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# Semantics is crucial for the right-hemisphere involvement in metaphor processing: Evidence from mouth asymmetry during speaking

Paraskevi Argyriou[a], Sarah Byfield[b] and Sotaro Kita[c]

[a]School of Psychology, Frankland Building, University of Birmingham, Edgbaston, B15 2TT

pxa180@bham.ac.uk

[b]School of Psychology, Frankland Building, University of Birmingham, Edgbaston, B15 2TT

sarahbyfield@btinternet.com

[c]Department of Psychology, University of Warwick, Coventry, CV47AL

s.kita@warwick.ac.uk

## Author Note

Correspondence concerning this article should be addressed to Paraskevi Argyriou, School of Psychology, Frankland Building, University of Birmingham, Edgbaston, B15 2TT, UK. Tel.: 0044(0)1214147209. E-mail address: pxa180@bham.ac.uk

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**Abstract**

Research on the neural basis of metaphor provides contradicting evidence about the role of right and left hemispheres. We used the mouth opening asymmetry technique to investigate the relative involvement of the two hemispheres whilst right-handed healthy male participants explained the meaning of English phrases. This technique is based on the contralateral cortical control of the facial musculature and reflects the relative hemispheric involvement during different cognitive tasks. In particular, right-handers show a right-sided mouth asymmetry (right side of the mouth opens wider than the left) during linguistic tasks, thus reflecting the left hemisphere specialisation for language. In the current study, we compared the right-sided mouth asymmetry during metaphor explanation (e.g., explain the meaning of the phrase "to spin a yarn") and concrete explanation (e.g., explain the meaning of the phrase "to spin a golf ball"), and during the production of content and function words. The expected right-sided mouth asymmetry reduced during metaphorical compared to concrete explanations suggesting the relative right-hemispheric involvement for metaphor processing. Crucially, this right-sided mouth asymmetry reduction was particularly pronounced for the production of content words. Thus, we concluded that semantics is crucial to the right-hemispheric involvement for metaphorical speech production.

*Keywords*: metaphorical speech production; word-class; mouth asymmetry; right-hemisphere

## Introduction

There are many studies investigating what determines the neural recruitment of metaphorical language processing, and several theoretical accounts have been proposed about the hemispheric lateralization of metaphor (for a review see Schmidt, Kranjec, Cardillo, & Chatterjee, 2010). However, there is contradicting evidence for the involvement of the right hemisphere in metaphor processing (e.g., Right Hemisphere Hypothesis, Brownell et al., 1990; for alternative views see Rapp et al., 2007). Furthermore, most of the studies have been focusing on metaphor processing in comprehension tasks rather than metaphorical speech production. In this study, we will use the mouth asymmetry technique during speech production, which reflects relative hemispheric involvement during verbal tasks (for a review see Graves and Landis, 1990). Additionally, we will provide evidence that the right hemisphere is involved during metaphorical speech production and in particular during production of content words related to metaphor.

According to the Right Hemisphere Hypothesis for Metaphor (Brownell et al., 1990) the right hemisphere has a privileged role in lexical-semantic processes related to metaphor comprehension. There are several empirical studies providing evidence in favour of this hypothesis. However, the overall conclusion based on the findings remains somewhat vague mainly because the studies used different populations (i.e., patients vs. healthy participants), tasks (i.e., metaphor judgement vs. plausibility judgement vs. lexical decision) and stimuli (i.e., sentences vs. single words; novel vs. familiar metaphors).

The first evidence for the right hemisphere involvement for metaphor came mainly from studies of patients with brain damage. For example, Winner and Gardner (1977) have shown a deficit in appreciation of metaphorical meanings in patients with right hemisphere lesions compared to those with left hemisphere lesions in a sentence-picture matching task. However, the pattern was reversed when patients were asked to verbally explain the meanings of the metaphorical phrases in the sentences; that is patients with right hemisphere lesions offered appropriate metaphorical explanations of the phrases while patients with left hemisphere lesions produced literal verbal explanations. They proposed that both hemispheres contribute to metaphorical competence, but the right hemisphere is crucially engaged in the "visualization" of metaphors.

In addition, studies with healthy participants have found stronger right-hemispheric engagement whilst processing metaphorical compared to literal stimuli. For example, Anaki et al. (1998) used the divided visual field technique and the word priming paradigm and showed that initial activation for metaphorical meanings involves both right and left hemispheres and maintenance particularly involves the right hemisphere only. Initial activation and maintenance of literal meanings involved the left hemisphere only. The findings, though limited to single words, highlight the importance of time course of each hemisphere's involvement in processing semantic link between words. Moreover, a positron emission tomography neuroimaging study (Bottini et al., 1994) found right-hemispheric activation during judgement of the plausibility of metaphorical sentences compared to literal ones. Bottini et al. (1994) also highlighted the importance of the task's semantic load for the relative hemispheric involvement during metaphor processing. For example, a lexical decision task where subjects had to identify non-words embedded within metaphorical and literal sentences reveals greater right-hemispheric activation than a metaphorical sentence comprehension task. Furthermore, some studies suggest that it is not metaphoricity *per se* which determines the involvement of each brain hemisphere. It is rather the degree of saliency. An expression is considered as salient when its meaning is familiar, conventional, highly frequent and predictable (Giora et al., 2000). Jung-Beeman (2005) suggests there is a core, bilateral, neural network which is involved in the semantic processing of metaphors. Specifically, the right hemisphere is predominantly involved for the processing of novel metaphors compared to conventional ones (Ahrens et al., 2007; Cardillo et al., 2010; 2012; Faust and Mashal, 2007; Mashal, et al., 2005; Schmidt et al., 2007), for the processing of non-salient meanings compared to salient ones (Giora et al., 2000), and for the processing of distant semantic relationships compared to closely related word meanings (Mashal et al., 2007).

Some fMRI studies failed to fully support the Right Hemisphere Hypothesis for Metaphor. For example, Stringaris et al. (2007) provided neuro-imaging data while participants judged the plausibility of metaphorical and literal sentences and failed to show a differential activation of the right-inferior frontal gyrus for the comparison literal vs. metaphorical. Also, Rapp et al. (2004; 2007) used metaphorical judgement ("is the sentence metaphorical or literal") and connotation judgement ("does the sentence have positive or negative connotations") of sentences, and they did not find any activation in the right-hemispheric structures for the metaphorical sentences. Benedek et al. (2014) investigated production of metaphor using a paraphrase task. Participants were presented with a short sentence (e.g., "the lamp is glaring") and asked to provide either a literal ("bright") or a metaphorical ("a supernova") word that replaces the adjective without changing the meaning very much. The regions more activated for the metaphor condition than for the literal condition are activated either bilaterally or only in the left hemisphere.

Mixed results regarding the Right Hemisphere Hypothesis for Metaphor may relate to various factors. First, different methodologies reveal different aspects of metaphor processing. For example, the cognitive activity measured in behavioural experiments (as in reaction times in Anaki et al., 1998) differs from the neural correlates of the activity captured in brain-imaging studies (as in BOLD signal in regions of interest in Rapp et al., 2004 and Stringaris, et al., 2007). Although equivalence in findings would clearly support a certain hypothesis about how the two hemispheres contribute to metaphorical and literal interpretations of linguistic stimuli, different findings from different methodologies are not necessarily contradictory. If two cognitive tasks (metaphorical vs. literal processing) result in different reaction times, this does not necessarily mean that they will be subserved by different neural pathways. Second, the nature of stimuli differs greatly across studies. For example, in some studies (e.g., Stringaris et al., 2007), the degree of saliency or novelty of the linguistic expressions has not been accounted for, whereas it is controlled in others (i.e., Mashal et al., 2005). Similarly, some studies focus on metaphorical comprehension for single words (i.e., Anaki et al., 1998) as opposed to sentences (i.e., Rapp et al., 2004; 2007). Finally, the involvement of each hemisphere during metaphor processing is task sensitive. For example, plausibility judgement (i.e., Stringaris et al., 2007) may involve too many cognitive processes that it has washed out the critical difference between literal and metaphorical stimuli thus failed to reveal any metaphor specific activations. To sum up, any study focusing on the hemispheric involvement during metaphorical processing and using any type of methodologies needs to carefully account for the role of semantics so that the involvement of the right hemisphere is neither masked nor marked due to not metaphor specific processing demands or linguistic variables.

As the above literature review reveals, the role of the two hemispheres and that of semantics in metaphor processing remains controversial. In addition, most of the studies investigated metaphor comprehension, rather than *production* (as far as we know, Benedek et al. 2014 is the only production study). Thus, it still remains unresolved if the right hemisphere is involved in metaphor processing during speech production and if semantics is crucial for this particular involvement.

The contributions of the two hemispheres during cognitive processes (e.g., linguistic, visual imagery, and emotional tasks) have been investigated using measurement of mouth asymmetry. The foundational assumption of this measurement is that each side of the lower facial areal is controlled by the contralateral cortex (Adams, Victor, & Ropper, 1997; Gardner, 1969). Therefore, if one hemisphere is particularly involved in a task that requires mouth opening, there will be greater opening on the contralateral side of the mouth.

Several studies validated asymmetries in mouth openings during speech production as an indicator of the role of the two hemispheres in various speech production tasks. For example, Graves and Landis (1985; 1990) indicated that healthy, right-handed speakers open the right side of their mouth wider than the left during propositional speech (e.g., spontaneous speech, word list generation, repetition), thus suggesting the left hemisphere control over speech production. This pattern is reversed (left side opens wider than the right) during automatic speech (e.g., singing, counting, reciting the days of the week), which is considered to be processed by the right hemisphere (see for a review Lindell, 2006). In addition, Code, Lincoln, and Dredge (2005) compared the mouth asymmetry patterns during propositional speech production by right-handed stuttering and non-stuttering speakers. They found a bilateral pattern for stutterers compared to a clear right-sided mouth asymmetry for the non-stutterers. This finding supports models about a distinct hemispheric control of speech production in stutters and non-stutters, thus further highlighting the sensitivity of the mouth asymmetry technique.

The mouth asymmetry as an indicator of hemispheric specialisation has also been validated in studies of emotional expressions (e.g. smile). Graves, Goodglass, and Landis (1982) showed that healthy, right-handed participants open the right side of the mouth more widely than the left during propositional speech linguistic tasks compared to spontaneous smiles. This reflects the left hemisphere cerebral specialization for language and the right hemisphere involvement for emotion processing during smiles. Similarly, Wyler, Graves, and Landis (1987) showed a clear left-sided mouth asymmetry during smiles, which is particularly apparent during spontaneous compared to posed smiles (Wylie & Goodale, 1988). Developmental studies with infants have also successfully used the mouth asymmetry technique to investigate the lateralization of emotional expressions. For example, Holowka and Petitto (2002) showed that infants (5-12 months old) open the right side of their mouth wider than the left when they are babbling (a precursor to speech) compared to smiling. Interestingly, Schuetze and Reid (2005) showed a right-hemispheric control for negative emotional expressions (left-sided bias in mouth movements of sadness) which strengthens with age (from 12 to 24 months old), while this pattern was absent for the control of positive emotional expressions.

The above studies show that the mouth asymmetry technique is sensitive to differential hemispheric involvement across tasks. In addition, it is a non-invasive, inexpensive and safe technique inferring relative involvement of the hemispheres in real time, during actual speech production. However, this technique has not been used to investigate the hemispheric involvement for metaphorical speech production, which is still a very much-unresolved question.

In a preliminary study, Argyriou and Kita (2013) tested right-handed speakers (different participants from the current study) and showed that right-sided mouth asymmetry reduced when they explained metaphorical phrases compared to concrete ones (e.g., “to spin a yarn” vs. “to spin a golf ball”). This finding is in line with the relative right-hemispheric involvement during metaphor compared to concrete explanations. However, what is not clear from this study is whether semantic processing during metaphorical speech production particularly involved the right-hemisphere. This is an important limitation as semantics is a crucial component of metaphor theories (e.g., Giora et al., 2000; Lakoff & Johnson, 1980).

The key aim of the present study is to shed light on lateralization of metaphor processing during speech *production* rather than comprehension, using the mouth asymmetry technique, and to investigate the role of semantics in the involvement of the right hemisphere.

More specifically, we investigated whether metaphor processing particularly involves the right hemisphere such that it reduces the right-sided mouth asymmetry during metaphorical compared to concrete speech production. In addition, we investigated whether semantics is crucial to the right-hemispheric involvement for metaphorical speech production such that the decrease of the right-sided mouth asymmetry during metaphorical compared to concrete speech production is particularly pronounced for production of content words, which carry meaning.

In order to test the first research question, we manipulated the content of speech production. That is, participants explained English phrases with either metaphorical or concrete meanings (e.g., “to spin a yarn”, “to spin a golf ball” respectively). We compared the laterality of maximum mouth openings (mouth opened wider at the right or left side or equally opened) in right-handed, male participants during metaphorical and concrete explanations. In line with previous research (Graves et al., 1982; Graves & Landis, 1985), we expect an overall right-side bias of maximum mouth openings in the explanation of phrases suggesting the role of the language dominant left hemisphere during speech production. Crucially, we hypothesized that, if metaphor production particularly involves the right hemisphere, the right-side bias of maximum mouth openings will be reduced when participants explain metaphorical compared to concrete phrases.

In addition, we investigated whether the relative right-hemispheric involvement during the metaphorical task is particularly pronounced for the production of content words (e.g., verbs, nouns) compared to function words (e.g., conjunctions, determiners). This is plausible; firstly because content words carry relatively more semantic information, thus presumably the meaning related to metaphor, while function words are less semantically rich, and subserve structural functions (Bradley & Garrett, 1983; Hinojosa et al., 2001). In addition, content words are less lateralized than function words. For example, Mohr, Pulvermuller, and Zaidel (1994) used the divided visual field technique in a lexical decision task (content and function words, non-words), and showed that function words presented in the right-visual field were processed faster than when presented in the left. Thus suggesting that the processing of function words relies heavily on the left-hemisphere. On the contrary, a clear visual field advantage was not found for the processing of content words. In addition, Bradley and Garrett (1983) showed that content and function words are identified equally accurately when presented in the right visual field. However, function words presented in the left visual field were identified less accurately than content words presented in the same field. These findings suggest that content words are bilaterally processed in left and right hemispheres, while function words seem to be strongly left hemispheric lateralized. The present study tested whether the relative involvement of the right hemisphere during metaphor production and, thus, the expected reduction in the right-sided mouth asymmetry during metaphor compared to concrete explanations is driven by semantically rich content words. Crucially, we hypothesised that if semantics is central for the right-hemispheric involvement for metaphorical speech production, the reduced right-sided mouth asymmetry in the metaphorical task compared to the concrete task will be particularly pronounced for the production of content words.

## Material and methods

### *Participants*

28 subjects (age: $M$ = 19.5 years, $SD$ = 1.9) took part in the experiment for a course credit or payment of £2. All participants were male, right-handed, native English speakers, monolinguals before the age of 5 years, and students at the University of Birmingham. We focused on males only because their bilateral representation of language processing is less frequent compared to females (McGlone, 1980). Handedness was assessed with a 12-items

questionnaire based on the Edinburgh Handedness Inventory (Oldfield, 1971). Two bimanual items (from Oldfield's long list) were added to his recommended 10-items questionnaire to equate the number of unimanual and bimanual items. Each "left" answer was scored with 0, each "either" answer with 0.5, and each "right" answer with 1. A total score of 8.5 and above determined right-handedness ($M$ = 10.98, $SD$ = .97). Text S1 in the Supplementary Material file available online includes the questionnaire. None of the participants had any previous serious injury to the face or jaw.

### *Stimuli*

The stimuli were three phrases for the metaphorical and three for the concrete condition. There was one "backup" phrase for each condition, in case participants could not recognize one of the main stimuli. The metaphorical stimuli were English idiomatic expressions with metaphorical meanings (e.g., "to pour oil onto the fire"). The concrete stimuli were matched to the metaphorical ones to refer to a physical event similar to the literal meaning of the metaphorical phrases (e.g., "to pour oil into the pan"). See Table 1 for the complete list of stimuli. Ten participants explained the reserve item for the metaphorical and concrete conditions.

----Table 1 about here ----

### *Procedure*

Participants were tested individually. They were seated on a chair, which was located between two tables of the same height (71 cm tall), and were asked to keep both hands still on specified marks (white sticky dots) on the tables throughout the task. Hand prohibition was a necessary experimental control, in order to collect a laterality measurement without the influence of gestural hand movements as gestures are sensitive to the division of labour between the two hemispheres in speaking tasks (Kita et al., 2007). The experimenter was standing and facing the participant, and the video camera recording participants' responses (Sanyo HD camera) was placed in front of the experimenter. Video-recording zoomed-in on the face area. Stimuli were presented one by one on a white sheet of paper (72 Times New Roman), which was held by the experimenter until the participant started giving their response.

Participants were instructed to explain the meaning of the phrases as if they were explaining it to a non-native English speaker. To encourage metaphorical thinking in the metaphor condition, participants were instructed to include an explanation as to how the literal meaning can be mapped on to the metaphorical meaning of the phrase and to give as much detail as possible (e.g., in the expression "to spin a yarn", "yarn" refers to a long, complicated story, and "spinning" refers to creating this story). For the concrete phrases, participants were instructed to paraphrase the phrase using synonyms and give as much detail as possible (see Table 2 for examples of the explanations participants produced). The order of the conditions (metaphorical – concrete) was counterbalanced across participants. At the end of the task, participants were debriefed about the purpose of the study.

------------Table 2 about here -----------------

***Maximum Mouth Openings Coding***

The video recordings were analysed using ELAN software (developed by the Max Planck Institute for Psycholinguists, Nijmegen, the Netherlands). Each video was analysed on a frame-by-frame basis to identify the maximum mouth openings in each phrase explanation. One maximum opening was defined as the widest point the mouth opens since the lips open to the lips resting or the lips meeting completely. We coded the laterality at each maximum mouth opening. The options for laterality classification were: right-side dominant (the right side of the mouth opens wider than the left), left-side dominant (the left side of the mouth opens wider than the right), or sides equally open (see Figure 1 for examples). Maximum openings for filled pauses (e.g. “eerm”) were coded but not included in the analysis, neither were the ones whilst participants were repeating the phrase to be explained in the beginning of each trial. We coded 60 maximum mouth openings (or as many as possible if less than 60 were available for coding because verbal responses were short) per condition per participants (in total we coded 1549 mouth openings in the concrete task and 1517 in the metaphorical task). Text S2 in the Supplementary Material file available online presents the coding manual.

One individual “blind” coder was trained and coded 26% of the data. Mouth openings from 7 randomly selected participants were coded in terms of right, left or equal sided mouth asymmetry (in total 798 maximum openings were double coded). Coding of mouth laterality matched between the two coders 84% of the time (Cohen’s $\kappa = .705$, $p < .001$).

---- Figure 1 about here ----

***Word-class Coding***

The word produced during each maximum mouth opening was coded as being “content” or a “function” word. The following grammatical classes were used to determine a content word: verbs (excluding auxiliary verbs), nouns, adjectives and adverbs. The following grammatical classes were used to determine a function word: determiners, conjunctions, auxiliary verbs and pronouns (see Table 3 for examples). Note that we did not include openings produced with and prepositions in the analysis, because of their dual role as both function and content words (e.g., “want to achieve”, the preposition “to” does not carry meaning thus is a function word; “add to a situation”, the preposition “to” is a content word which carries spatial meaning).

---- Table 3 about here ----

***Measurement and Design***

A right-sided mouth asymmetry index was computed for each participant in each linguistic task based on the laterality (right-R, left-L, equal-E) of participants’ first twenty maximum mouth openings per trial: (R-L)/(R+L+E) (adopted from Holowka and Petitto, 2002). Mean scores were calculated for each task (metaphorical vs. concrete), and for each word-class (content vs. function). Thus, a positive mean score indicated more instances of right-side dominant mouth openings (left-hemispheric lateralization), and a negative mean score indicated more instances of left-side dominant mouth openings (right-hemispheric lateralization). We compared the right-sided mouth asymmetry index in the metaphorical and the concrete task, and for the production of different word-classes (content vs. function) in each task.

**Results**

We coded 3066 maximum mouth openings across participants (1549 in concrete and 1517 in metaphorical task). On average, for each participant we coded 55.32 ($SD$ = 7.66) mouth openings in the concrete task and 54.18 ($SD$ = 10.61) in the metaphorical task. Though we aimed to code 60 mouth openings per condition per participant, the means were less than 60 because some participants gave short explanations and thus we could only obtain less than 60 mouth opening per condition. Furthermore some mouth openings were excluded from the analysis due to the low visual clarity of the recording (i.e., 33 mouth openings in the concrete task and 49 in the metaphorical task were coded as "unclear"). Out of the 3066 mouth openings which were coded we further excluded from the analysis 253 openings produced with filler pauses (e.g., "eerm") and 240 openings produced with prepositions (e.g., up, to). Out of 1248 maximum openings which were included in the analysis from the concrete task, 65% were produced with content and 35% with function words. Similarly, out of the 1325 maximum mouth openings in the metaphorical task, 67% were produced with content and 33% with function words (see Table 4 for means). The proportion of content words in the concrete task did not differ significantly compared to the proportion of content words in the metaphorical task, $t$ (27) = -1.425, $p$ = .166. Therefore, the proportion of each word class (content vs. function) is comparable for each linguistic task (concrete vs. metaphorical).

----------- Table 4 about here -----------

First, we compared the number of mouth openings included in the analyses to follow. The number of mouth openings is comparable for each linguistic task (concrete vs. metaphorical), $t$ (27) = -1.662, $p$ = .108. See Table 5 for average proportion of mouth openings coded (equal, left-dominant, right-dominant) and included for the calculation of the laterality index for each condition (concrete, metaphorical) and type of word (content, function).

------------ Table 5 about here ---------------

In addition, we compared the mean length of the explanations in each condition (see Table 4 for means). Explanations produced in the concrete task were significantly shorter than metaphorical explanations, $t$ (27) = -2.79, $p < .05$. However, there was no significant correlation ($p > .05$) between the right-sided mouth asymmetry and the length of explanations in either task (concrete and metaphorical). Therefore, there is no evidence that any mouth asymmetry difference between the two tasks could be caused by the length of explanations.

We also compared the mean word length (i.e., the number of letters) in each word class (see Table 4 for means). As expected (Gordon & Caramazza, 1982) function words were significantly shorter than content words, $t$ (27) = -16.054, $p < .001$. However, there was no significant correlation ($p > .05$) between the right-sided mouth asymmetry and the word length in either task (concrete and metaphorical). Therefore, there is no evidence that any mouth asymmetry difference between the two word classes could be caused by word lengths.

Then, we analysed whether mouth openings were right-side dominant. The right-sided mouth asymmetry index (as described in section Measurement and Design) was significantly larger than zero in the concrete condition for content ($t$ (27) = 12.726, $p < .001$) and function words ($t$ (27) = 11.890, $p < .001$), and in the metaphorical condition for content ($t$ (27) = 5.089, $p < .001$) and function words ($t$ (27) = 7.081, $p < .001$) (see Figure 2 for the means). Thus, speech production, in general, relies on left-hemisphere processing.

Next, we analysed whether mouth-opening asymmetry differed between the two linguistic tasks and during the production of the two different word-classes. A 2x2 repeated measures within subjects ANOVA was performed on the right-sided mouth asymmetry index with linguistic task (concrete vs. metaphorical) and word-class (content vs. function) as the independent variables. This yielded a significant main effect of linguistic task (concrete vs. metaphorical), $F$ (1, 27) = 34.638, $p < .001$, partial $\eta^2 = .562$. As predicted, participants demonstrated a significantly lower right-side bias in mouth openings during metaphorical explanations compared to the concrete ones (see Figure 2). In addition, there was a significant main effect of word-class (content vs. function), $F$ (1, 27) = 4.994, $p = .034$, partial $\eta^2 = .156$.

In particular, participants demonstrated a significantly lower right-side bias in mouth openings when they produced content compared to function words (see Figure 2). Finally, there was significant interaction between linguistic task and word-class, $F$ (1, 27) = 5.322, $p$ = .029, partial $\eta^2$ = .165. This indicates that the linguistic task had different effect on right-sided mouth asymmetry depending on what class of word (content vs. function) people produced. Post-hoc t-tests with Bonferroni corrected alpha level ($p < .0125$) between conditions indicated that right-sided mouth asymmetry was significantly lower in the metaphorical task than the concrete task for content words ($t$ (27) = -6.679, $p < .001$), and for function words ($t$ (27) = -3.306, $p$ = .003); right-sided mouth asymmetry was marginally lower for content words than function words during the metaphorical task ($t$(27) = -2.791, $p$ = .010), but not during the concrete task ($t$ (27) = -.181, $p$ = .857) (see Figure 2). Thus, the interaction is because the task effect (i.e., reduced right-sided mouth asymmetry in the metaphorical task) is larger for content words than for function words. As evident in Table 5, the right-sided mouth asymmetry is lower in the metaphorical task because the right-side dominant openings decrease and the left-side dominant openings increase.

---- Figure 2 about here ----

The next analysis aimed to further support that the differences in mouth asymmetry were resulting from the manipulation of the variable in interest (metaphor vs. concrete) rather than the words produced. Thus, we focused on words that appeared in both concrete and metaphorical conditions at least once. The analysis included 613 content word tokens (49% of all content word tokens produced) and 777 function word tokens (59% of all function word tokens produced) (see Text S3 in Supplementary Material for a full list of the words and their token frequencies in each condition). The analysis was limited to 682 maximum mouth openings in the concrete task and 708 in the metaphorical task. Results remained the same. The 2x2 repeated measures within subjects ANOVA yielded a significant main effect of linguistic task (concrete vs. metaphorical), $F$ (1, 27) = 24.175, $p < .001$, partial $\eta^2 = .472$. Participants demonstrated a significantly lower right-side bias in mouth openings during metaphorical explanations compared to the concrete ones. In addition, there was a marginally significant main effect of word-class (content vs. function), $F$ (1, 27) = 4.015, $p = .05$, partial $\eta^2 = .129$. Participants demonstrated a significantly lower right-side bias in mouth openings when they produced content compared to function words. Finally, there was a significant interaction between linguistic task and word-class, $F$ (1, 27) = 5.947, $p = .022$, partial $\eta^2 =$ .181. In summary, the pattern of results remained the same as in the previous analysis. Thus there is no evidence that the effects are driven by the words spoken uniquely in the metaphorical or concrete condition.

-------------Figure 3 about here --------------

**Discussion**

The present study investigated whether metaphor processing particularly involves the right hemisphere such that it reduces the right-side bias in mouth openings during metaphorical speech production. First, we compared speakers' mouth asymmetry during explanation of phrases with metaphorical and concrete meanings. The mouth opened more widely on the right side during speaking in both the metaphorical and concrete conditions suggesting the involvement of the left hemisphere during speech production. However, the right-sided mouth asymmetry significantly reduced in the metaphor compared to the concrete task. In addition, we crucially showed that the reduced right-sided mouth asymmetry during metaphorical explanation, as compared to concrete explanations, is particularly pronounced during the production of content words than that of function words. We propose that semantics is crucial for the right-hemispheric involvement in metaphorical speech production.

The present findings are in line with the Right Hemisphere Hypothesis for Metaphor (e.g., Brownell et al., 1990) according to which the right hemisphere is predominantly involved in metaphor processing. Although several studies manipulated linguistic content (literal vs. non-literal stimuli) to assess the neural basis for metaphor processing (e.g., Brownell et al., 1990; Anaki, et al., 1998), only one study  (Benedek et al. (2014) has explored the involvement of the right hemisphere during metaphorical speech *production*. The “open-endedness” and the description of the metaphorical mapping in the current task was effective as it revealed the differential hemispheric involvement between metaphor and literal explanations. Participants in this task were free to choose from a wide range of possible responses. This “semantic exploration” between possible meanings is crucial for metaphorical processing, which entails the creation of semantic link between otherwise distant concepts (Jung-Beeman, 2005). Therefore, this task was sensitive to capture the crucial element for the right-hemispheric involvement for metaphor processing. Furthermore, the study of metaphor production during an on-line task (as opposed to passive tasks of covert reading and comprehension) offers a new approach to how speakers develop new ideas, which is important to communication *per se* and theories about creative cognition (i.e. Benedek et al., 2014l Dietrich & Kanso, 2010).

Moreover, the present study is in accordance with research on the involvement of each hemisphere for the representation of content and function words (Mohr et al., 1994). For example, the present study found that for content words, the right-sided mouth asymmetry was significantly smaller during metaphorical explanations than concrete explanations. Therefore, suggesting that the hemispheric involvement for the production of content words can be determined by the semantic meaning they carry. When content words are produced to represent concepts related to metaphorical concepts, as opposed to concrete and literal concepts, the right hemisphere is particularly involved. Firstly, this finding validates our initial hypothesis that semantics is crucial for the reduced right-sided mouth asymmetry in metaphorical as compared to literal speech production. In addition, it is compatible with observations that content words are bilaterally represented, thus do not demonstrate a processing advantage when presented in either (left or right) visual field (e.g., Bradley & Garrett, 1983; Mohr et al., 1994) .

Not only for content words, but also for function words, the right-sided mouth asymmetry reduced for metaphor explanation. This may be because function words also carry semantic information related to metaphor, albeit less substantially than content words. For example, pronouns classified as function words may refer to content words in preceding discourse. If the content words' meaning has been processed in the right hemisphere, the right hemisphere may also play an important role in producing a subsequent co-referential pronoun. In addition, it is possible that left-hemisphere involvement by content words during metaphor explanations was carried over to the production of function words as well. For example, when a function word is produced in a sequence of content words within an utterance, it is possible that the right hemisphere involvement may be carried over to the function word. This is possible if it incurs processing cost to switch on and off the right-hemisphere's involvement in speech production.  Then, even if it is not efficient to process a function word with the right-hemisphere's involvement, it may sometimes be overall more efficient to keep the right-hemisphere's involvement (not to switch it on and off too often).

In addition, present results are compatible with previous studies on task-dependent mouth asymmetry. Mouth asymmetry studies have shown that tasks involving right hemisphere processes (e.g., emotional tasks, automatic speech) lead to reduced right-sided asymmetry in mouth opening. For example, right-sided asymmetry was reduced when spontaneously smiling compared to generating word lists (Graves et al., 1982) and it was also smaller when singing and counting (serial speech) than naming pictures and spontaneously speaking (propositional speech) (Graves & Landis, 1985). The present study is the first study to show the same effect for metaphor. Thus, this study further validated mouth asymmetry as an indicator of lateralisation of processes underlying various communication behaviours.

But what exactly is happening in the two brain hemispheres during metaphorical explanation? We may speculate based on our current findings and also in light of metaphor theories. Metaphor is a way of speaking about one conceptual domain in terms of another (Lakoff & Johnson, 1980). In particular, during metaphorical explanation speakers explain the metaphorical mapping of a concrete concept (source domain of metaphor) onto a more abstract one (target domain of metaphor) (e.g., when explaining the phrase “to spin a yarn”, the spinning represents the elaborate creation and narration of a story). This specific process of mapping during metaphorical processing is essentially the speaker’s effort to bring closer two semantically distant concepts (i.e., the action of spinning and the action of narrating). Such semantic processes are an instance of the processing of coarse semantic links, which is more strongly represented in the right hemisphere than the left (following the Fine-Coarse Coding Theory; Jung-Beeman, 2005). Crucially, the current study found a significant interaction between linguistic task and word-class. That is, the right-sided mouth asymmetry was significantly lower when participants explained metaphorical phrases than concrete phrases and this difference was particularly pronounced for production of content words. Presumably, when speakers produced content words for the explanation of metaphors, they produced words which carry semantic information related to the metaphorical mapping. For example, in the phrase “to spin a yarn”, a source domain concept, “objects (yarn)”, maps to a target domain concept, “story”. Through the metaphorical mapping, some attributes can also be mapped from the source to the target domain. So, “a *complicated* (content word) object like a yarn is used to represent a *complicated* story”. This mapping is lexically encoded more often with content words compared to function ones, because function words do not carry enough semantic content to allow for the representation of abstract concepts in the form of concrete senses (Gonzálvez-García, Peña-Cervel, & Pérez-Hernández, 2013). Therefore, we propose that during metaphorical speech production semantics might be what determines the relative involvement of the right hemisphere.

The current study used so-called frozen metaphors in idiomatic phrases, which in some studies did not involve the right hemisphere as well as novel metaphors (Cardillo et al., 2012; Mashal et al., 2005). We argue that how much the right hemisphere is involved in metaphor processing depends not only on the type of stimulus materials but also on the task. The current study showed that, with frozen metaphors, if the participants were required to explicitly think about the metaphorical mapping between source and target domains (e.g., in the phrase “to spin a yarn”, the yarn represents a long complicated story), the right hemisphere got involved in the process.

In general, in the discussion of the Right Hemisphere Hypothesis for Metaphor (e.g., Brownell et al., 1990), it may be important to carefully examine the nature of task used in each study. For example, the fMRI study by Rapp et al. (2007) failed to show activation of the right hemisphere whilst participants silently read sentences (literal and non-literal) and performed metaphorical judgments (“is it a metaphor or not?”) and connotation judgments (“does it have a positive or negative connotation?”). The task did not require processing of the mapping between source and target domains. For example, the metaphorical judgment could have been made based on semantic anomaly in the literal interpretation. In sentences such as “the director was a bulldozer” participants could judge if the sentence is literally plausible or not, without thinking about the metaphorical mapping. If so, these tasks probably did not strongly activate metaphorical thinking, thus failed to activate the right hemisphere.

The present study validates the effectiveness of the mouth asymmetry technique and opens new doors for future research. For example, it would be interesting to observe the sequence of mouth asymmetries as this might reveal how the two hemispheres collaboratively produce an utterance. Mouth asymmetry is a suitable technique for such questions, which would be difficult to answer with functional imaging techniques due to low time-resolution (fMRI) or articulatory movement artefacts (EEG). Finally, calculating the mouth asymmetry index during metaphorical tasks could supplement future studies with an individual-subjects localization approach and lead to a clearer picture of the neural basis of metaphorical processing.

## Conclusions

In conclusion, the reduced right-sided mouth asymmetry during metaphorical compared to concrete explanations is particularly driven by the production of content words related to metaphor; thus indicating that semantics is crucial for the relative involvement of the right hemisphere for metaphorical speech production. The study also validated the sensitivity of the mouth asymmetry technique to capture the differential hemispheric involvement for different verbal tasks, and also for different word-classes.

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**Table 1** Complete list of stimuli for the metaphorical and concrete conditions. The first three items in each column are the main items. The items in parentheses are reserve items used when the participants did not know the main items.

| **Metaphorical phrases** | **Concrete phrases** |
|---|---|
| To pour oil onto the fire | To pour oil into a pan |
| To set your sights higher | To put a shelf higher |
| To spin a yarn | To spin a golf ball |
| (To hit the nail on the head) | (To hit someone on the head) |

**Table 2** Examples of produced explanations for each linguistic task.

| **Concrete Explanations** | **Metaphorical Explanations** |
| --- | --- |
| "To spin a golf ball, the golf ball is a ball you hit and try and get it in the hole, it is a small ball normally white and to spin it is to rotate it round" | "To spin a yarn, that is to tell a story, the spinning implies you are making it up as you go along as if you are spinning cotton and the yarn is the story that you are making up" |
| "To pour oil into a pan would mean that you take a bottle of liquid that originated from a kind of plant or fuel source and you tip the container into a pan which is a cooking utensil" | "To pour oil onto the fire, if you pour oil into the fire it's going to make it spark up so if there is a situation where your anger is firing, to pour oil into the fire would be to stir things up and make it even more ferocious". |

**Table 3** Examples of words classified as content or function words.

| **Word type** | **Examples** |
|---|---|
| **Content Words** | Aim, Keep, Structure, Higher, Constantly |
| **Function Words** | ***Determiners***: A(n), Another, Any, Some, The<br>***Conjunctions***: And, If, Or, So<br>***Auxiliary Verbs***: Are, Be, Being, Could, Do<br>***Prounouns***: I, It, That (is), Those, Yourself |

**Table 4** Mean number of words coded in each linguistic task and word-class, the mean word lengths (i.e., the number of letters) for the coded words, and the mean word count per explanation (i.e., the length of explanation) in each linguistic task. The means are all across participants. The numbers in brackets represent the standard deviation.

| | Concrete Task | | Metaphorical Task | |
|---|---|---|---|---|
| | Content Words | Function Words | Content Words | Function Words |
| Number of words coded | 20.07 (*6.90*) | 15.5 (*4.09*) | 31.85 (*7.77*) | 15.46 (*5.85*) |
| Word length | 5.19 (*.59*) | 3.18 (*.57*) | 6.14 (*.61*) | 3.59 (*.76*) |
| Length of explanation (word count) | 37.31 (*9.93*) | | 44.04 (*12.0*) | |

**Table 5** Mean proportion of coded mouth openings (equal, left-dominant, right-dominant) and included in the analyses for each linguistic task (concrete, metaphorical) and word type (content, function). The means are all across participants. The numbers in brackets represent the standard deviation.

| | | Concrete Task | Metaphorical Task |
|---|---|---|---|
| Content Words | Equal | 0.13 (*0.09*) | 0.12 (*0.09*) |
| | Left-dominant | 0.06 (*0.07*) | 0.18 (*0.09*) |
| | Right-dominant | 0.47 (*0.12*) | 0.38 (*0.14*) |
| Function Words | Equal | 0.07 (*0.07*) | 0.06 (*0.04*) |
| | Left-dominant | 0.02 (*0.03*) | 0.06 (*0.05*) |
| | Right-dominant | 0.25 (*0.09*) | 0.20 (*0.07*) |

**Figure captions**

**Figure 1** (From left to right) Examples of equal, right-side dominant, left-side dominant maximum mouth openings. “Right” and “Left” refer to the speakers’ right and left.

**Figure 2** Mean right-sided mouth asymmetry index (R-L)/(R+L+E) per linguistic task and word-class produced, where R = right-side dominant mouth opening, L = left-side dominant, E = lips equally opened. The larger value indicates stronger right-side dominance in mouth openings, thus stronger left-hemispheric specialization. Error bars represent the standard errors.

**Figure 3** This analysis included only the words produced at least once in both concrete and metaphorical task. Mean right-sided mouth asymmetry index (R-L)/(R+L+E) per linguistic task and word-class produced, where R = right-side dominant mouth opening, L = left-side dominant, E = lips equally opened. The larger value indicates stronger right-side dominance in mouth openings, thus stronger left-hemispheric specialization. Error bars represent the standard errors.

Figure1

Figure2

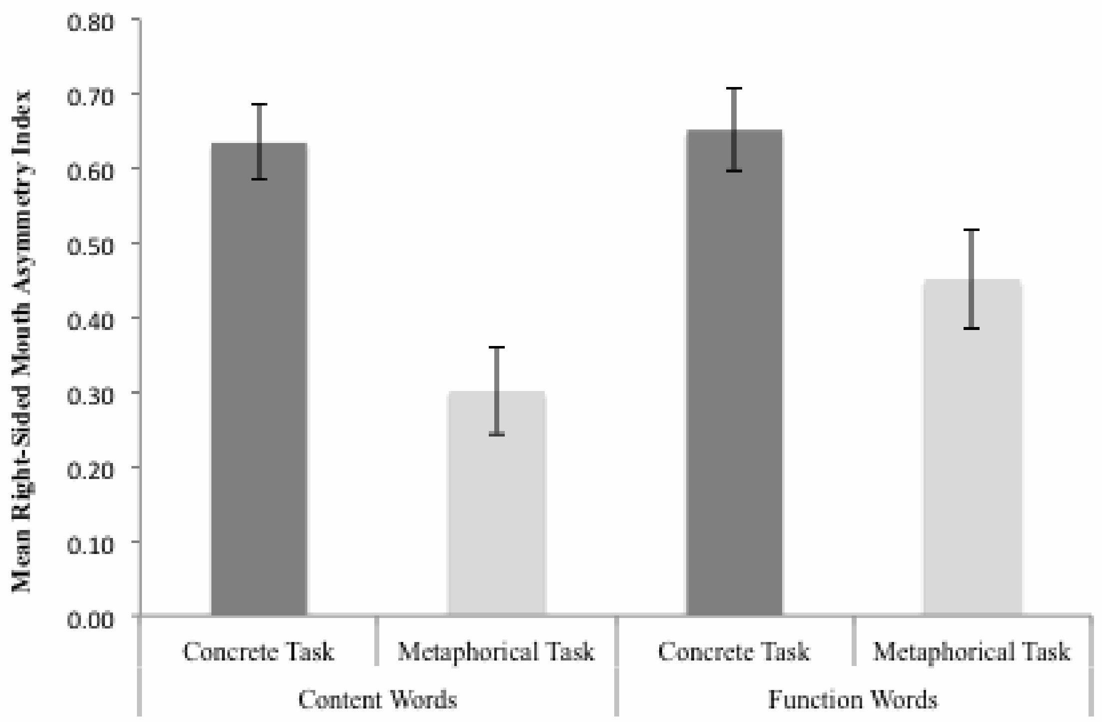


Figure 3