alternative patterns of data including a U- or inverted U-shaped function. For this reason, we include an explicit test of whether a bilinear function provided a better fit to the data than a linear function, and also show the individual participant model fits (Figure 3).

³ For example, previous values for the subitizing range, and subitizing/counting rates include: 3.37 items, 40.85 ms/item, 342.15 ms/item (Watson, Maylor, Allen & Bruce., 2007), 3.60 items, 29.3 ms/item, 311.7 ms/item (Watson, Maylor & Bruce, 2005a), and 3.32 items, 22.2 ms/item, 320.0 ms/item (Watson, Maylor & Bruce, 2005b).

Acknowledgements

We are grateful to Rhian Lewis and Emma Chew, for their kind assistance in collecting the data for Experiments 1 and 2, and Francesca Woolgar and Jacqueline Jordan in Experiments 4 to 6.

References

- Atkinson, J., Campbell, F. W., & Francis, M. R. (1976). The magic number 4_0: A new look at visual numerosity judgments. *Perception, 5*, 327–334.
- Blagrove, E. & Watson, D.G. (2010). Visual marking and facial affect: Can an emotional face be ignored? *Emotion, 10*, 147-168.
- Blanchette, I. (2006). Snakes, spiders guns & syringes: How specific are evolutionary constraints on the detection of threatening stimuli? *Quarterly Journal of Experimental Psychology, 59*, 1484-1504.
- Brosch, T., Sander, D., Pourtois, G., & Scherer, K.R. (2008). Beyond fear: Rapid spatial orienting toward positive emotional stimuli. *Psychological Science, 19*, 362-370.
- Cerella, J. (1990). Aging and information-processing rate. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 201–221). San Diego, CA: Academic Press.
- Cerella, J., Poon, L. W., & Williams, D. M. (1980). Age and the complexity hypothesis. In L. W. Poon (Ed.), *Aging in the 1980s* (pp. 332–340). Washington, DC: American Psychological Association.
- Cole, G. C., Kentridge, R. W., & Heywood, C. A. (2004). Visual salience in the change detection paradigm: The special role of object onset. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 464-477.
- Dimburg, U. & Öhman, A. (1996). Behold the Wrath: Psychophysiological Responses to Facial Stimuli. *Motivation and Emotion, 20*, 149-182.
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433–458.

- Eastwood, J., Smilek, D., & Merikle, P.M. (2001). Differential attentional guidance by unattended faces expressing positive and negative emotion. *Perception & Psychophysics*, 63, 1004-1013.
- Eastwood, J.D., Smilek, D., & Merikle, P.M. (2003). Negative facial expression captures attention and disrupts performance. *Perception & Psychophysics*, 65, 352-358.
- Egeth, H.E., Leonard, C.J., & Palomares, M. (2008). The role of attention in subitizing: Is the magical number 1? *Visual Cognition*, 16, 463-473.
- Fenske, M. J., & Eastwood, J. D., (2003). Modulation of focused attention by faces expressing emotion: Evidence from flanker tasks. *Emotion*, 3, 327–343
- Folk, C.L., & Anderson, B.A. (2010). Target-uncertainty effects in attentional capture: Color-singleton set or multiple attentional control settings? *Psychonomic Bulletin & Review*, 17, 421-426.
- Folk, C.L., Remington, R.W. & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 1030-1044.
- Folk, C.L., Remington, R.W., & Wright, J.H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 317-329.
- Found, A & Müller, H.J. (1996). Searching for unknown feature targets on more than one dimension: Investigating a “dimension-weighting” account. *Perception & Psychophysics*, 58, 88-101.
- Fox, E., Lester, V., Russo, R., Bowles, R.J., Pichler, A., & Dutton, K. (2000). Facial expressions of emotion: Are angry faces detected more efficiently? *Cognition & Emotion*, 14, 61-92.

- Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General*, 130, 681-700.
- Georgiou, G.A., Bleakley, C., Hayward, J., Russo, R., Dutton, K., Eltiti, S and Fox, E. (2005). Focusing on fear: Attentional disengagement from emotional faces. *Visual Cognition*, 12, 145-158.
- Hampton, C., Purcell, D. G., Bersine, L., Hansen, C. H., & Hansen, R. D. (1989). Probing “pop-out”: Another look at the face-in-the-crowd effect. *Bulletin of the Psychonomic Society*, 27, 563-566.
- Hansen, C. H., & Hansen, R. D. (1988). Finding the face in the crowd: An anger superiority effect. *Journal of Personality & Social Psychology*, 54, 17-924.
- Horstmann, G., Borgstedt, K., & Heumann, M. (2006). Flanker effects with faces may depend on perceptual as well as emotional differences. *Emotion*, 6, 28-39.
- Horstmann, G., Scharlau, I, & Ansorge, U. (2006). More efficient rejection of happy than of angry face distractors in visual search. *Psychonomic Bulletin & Review*, 13, 1067-1073.
- Kaufman, E. L., Lord, M. W., Reese, T. W., & Volkman, J. (1949). The discrimination of visual number. *American Journal of Psychology*, 62, 498–525.
- LeDoux, J. E. (1998). Fear and the brain: Where we have been, and where are we going? *Biological Psychiatry* 44, 1229-1238.
- LeDoux, J.E. (1996) *The emotional brain*. New York: Simon & Schuster.
- Lipp, O.V., Derakshan, N., Waters, A.M. & Logies , S. (2004) Snakes and cats in the flower bed: Fast detection is not specific to pictures of fear-relevant animals, *Emotion*, 4, 233-250.
- Loftus, G.R., & Masson, M.E. (1994). Using confidence intervals in within-subjects designs. *Psychonomic Bulletin & Review*, 1, 476-490.

- Lundqvist, D., & Öhman, A. (2005). Emotion regulates attention: The relation between facial configurations, facial emotion, and visual attention. *Visual Cognition*, 12, 51-84.
- Lundqvist, D., Esteves, F., & Öhman, A. (1999). The face of wrath: Critical features for conveying facial threat. *Cognition and Emotion*, 13, 691-711.
- Lundqvist, D., Esteves, F., & Öhman, A. (2004). The face of wrath: The role of features and configurations in conveying social threat. *Cognition and Emotion*, 18, 161-182.
- Martin, M., Williams, R., & Clark, D. (1991). Does anxiety lead to selective processing of threat-related information? *Behaviour, Research and Therapy*, 29, 147-160.
- Most, S.B., Smith, S.D., Cooter, A.B., Levy, B.N., & Zald, D.H. (2007). The naked truth: Positive, arousing distractors impair rapid target perception. *Cognition and emotion*, 21, 964-981.
- Nasrallah, M., Carmel, D., & Lavie, N. (2009). Murder, she wrote: Enhanced sensitivity to negative word valence. *Emotion*, 9, 609-618.
- Öhman, A., & Mineka, S. (2001) Fears, phobias and preparedness: Towards an evolved module of fear and fear learning. *Psychological Review*, 108, 483-522.
- Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: A threat advantage with schematic stimuli. *Journal of Personality & Social Psychology*, 80, 381-396.
- Olivers, C.N.L., & Watson, D.G. (2008). Subitizing requires attention. *Visual Cognition*, 16, 439-462.
- O'Regan, J. K., Rensink, R. A., Clark, J. J. (1999). Change-blindness as a result of 'mudsplashes'. *Nature*, 398, 34-34.
- Phelps, E.A., Ling, S., Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science*, 17, 292-299.

- Puts, M. J. H., & de Weert, C. M. M. (1997). Does color influence subitization? *Acta Psychologica*, 97, 71-78.
- Pylyshyn, Z. W. (1989). The role of location indexes in spatial perception: A sketch of the FINST spatial-index model. *Cognition*, 32, 65-97.
- Pylyshyn, Z. W. (2000). Situating vision in the real world. *Trends in Cognitive Sciences*, 4, 197-207.
- Pylyshyn, Z. W. (2001). Visual indexes, preconceptual objects, and situated vision. *Cognition*, 80, 127-158.
- Rensink, R. A. (2000). The dynamic representation of scenes. *Visual Cognition*, 7, 17-42.
- Salthouse, T. A. (1985). *A theory of cognitive aging*. Amsterdam: North-Holland.
- Seligman, M.E.P. (1970). On the generality of the laws of learning. *Psychological Review*, 77, 406-418.
- Seligman, M.E.P. (1971). Phobias and preparedness. *Behaviour Therapy*, 2, 307-330.
- Simon, T. J., & Vaishnavi, S. (1996). Subitizing and counting depend on different attentional mechanisms: Evidence from visual enumeration in afterimages. *Perception & Psychophysics*, 58, 915-926.
- Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science*, 7, 301-305.
- Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, 1, 261-267.
- Simons, D. J., & Levin, D. T. (1998). Failure to detect changes to people during a real-world interaction. *Psychonomic Bulletin & Review*, 5, 644-649.
- Svenson, O., & Sjöberg, K. (1983). Speeds of subitizing and counting processes in different age groups. *Journal of Genetic Psychology*, 142, 203-211.

- Tipples, J., Atkinson, A. P., Young, A. W. (2002). The eyebrow brown: A salient social signal. *Emotion*, 2, 288-296.
- Tottenham, N., Borscheid, A., Ellertsen, K., Marcus, D.J., & Nelson, C.A. (2002). *Catgorization of facial expressions in children and adults: Establishing a larger 367 stimulus set*. Poster presented at the Cognitive Neuroscience Society annual meeting, San Francisco, CA.
- Treisman, A., & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 459-478.
- Trick, L. M., & Enns, J. T. (1997a). Clusters precede shapes in perceptual organization. *Psychological Science*, 8, 124–129.
- Trick, L.M., & Pylyshyn, Z.W. (1994). Why are small and large numbers enumerated differently? A limited-capacity preattentive stage in vision. *Psychological Review*, 101, 80-102.
- Watson, D.G. & Humphreys, G.W. (1997). Visual Marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review*, 104, 90-122.
- Watson, D.G. & Humphreys, G.W. (1998). Visual marking of moving objects: A role for top-down feature based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 946-962.
- Watson, D.G. & Humphreys, G.W. (1999). The magic number four and temporo-parietal damage: Neurological impairments in counting targets amongst distractors. *Cognitive Neuropsychology*, 16, 609-629.

- Watson, D.G., Maylor, E.A., & Manson, N.J. (2002). Aging and enumeration: A selective deficit for the subitization of targets among distractors. *Psychology and Aging, 17*, 496-504.
- Watson, D.G., & Maylor, E.A. (2006). Effects of color heterogeneity on subitization. *Perception & Psychophysics, 68*, 319-326.
- Watson, D.G., Maylor, E.A., & Bruce, L.A.M. (2005a). Search, enumeration and aging: Eye movement requirements cause age-equivalent performance in enumeration but not in search tasks. *Psychology and Aging, 20*, 226-240.
- Watson, D.G., Maylor, E.A., & Bruce, L.A.M. (2005b). Effects of age on searching for and enumerating targets that cannot be detected efficiently. *Quarterly Journal of Experimental Psychology, 58A*, 1119-1142.
- Watson, D.G., Maylor, E.A., & Bruce, L.A.M. (2007). The role of eye movements in subitizing and counting. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1389-1399.
- Watson, D.G., Maylor, E.A., & Manson, N.J. (2002). Aging and enumeration: A selective deficit for the subitization of targets among distractors. *Psychology & Aging, 17*, 496-504.
- Watson, D.G., Maylor, E.A., Allen, G.E.J., & Bruce, L.A.M. (2007). Early visual tagging: Effects of target-distractor similarity and old age on search, subitization, and counting. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 549-569.
- Williams, M.A., McGlone, F., Abbott, D.F., & Mattingley, J.B. (2008). Stimulus driven and strategic neural responses to fearful and happy facial expressions in humans. *European Journal of Neuroscience, 27*, 3074-3082.

- Williams, M.A., Moss, S.A., Bradshaw, J. L., Mattingley, J.B. (2005b). Look at me, I'm smiling: Visual search for threatening and non-threatening facial expressions. *Visual Cognition*, 12, 29-50.
- Wolfe, J. M. (1998). Visual search. In H. Pashler (Ed.), *Attention* (pp. 13-74). Hove, East Sussex, England: Psychology Press.
- Wolfe, J.M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review*, 1, 202-238.
- Wolfe, J.M., Cave, K.R., & Franzel, S.L. (1989). Guided search: an alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 15, 419-433.
- Yantis, S., & Hillstrom, A. P. (1994). Stimulus driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 95- 107.
- Zeelenberg, R., Wagenmakers, E-J., & Rotteveel, M. (2006). The impact of emotion on perception: Bias or enhanced processing? *Psychological Science*, 17, 287-291.

Table 1. Mean percentage error rates as a function of target type and numerosity for Experiments 1 to 5.

Target Type	Numerosity								
	1	2	3	4	5	6	7	8	9
Experiment 1									
Positive	1.56	1.04	0.78	1.56	0.78	7.81	2.86	6.51	4.69
Negative	0.78	0.26	2.08	0.52	2.08	3.65	4.69	5.99	4.17
Experiment 2									
Positive	1.04	7.03	7.29	10.68	11.98	17.19	19.27	26.56	24.48
Negative	0.78	3.65	3.39	4.95	7.55	10.16	14.58	20.05	20.05
Experiment 3									
Positive distractors	0.52	2.34	2.08	6.51	6.77	12.24	12.50	15.89	15.89
Negative distractors	0.78	1.56	3.39	3.65	6.25	8.85	10.94	10.94	14.06
Experiment 4									
u-shaped curve	0.00	1.56	0.78	1.82	0.52	3.65	3.39	6.77	5.21
n-shaped curve	0.52	0.26	0.52	1.82	2.08	2.34	4.17	6.25	4.17
Experiment 5									
Positive	0.52	0.78	1.30	0.26	1.04	3.65	2.60	4.43	
Neutral	1.04	0.00	0.52	0.52	1.30	3.39	2.86	5.47	
Negative	0.26	1.04	0.26	0.78	1.04	2.34	2.86	7.29	
Experiment 6									
Positive	0.52	1.30	0.52	0.78	0.78	2.60	2.08	7.29	
Neutral	1.30	0.26	0.78	1.30	1.04	1.82	3.13	7.03	
Negative	1.30	0.26	1.04	1.56	0.78	1.82	4.43	7.03	

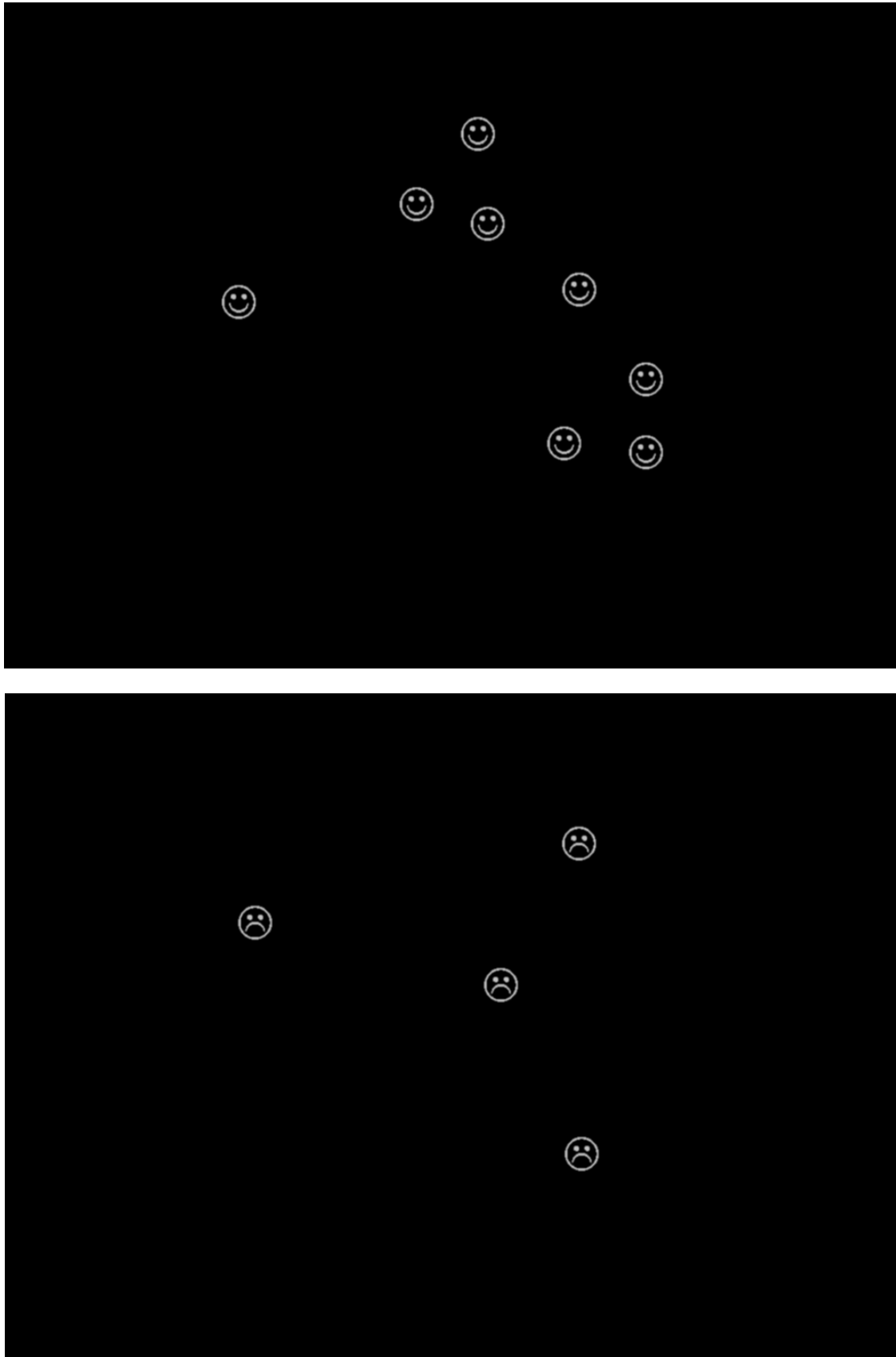


Figure 1. Example displays (screen captures) for positive targets (top panel) and negative targets (bottom panel) for Experiment 1.

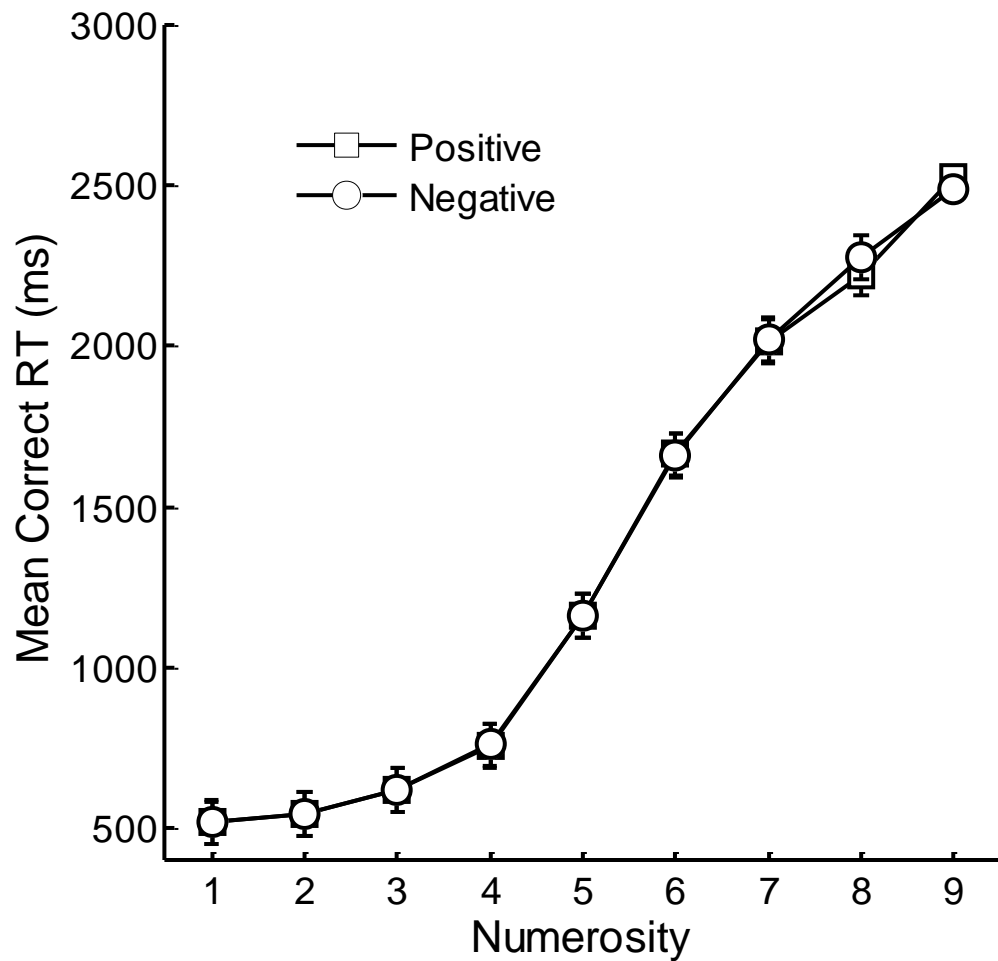


Figure 2. Mean correct RTs as a function of valence and numerosity for Experiment 1 (enumerating valenced faces). Error bars indicate $\pm 95\%$ CI appropriate for a within-subjects design (Loftus & Masson, 1994).

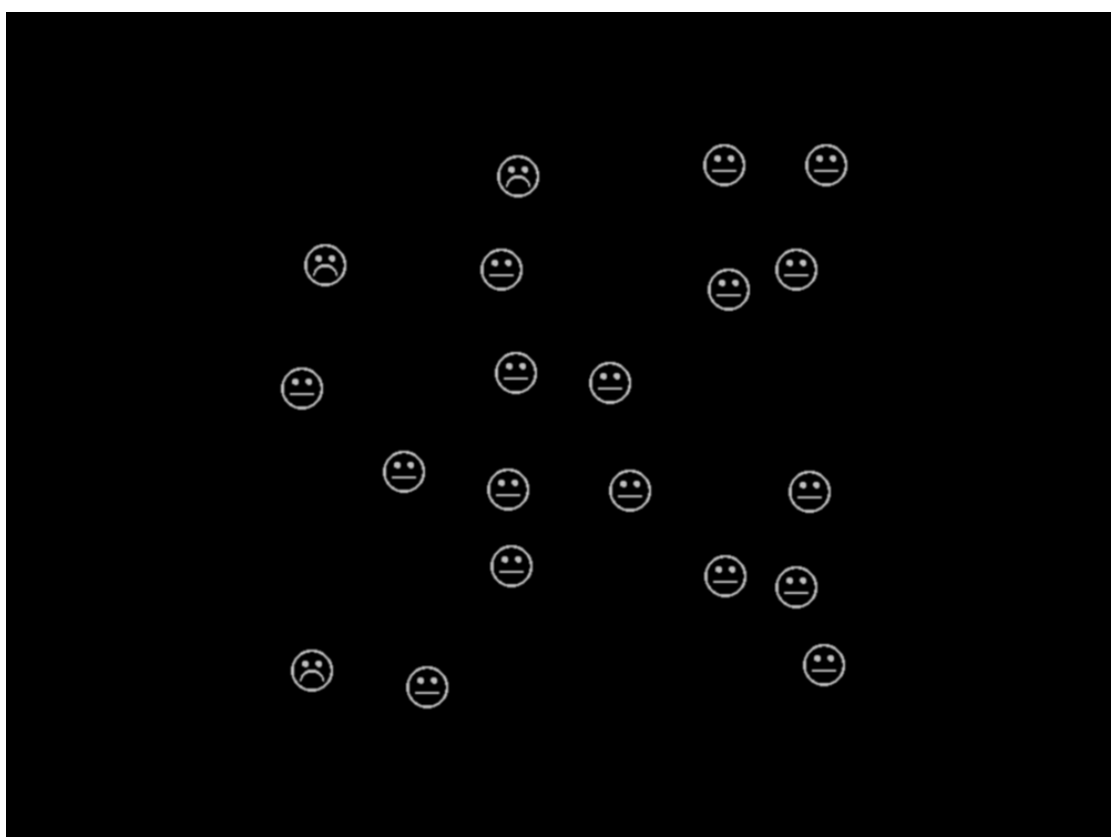
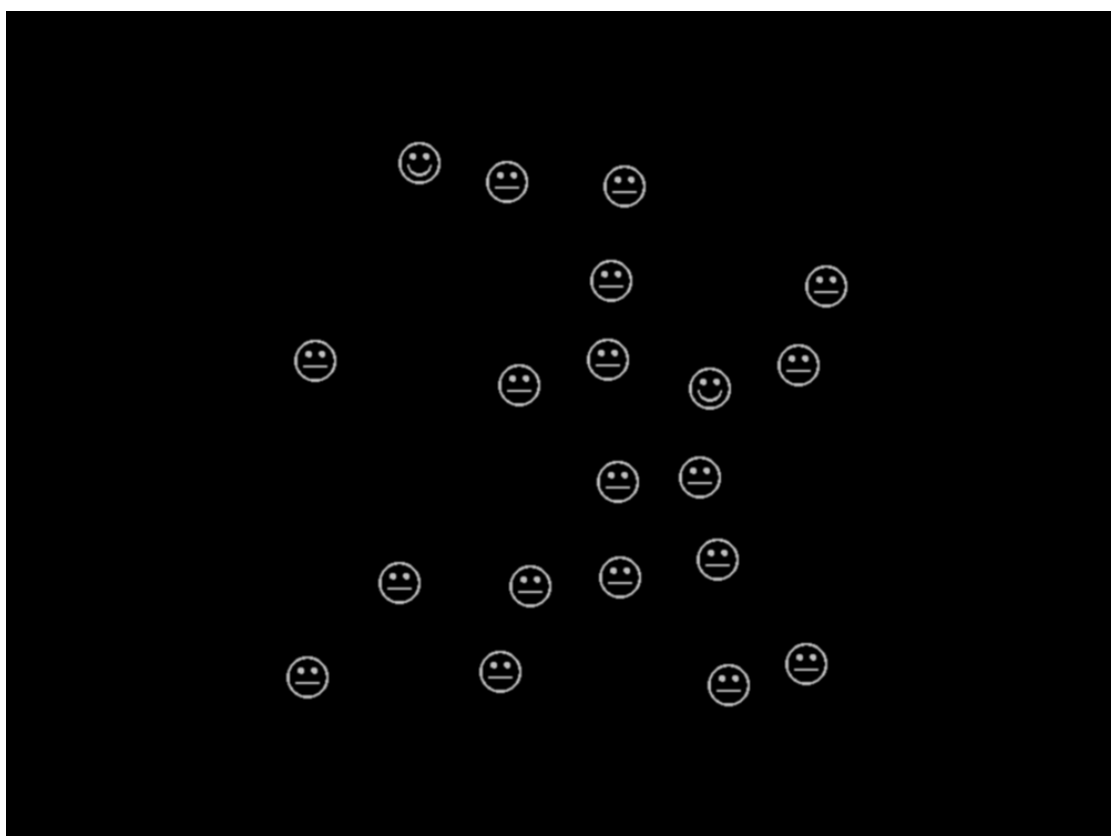


Figure 3. Example displays for positive targets (top panel) and negative targets (bottom panel) for Experiment 2.

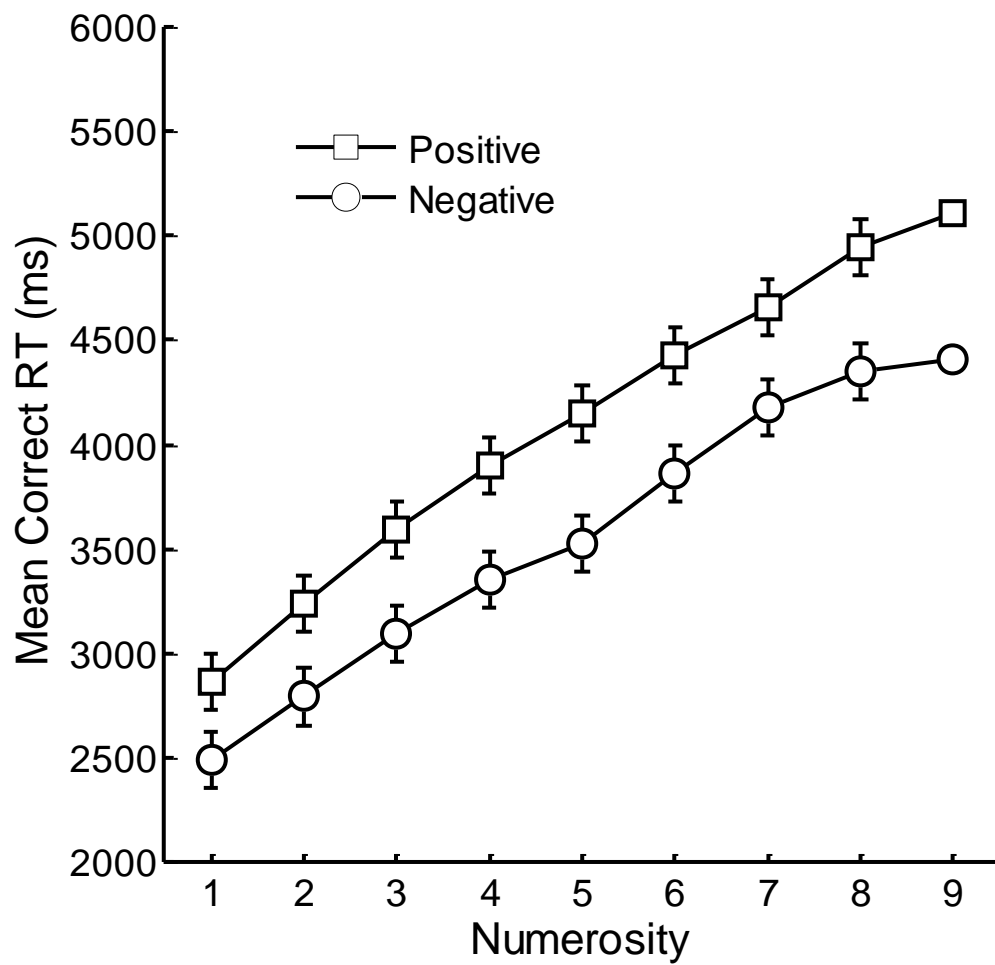


Figure 4. Mean correct RTs as a function of valence and numerosity for Experiment 2 (enumerating valenced faces among neutral distractors). Error bars indicate $\pm 95\%$ CI appropriate for a within-subjects design (Loftus & Masson, 1994).

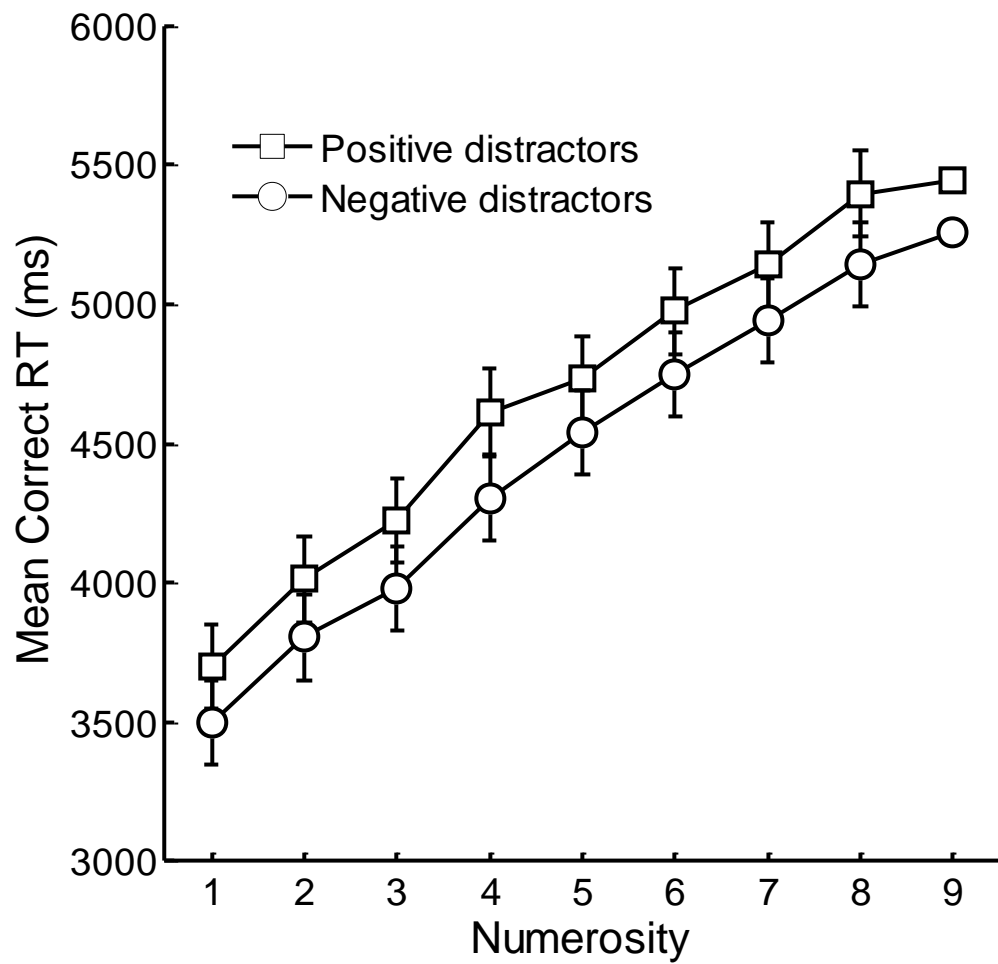


Figure 5. Mean correct RTs as a function of valence and numerosity for Experiment 3 (enumerating neutral faces among valenced distractors). Error bars indicate $\pm 95\%$ CI appropriate for a within-subjects design (Loftus & Masson, 1994).

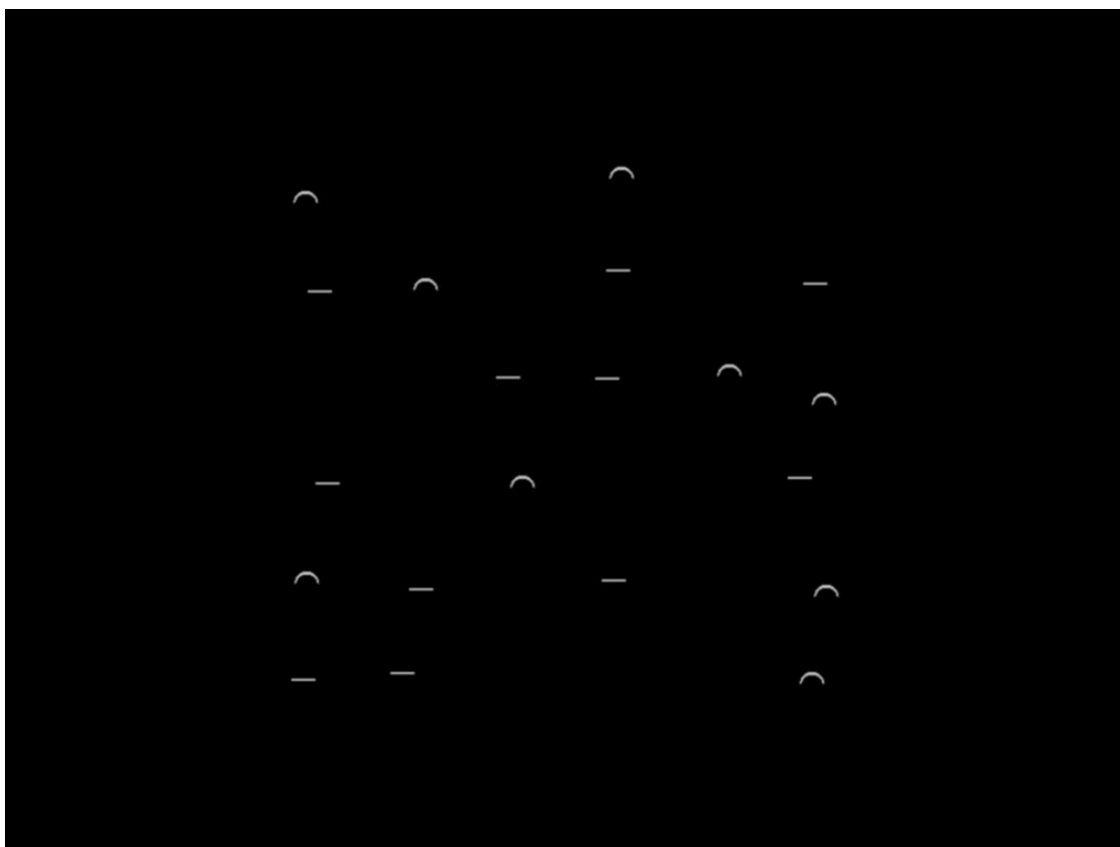
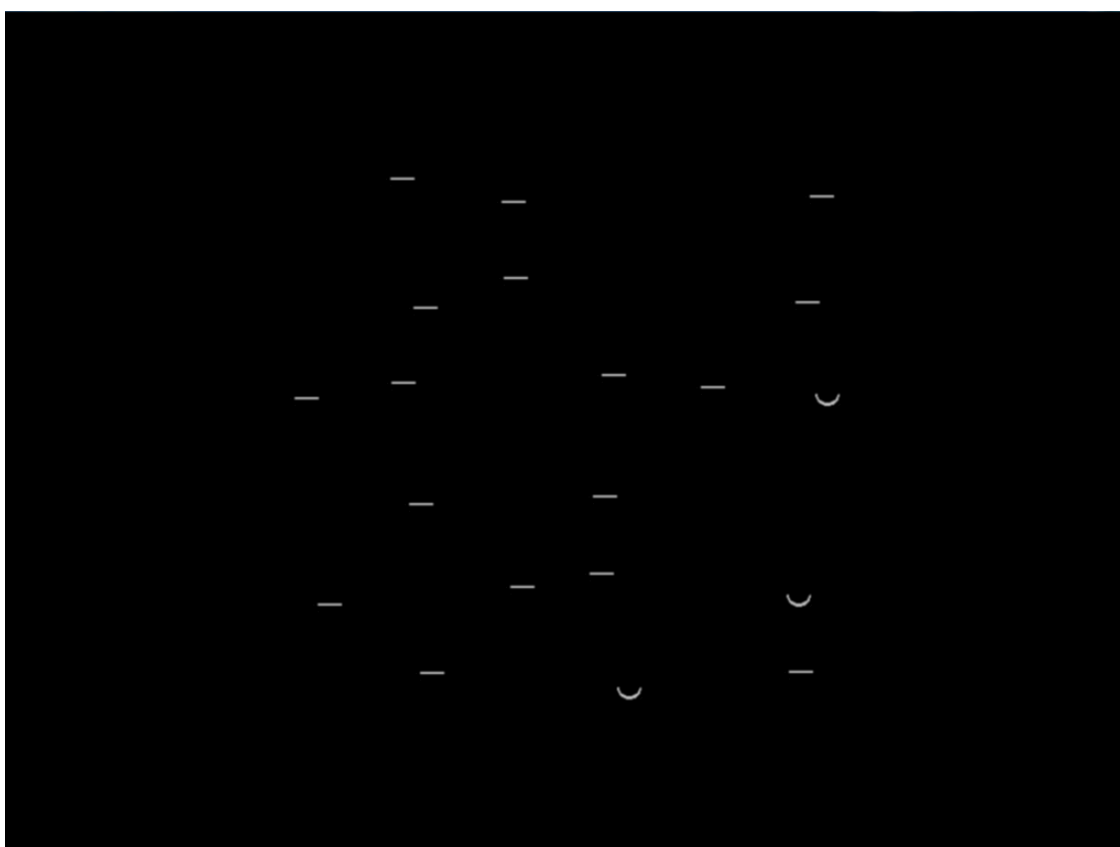


Figure 6. Example displays for u-shaped targets (top panel) and n-shaped targets (bottom panel) for Experiment 4.

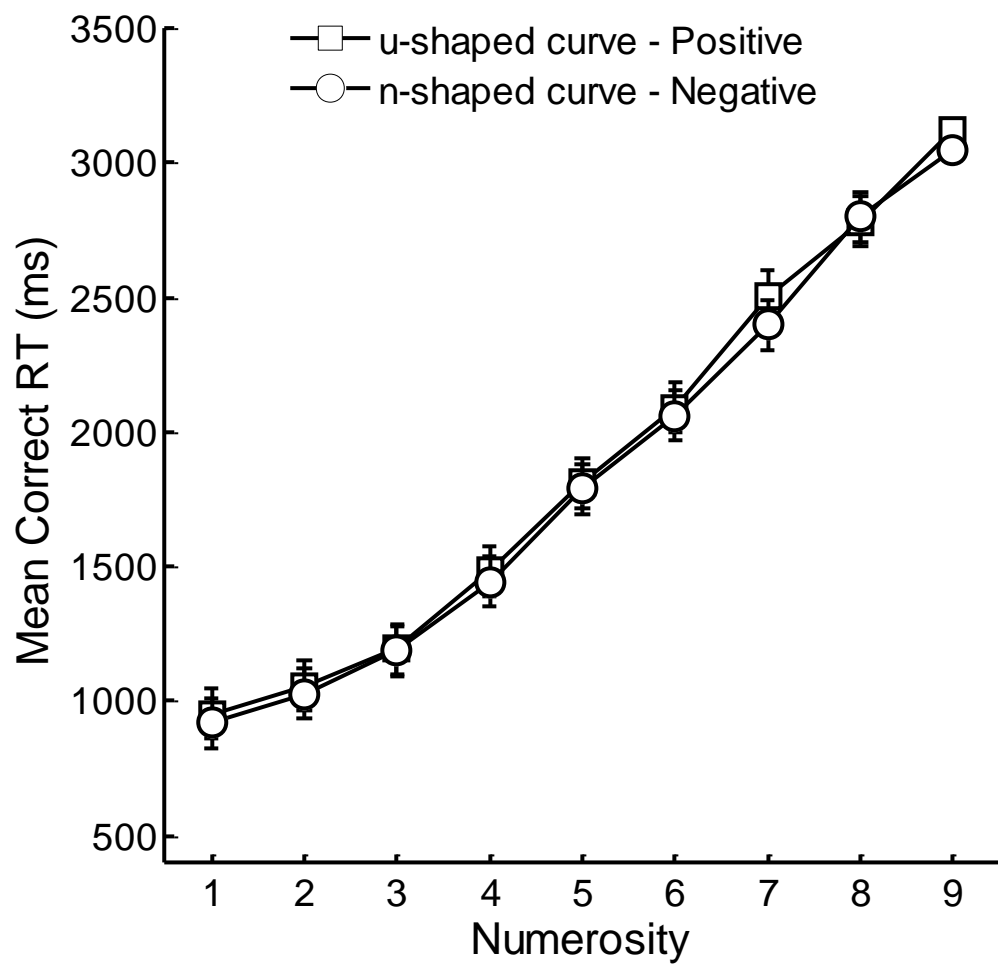


Figure 7. Mean correct RTs as a function of valence and numerosity for Experiment 4 (enumerating curved lines among straight lines). Error bars indicate $\pm 95\%$ CI appropriate for a within-subjects design (Loftus & Masson, 1994).

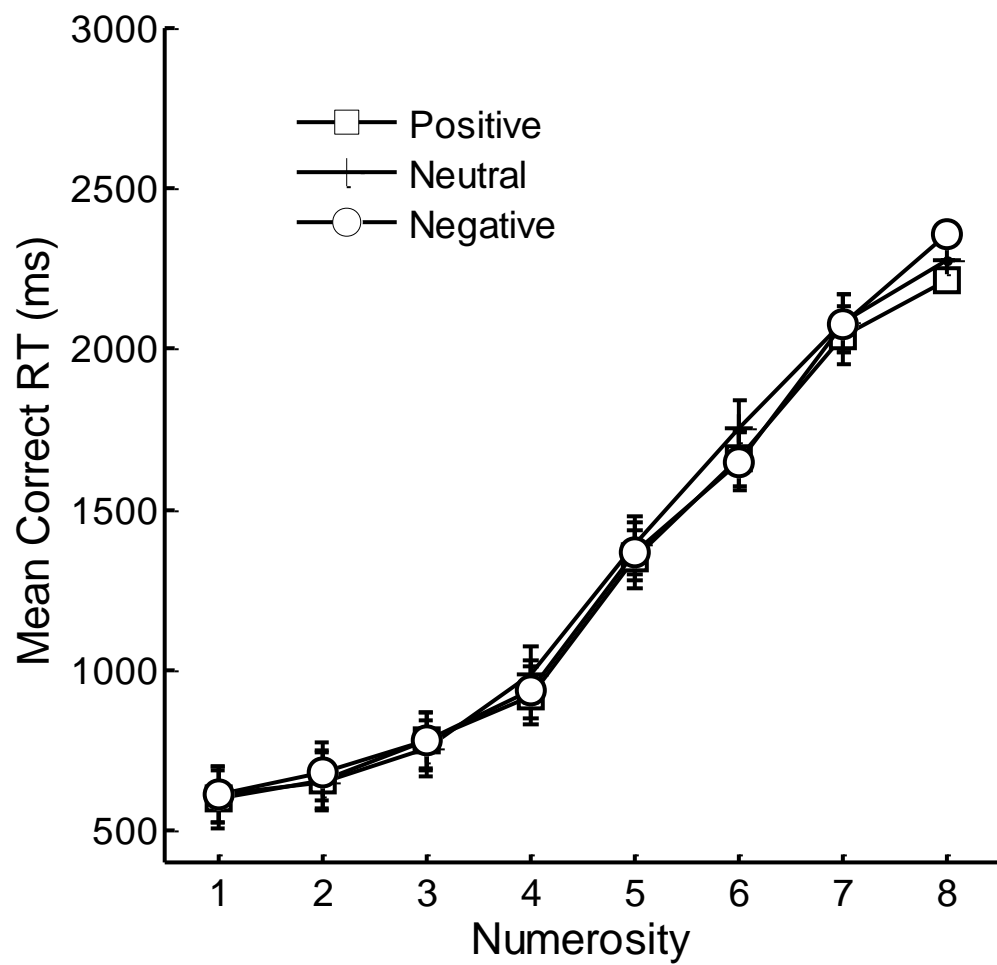


Figure 8. Mean correct RTs as a function of valence and numerosity for Experiment 5 (enumerating valenced stimuli). Error bars indicate $\pm 95\%$ CI appropriate for a within-subjects design (Loftus & Masson, 1994).

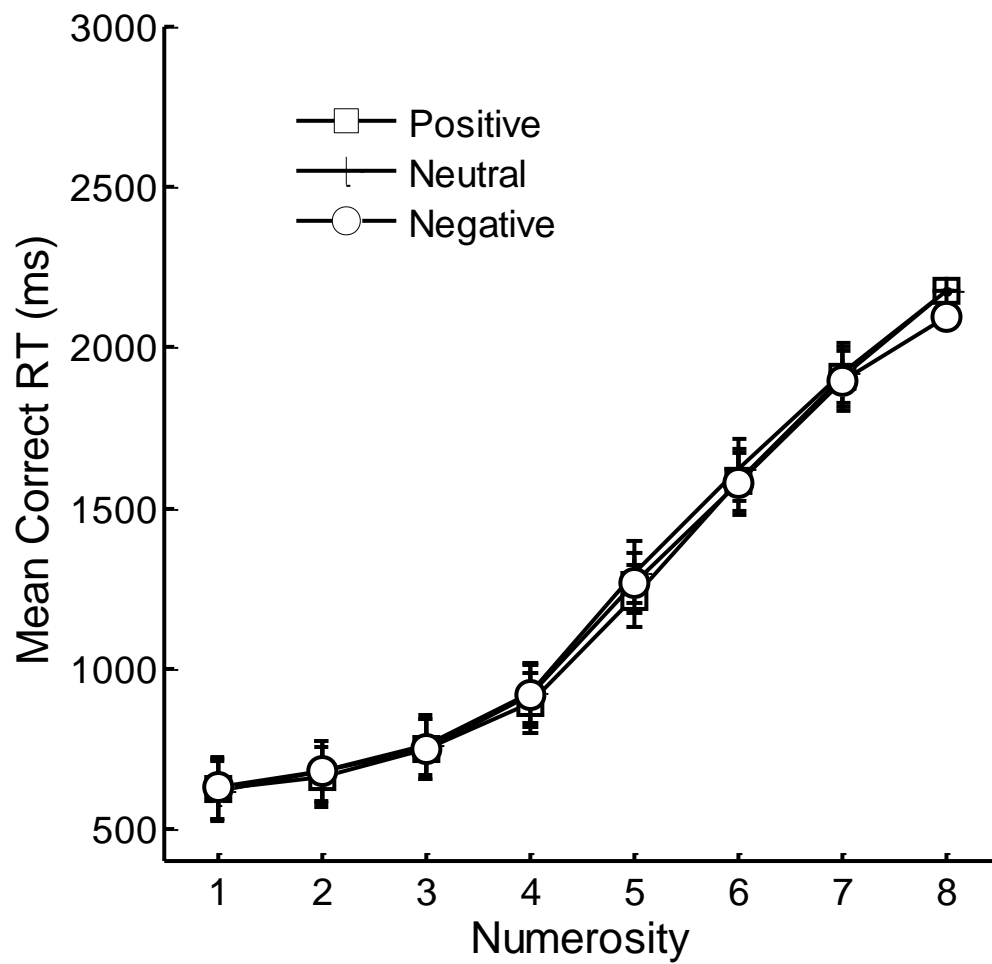


Figure 9. Mean correct RTs as a function of valence and numerosity for Experiment 6 (enumerating valenced photorealistic stimuli). Error bars indicate $\pm 95\%$ CI appropriate for a within-subjects design (Loftus & Masson, 1994).