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Horizontal Information Flow in Spoken Sentence Production

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In 4 experiments the authors used a variant of the picture–word interference paradigm to investigate whether there is a temporal overlap in the activation of words during sentence production and whether there is a flow of semantic and phonological information between them. Experiments 1 and 2 demonstrate that 2 semantically related nouns produce interference effects either when they are in the same or different phrases of a sentence. Experiments 3 and 4 demonstrate that 2 phonologically related nouns produce facilitation effects but only when they are within the same phrase of a sentence. The results argue against strictly serial models of multiple-word access and provide evidence of a flow of semantic and phonological information between words during sentence production.

Much psycholinguistic research has investigated the two issues of whether the flow of information during language production is serial or parallel and whether it is modular or interactive. For the most part, such research has confined itself to investigating these issues in relation to the vertical flow of information between high- and low-level processing stages during the production of single words. Thus, researchers have asked whether the phonological encoding of a word can be initiated before its grammatical encoding is complete or whether there is a strict temporal separation between these two processes (e.g., Levelt et al., 1991; Van Turrenout, Hagoort, & Brown, 1998). In addition, researchers have asked whether the grammatical encoding of a word is encapsulated from its phonological encoding or whether information generated during the phonological encoding of a word can feed back to and inform its grammatical encoding (e.g., Dell, 1986, 1988; Dell & Reich, 1981; Levelt, Roelofs, & Meyer, 1999; Stemberger, 1985). Recently, however, experimental studies have begun to investigate the horizontal flow of information between multiple words in a phrase or sentence. Thus, eye-tracking studies by Meyer and colleagues (Meyer, Sleiderink, & Levelt, 1998; Meyer & van der Meulen, 2000) have probed whether there is a temporal overlap between the access of one word and that of another during the production of a coordinated noun phrase. In addition, sentence completion experiments by Rapp and Samuel (2002) have shown that the access of a word can be influenced by information generated during the access of another word in the same sentence. Clearly, the analysis of horizontal information flow offers a new means of probing the issues of serial versus parallel and modular versus interactive processing. However, it also raises issues that are unique to the production of sentences. Most obviously, there is the question of whether temporal overlap in lexical access is constrained by syntactic units such as phrases and clauses such that parallel processing is possible only for words within a given syntactic unit. In addition, however, there is the issue of whether linguistic dependencies among the words of a sentence such as gender agreement will necessitate interactive processing. It is critical that distinct forces and constraints act on horizontal information flow, suggesting the possibility that horizontal and vertical information flow may differ—that, for example, vertical information flow could be modular whereas horizontal information flow is interactive. To further probe horizontal information flow, in the current article we apply a new experimental technique to spoken sentence production. Before presenting this research, however, a brief overview of the relevant speech production literature is provided.

Serial Versus Parallel Processing in Horizontal Information Flow

In general, there are few experimental studies of whether horizontal information flow is serial or parallel in nature. There are, for example, many experimental studies of the closely related issue of processing scope. In such studies speech onset latencies are used to investigate the quantity of a sentence that has been produced at a given processing level prior to speech onset. Thus, using such a design, Smith and Wheeldon (1999) indicated that lemma access is completed for the initial phrase of a sentence prior to speech onset. However, the data from such studies fail to determine whether horizontal information flow is serial or parallel. Thus, Smith and Wheeldon's results are compatible both with the view that the lemmas within the initial phrase of a sentence are accessed at overlapping times in the period prior to speech onset and with the view that they are accessed at discrete times in the period prior to speech onset. In contrast, a series of eye-tracking studies by Meyer and colleagues (Meyer et al., 1998; Meyer & van der Meulen, 2000) has provided experimental evidence regarding the issue of whether words are accessed at overlapping times during speech production. In a study by Meyer et al. (1998), for example, participants were required to describe pictures representing two

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discrete objects using coordinated noun phrases such as “the book and the pipe.” It was found that viewing times for the left-most (and first named) object were significantly longer when it corresponded to a low-frequency lexeme than when it corresponded to a high-frequency lexeme. Such a result clearly suggests that the second picture is not attended to and its grammatical encoding is not initiated until the phonological encoding of the lexeme corresponding to the first object has been carried out. This finding was further reinforced by the results of a study by Meyer and van der Meulen (2000), which indicated that viewing times to the left-most object were shorter after phonologically related than phonologically unrelated auditory primes. Such a result again indicates that the right-most object is not fixated on until the phonological planning of the word corresponding to the left-most object has been conducted. Overall, then, such results suggest that the grammatical and phonological planning of the nouns within a coordinated noun phrase occurs at discrete rather than overlapping times and provide support for a serial rather than parallel view of multiple-word access. Discussing these results, Levelt and Meyer (2000) argued that speakers engage in such serial processing to ensure that the burden of processing is spread evenly throughout the period in which a phrase or sentence is being produced. Clearly, achieving such a spreading of the cognitive load inevitably raises the risk of initiating word access too late and thereby giving rise to dysfluency. However, as Levelt and Meyer (p. 450) observed, the results of the studies by Meyer and colleagues indicate that this is a risk that speakers seem willing to run to ensure serial processing. Although such studies argue for a highly serial view of multiple-word access, however, a series of recent studies by Meyer and colleagues have indicated that the eye-tracking data presented in studies such as Meyer et al. (1998) are not incompatible with a parallel model of word access because some processing of a picture can be conducted prior to fixation on it. Thus, Meyer and Dobel (2003) reported a number of eye-tracking studies indicating that the conceptual planning of an object can occur prior to fixation on that object while the participant is still fixating on a different object. Consequently, although the majority of studies argue for a serial view of lemma access, a parallel view of lemma access cannot be ruled out.

Modular Versus Interactive Processing in Horizontal Information Flow

Just as data regarding processing scope fail to determine whether horizontal information flow is serial or parallel in nature, data regarding temporal overlap also fail to determine whether horizontal information flow is modular or interactive in nature. Thus, it cannot be inferred from evidence that horizontal information flow is parallel and interactive. It is entirely possible, for example, that the information generated during the access of one word does not feed back to and inform the access of another word even though the two words are accessed at overlapping times. Consequently, data from eye-tracking studies such as those by Meyer and colleagues (Meyer et al., 1998; Meyer & van der Meulen, 2000) do not demonstrate that horizontal information flow is interactive. Nevertheless, there is a wide range of studies that do provide evidence to this effect. Most obviously, such evidence is provided by speech errors, such as the following sound exchange error from Garrett (1980b):

1. “We have a lot of pons and pats to wash.” (intended: pots and pans)

In this example, the consonant “n” is shifted leftward out of its intended lexeme and inserted into a second lexeme in place of the consonant “t”. In this way, the error demonstrates not just that the two lexemes are accessed at overlapping times but also that the information generated during the access of one lexeme has influenced the access of another (cf. Dell, 1990). Although such errors do provide evidence of interactivity in horizontal information flow, it is possible, however, that they reflect only the disrupted rather than the normal functioning of the language production system. Indeed, we might expect horizontal information flow to be highly modularized to minimize such interference-based errors. Other observational evidence suggests, however, that interactive horizontal information flow is a beneficial feature of a normally functioning language production system. Consider, for example, the following Greek phrase (with gender marked in brackets):

2. “η $\tau o\upsilon$ $\sigma\tau\rho\alpha\tau\iota\omega\tau o\upsilon$ $\alpha\nu\delta\rho\epsilon\iota\alpha$”

the (f) the (m) of the soldier (m) courage (f)

“The soldier’s courage”

In this example, the feminine gender marking of the determiner “η” depends on and must be informed by the access of the feminine noun “$\alpha\nu\delta\rho\epsilon\iota\alpha$”. Consequently, the construction of such a phrase requires there to be a horizontal information flow between two words at opposite ends of the phrase. Such linguistic dependencies are extremely common (particularly between words within the same phrase) and suggest that horizontal information flow may be a vital feature of an effective language production system (cf. also Levelt, 1992; Smith, 2000; Wheeldon, Meyer, & Smith, 2003). Moreover, experimental evidence for such a flow of information has been provided in a study by Rapp and Samuel (2002). In this study, participants were required to select a word to fill in the blank in a sequence of two sentences. In the *rhyme prime* condition, the sentences featured a word that rhymed with a target word that participants could fill the blank with. Thus, the sentences, “The man walked into the bank and slipped on some ice. He’d gone to deposit his check and nearly broke his _____”, featured the word “check” and could be filled by the word “neck”. In the *nonrhyme prime* condition, the sentences did not feature a word that rhymed with the target word. Thus, the aforementioned sentences would be presented with the word “payment” substituted for the word “check”. Rapp and Samuel found that the target word was produced more frequently and more rapidly in the rhyme prime condition than in the nonrhyme prime condition. As Rapp and Samuel argued, such a finding suggests that lemma access is influenced by a vertical flow of information feeding back from the phonological to the grammatical encoding stage. In addition, however, it suggests that there is a horizontal flow of phonological information between the distinct words of a sentence.

The Present Experiments

Our aim in the current study is to provide an additional test of whether horizontal information flow in multiple-word access is serial or parallel and whether it is modular or interactive. To probe these two issues, the current study uses a modified version of the picture–word interference task. In the standard version of the picture–word interference task (e.g., Golinkoff & Rosinski, 1976; Starreveld & LaHeij, 1996), participants name a line drawing of a familiar object (the target) while ignoring a written word (the distractor) that is superimposed on it. Typically, it has been found that naming latencies vary as a function of the relation between the target and distractor (Damian, 2000; Damian & Martin, 1999; Fox, 1994, 1996; Glaser & Dunglehoff, 1984; Yee, 1991). Specifically, such experiments yield either a semantic interference effect (i.e., naming latencies are longer when the target is semantically related to the distractor than when it is semantically unrelated) or a phonological facilitation effect (i.e., latencies are shorter when the target is phonologically related to the distractor than when it is phonologically unrelated). In general, it has been argued that the semantic interference effect arises at the grammatical encoding stage of speech production whereas the phonological facilitation effect arises at the phonological planning stage (e.g., Damian, Vigliocco, & Levelt, 2001; Jescheniak, Schriefers, & Hantsch, 2001; Schriefers, 1993; Schriefers, Meyer, & Levelt, 1990). Crucially, such effects indicate both that there is a temporal overlap in the processing of the target and distractor word and that semantic and phonological information generated during the processing of the distractor word has influenced the access of the target word (cf. Cohen, Dunbar, & McClelland, 1990; Phaf, Van der Heijden, & Hudson, 1990; Roelofs, 1992). Clearly, if the access of the target word had been completed prior to that of the distractor word and no information had flowed between the two words, neither the semantic interference effect nor the phonological facilitation effect should have occurred.

In the current study, we combine the picture–word interference task with a sentence production task in which participants produced sentences describing the movement of pictures on a computer screen (e.g., Levelt & Maassen, 1981; Smith & Wheeldon, 1999, 2001). Thus, in the current study, a participant might see a line drawing of a saw moving above the written word "axe" and would be required to produce the sentence, "The saw moves above the axe", in response. By comparing latencies to sentences where the two target words are either semantically or phonologically related or unrelated in such a task, it is possible to gauge whether there is a flow of information between these two target words in the production of the sentence. It is important that because the current task does not spatially superimpose the target and distractor words as in the standard picture–word interference task, it does not force participants to process the two targets simultaneously but allows them the option of processing the words in a discrete, modular manner. If either the semantic interference effect or the phonological facilitation effect were to be observed in such a task, however, it would indicate that there is some degree of temporal overlap and a flow of either semantic or phonological information between the target and distractor words. In the present study we also manipulate the kinds of sentence structure that the targets appear to determine the range over which horizontal information flow occurs. Specifically, the experiments place the target and distractor words either within the same phrase or within different phrases to determine whether semantic and phonological information can flow between words in different phrases or between words in the same phrase only.

Experiment 1

Our aim in Experiment 1 was to test for the horizontal flow of information during lemma access and to determine the range over which such information flow obtains. To this end, we designed an experiment that probed for semantic interference effects during spoken sentence production. Thus, on each trial participants saw a display comprised of a picture of an object and, to its right, either a semantically related or a semantically unrelated distractor word. The picture and word moved either vertically in the same direction or horizontally in opposing directions. Participants were instructed to describe the vertical and horizontal movements using particular sentence types. Specifically, vertical movements were described using sentences that placed the target and distractor words within the same phrase whereas horizontal movements were described using sentences that placed the target and distractor words in the different phrases. This gave rise to the following four conditions:

Same phrase related: "The saw and the axe move down"
Same phrase unrelated: "The saw and the cat move down"
Different phrase related: "The saw moves towards the axe"
Different phrase unrelated: "The saw moves towards the cat"

Clearly, in comparing latencies with semantically related and unrelated sentences, such a design tests for semantic interference effects. In standard picture–word interference studies, such effects arise when semantic information generated during the processing of the distracter word influences the access of the lemma corresponding to the picture (e.g., Cohen et al., 1990; Damian et al., 2001; Jescheniak et al., 2001). Consequently, this outcome provides evidence both for a temporal overlap in the activation of the target and distracter word and for a flow of semantic information between them. Were such an outcome to be observed in the current design, therefore, it would also indicate that there is a temporal overlap in the processing of the target and distracter words and a flow of semantic information between them. Moreover, the design tests for semantic interference effects both when the target and distracter words are in the same phrase and when they are in different phrases. As such, the design allows for a test of whether the horizontal flow of semantic information is obtained between words in different phrases or only between words within the same phrase.

Method

Materials. A set of 48 pictures and 48 words were used. The pictures were taken either from Snodgrass and Vanderwart's (1980) picture norms or were drawn in a similar size and style. The pictures were selected on the basis of the norming data from a picture-naming pretest (see Wheeldon & Monsell, 1992). The set of 48 pictures was further divided into a set of 24 pictures for use on the experimental trials and a set of 24 pictures for use on the nonexperimental, "filler" trials. To facilitate picture naming, we ensured that the pictures used in the experimental trials were consistently named using a single word on at least 97% of trials during the pretest and that they had a mean naming latency of less than 650 ms during the pretest. For the same reason, we ensured that a set of pictures was chosen whose corresponding words were short. Specifically, the set of words had a mean length of 1.4 syllables and 3.7 phonemes. In addition, only experimental pictures that were described with familiar target words were selected. Thus, the target words used to describe the experimental pictures had a log frequency of 3.4 and an average frequency count of 61 occurrences per million (Hofland & Johansson, 1982; Kucera & Francis, 1967). The set of 48 words was also divided up into a group of 24 experimental words and a group of 24 nonexperimental words. The experimental words were selected primarily on the basis of their semantic relatedness to the target words corresponding to the experimental pictures. In particular, each of the experimental words was required to be either highly semantically related or a near synonym of one of the target words corresponding to the experimental pictures (thus, the experimental word "axe" was selected as being highly semantically related to the experimental picture “saw”). In addition, however, the experimental words were required to be easy to name. Thus, they had a mean length of 1.1 syllables and 2.8 phonemes and an average frequency count of 47 occurrences per million and a log frequency of 3.1.

Design. The experiment comprised two practice blocks of 16 trials and four experimental blocks of 44 trials. Each experimental block was divided up into 20 filler trials and 24 experimental trials. These 24 experimental trials were divided up into four sets of 6 trials—one set for each of the four sentence types. In trials featuring *same phrase* sentences, the picture and the word would both move up or down in the same direction. In trials featuring *different phrase* sentences, the picture and the word would move either toward each other horizontally or away from each other horizontally. The four experimental trial movement types (i.e., “up”, “down”, “away from”, and “toward”) were distributed so that participants would see equal numbers of all of the movements. In the case of the same phrase and different phrase sentences, the picture and the word moved at an equivalent rate and for an equivalent distance during each of the trials to ensure that their movements made a balanced contribution to the latencies. In total, there were 96 experimental trials over the course of each experimental session, 24 for each of the four conditions. The filler trials all featured a single picture or word that would move either left or right and was described using a sentence such as, “The candle moves right”. Such sentences were used during the filler trials to provide a syntactic contrast to both the same phrase sentence (in terms of the complexity of its subject phrase) and the different phrase sentence (in terms of the number of noun phrases) and thereby to minimize intertrial priming (cf. Smith & Wheeldon, 2001). The order in which filler and experimental trials were presented was also manipulated to lessen the ability of participants to predict the condition featuring in the upcoming trial. In addition, the order in which the four blocks were presented was rotated across participants. A number of constraints were observed in assigning pictures to trials. First, whenever a trial featured both a picture and a word, the picture was always assigned to the leftmost screen position. Because participants were instructed to describe the picture and the word from left to right, this ensured sentences in which the picture was described before the word. In the practice blocks, all of the experimental pictures and words were featured once so that the experimenter could check that the participant knew the correct name for each picture. Furthermore, during the experimental blocks, each of the experimental pictures and words occurred once in each of the four conditions to ensure that they contributed equally to latencies and durations for each condition. In the related conditions, pictures were paired with semantically related words whereas in the unrelated conditions pictures were paired with semantically unrelated words. The picture and word pairs in the unrelated conditions always featured a living and a nonliving item to ensure that they were semantically unrelated. In addition, experimental words were paired with experimental pictures whose target word they were phonologically unrelated to. The experimental pictures and words were distributed across the four blocks to ensure that they occurred once in each block.

Procedure. Prior to the experiment, participants were informed as to what types of movements they would see and how these movements should be described. They were also requested to describe the pictures from left to right. At the beginning of each trial, a rectangle appeared in the center of the screen for 2 s. At its offset, a picture and/or word was presented in the center of the screen. As soon as these items appeared they began to move. The whole movement covered 2.5 cm of the screen and lasted 1,500 ms. The pictures disappeared from the screen 500 ms after speech offset. An interval of 4 s then preceded the onset of the next trial.

Participants. The participants were 24 students from Birmingham University. They were all native English speakers and were paid either in participation credits or at the rate of £5 (U.S. $8) per hr.

Results

Responses with latencies less than 350 ms and longer than 1,750 ms were regarded as outliers and excluded from the analyses, as were trials on which technical errors occurred such as voice key failures. This resulted in the loss of 0.9% of the data. Three types of response were categorized as errors: responses in which participants did not use the expected picture names, responses in which participants did not use the expected syntactic structure, and dysfluent responses in which participants stuttered or repaired the utterance. Data from all of these trials were excluded from the analyses. Mean latencies, mean durations, and percentage error rates are shown in Table 1.

Error rates were highest in conditions with the longest latencies, thus providing no evidence of a speed–accuracy trade-off. Analyses were carried out with subjects and items as random variables, yielding F_1 and F_2 statistics, respectively. The units of analysis in the item analyses were the pictures. An analysis of variance (ANOVA) including the variables phrase structure (same phrase vs. different phrase) and semantic relatedness (semantically related vs. semantically unrelated) was performed on error rates, but it yielded no significant effects.

An ANOVA including the variables phrase structure and semantic relatedness was performed on the latencies. The analysis did not yield a significant main effect of phrase structure, $F_1(1, 23) = 0.1$, and $F_2(1, 23) = 1.6$. However, latencies to semantically related sentences were, on average, 40 ms longer than latencies to semantically unrelated sentences, and this gave rise to a significant main effect of semantic relatedness, $F_1(1, 23) = 35.1$, $MSE = 1{,}070$, $p < .01$, and $F_2(1, 23) = 30.9$, $MSE = 1{,}228$, $p < .01$. In addition, an interaction between phrase structure and semantic relatedness demonstrated that the 58-ms difference between latencies to the related and unrelated same phrase sentences was significantly greater than the 21-ms difference between latencies to the related and unrelated different phrase sentences, $F_1(1, 23) = 6.2$, $MSE = 1{,}285$, $p < .05$, and $F_2(1, 23) = 6.6$, $MSE = 1{,}563$, $p < .05$. Further analyses revealed that the difference between latencies to the related and unrelated same phrase sentences was significant, $F_1(1, 23) = 29.8$, $MSE = 1{,}108$, $p < .01$, and $F_2(1, 23) = 34.2$, $MSE = 1{,}287$, $p < .01$, as was the difference between latencies to the related and unrelated different phrase sentences, $F_1(1, 23) = 8.3$, $MSE = 992$, $p < .01$, and $F_2(1, 23) = 5.1$, $MSE = 1{,}363$, $p < .05$. To test if performance differed over the two halves of the experiment, an ANOVA including the variables experiment half, phrase structure, and semantic relatedness was performed on the latencies. Latencies in the first half of the experiment were, on average, 34 ms longer than in the second half, and this gave rise to a significant main effect of experiment half, $F_1(1, 23) = 10.0$, $MSE = 5{,}744$, $p < .01$, and $F_2(1, 63) = 16.1$, $MSE = 3{,}329$, $p < .01$. However, no significant interactions involving the variable experiment half were observed.

Table 1
Latencies, Durations, and Percentage Error Rates for the Sentence Types of Experiment 1

Sentence type	Latency (ms)	Duration (ms)	Error rate (%)
Complex related	911	2,327	2.1
Complex unrelated	853	2,297	0.9
Difference	58	30	1.2
Simple–simple related	890	2,423	2.0
Simple–simple unrelated	869	2,398	1.5
Difference	21	25	0.5

An ANOVA including the variables phrase structure and semantic relatedness was performed on the durations. Different phrase sentence durations were, on average, 98 ms longer than same phrase sentence durations, and this gave rise to a significant main effect of phrase structure, $F_1(1, 23) = 19.9$, $MSE = 11{,}736$, $p < .01$, and $F_2(1, 23) = 41.8$, $MSE = 5{,}440$, $p < .01$. In addition, semantically related sentence durations were, on average, 28 ms longer than semantically unrelated sentence durations, and this gave rise to a significant main effect of semantic relatedness, $F_1(1, 23) = 5.4$, $MSE = 3{,}267$, $p < .05$, and $F_2(1, 23) = 4.4$, $MSE = 14{,}249$, $p < .05$. However, no significant interaction between phrase structure and semantic relatedness was observed, $F_1(1, 23) = 0.03$, and $F_2(1, 23) = 0.04$. To test if performance differed over the two halves of the experiment, an ANOVA including the variables experiment half, phrase structure, and semantic relatedness was performed on the durations. Durations in the first half of the experiment were, on average, 96 ms shorter than in the second half of the experiment, and this gave rise to a significant main effect of experiment half, $F_1(1, 23) = 20.1$, $MSE = 23{,}106$, $p < .01$, $F_2(1, 23) = 19.3$, $MSE = 24{,}768$, $p < .01$. However, no significant interactions involving the variable experiment half were observed.

Discussion

In the current experiment, we observed that latencies to both different phrase and same phrase sentences are longer when those sentences feature semantically related words than when they feature semantically unrelated words. As argued above, such semantic interference effects indicate that the processing of the two nouns in these sentences overlaps temporally and that there is a horizontal information flow between them. The results from Experiment 1 also serve to indicate the range over which horizontal information flow is obtained during conceptual and grammatical planning. Thus, the fact that semantic interference effects were observed both in the case of different phrase sentences and same phrase sentences indicates that a horizontal information flow can be obtained both between the words within a phrase and between words within separate phrases. In addition, however, the fact that a stronger semantic interference effect was observed in the case of the same phrase sentences than in the case of the different phrase sentences suggests that there might be less or weaker information flow within phrases than between phrases. An alternative explanation of this interaction is that it reflects differences in the picture movements used for the same phrase and different phrase sentences (specifically, the fact that pictures move in the same direction in the case of the same phrase sentences but in opposing directions in the case of the different phrase sentences). To test this alternative interpretation of the interaction, we conducted Experiment 2.

Experiment 2

We designed Experiment 2 to test whether the interaction observed in Experiment 1 reflected a dissipation of horizontal information flow at greater ranges or simply differences in the picture movements used for the same phrase and different phrase sentences. In this experiment, participants saw the same picture movements as in Experiment 1 but were instructed to describe them with the following same phrase sentences:

Vertical related: “The saw and the axe move down”
Vertical unrelated: “The saw and the cat move down”
Horizontal related: “The saw and the axe move apart”
Horizontal unrelated: “The saw and the cat move apart”

Clearly, if the interaction observed in Experiment 1 resulted from the use of differing picture movements rather than differing syntactic descriptions, the interaction should still be observed in an experiment that retained the differing picture movements but not the differing syntactic descriptions. In contrast, if the interaction was the product of the differing syntactic descriptions rather than the differing picture movements, then the interaction should no longer be observed.

Method

The method was the same as for Experiment 1 except that participants were instructed to describe two horizontal picture movements using same phrase rather than different phrase sentences.

Results

Outliers were excluded from the analyses following the same criteria used for Experiment 1, as were data from trials with technical problems. This resulted in the loss of 1.1% of the data. Responses were categorized as errors as in Experiment 1 and were excluded. Mean latencies, mean durations, and percentage error rates are shown in Table 2.

Error rates were highest in conditions with the longest latencies, thus providing no evidence of a speed–accuracy trade-off. Analyses by subject and by item were carried out as in Experiment 1. An ANOVA including the variables movement type (vertically vs. horizontally moving pictures) and semantic relatedness was performed on error rates, but it yielded no significant effects.

An ANOVA including the variables movement type and semantic relatedness was performed on the latencies. The analysis did not yield a significant main effect of movement type, $F_1(1, 23) = 0.2$, and $F_2(1, 23) = 0.7$. However, latencies to semantically related sentences were, on average, 22 ms longer than latencies to semantically unrelated sentences, and this gave rise to a significant main effect of semantic relatedness, $F_1(1, 23) = 7.4$, $MSE = 1{,}525$, $p < .05$, and $F_2(1, 23) = 8.5$, $MSE = 1{,}352$, $p < .01$. The interaction between movement type and semantic relatedness proved to be nonsignificant, $F_1(1, 23) = 0.2$, and $F_2(1, 23) = 0.02$. Further analyses revealed that the difference between latencies to the related and unrelated vertical sentences was significant, $F_1(1, 23) = 6.0$, $MSE = 1{,}137$, $p < .05$, $F_2(1, 23) = 4.4$, $MSE = 1{,}670$, $p < .05$, as was the difference between latencies to the related and unrelated horizontal sentences, $F_1(1, 23) = 4.3$, $MSE = 1{,}053$, $p <$

Table 2
Latencies, Durations, and Percentage Error Rates for the Sentence Types of Experiment 2

Sentence type	Latency (ms)	Duration (ms)	Error rate (%)
Vertical related	826	2,301	1.1
Vertical unrelated	802	2,318	0.3
Difference	24	−17	0.8
Horizontal related	826	2,436	1.3
Horizontal unrelated	807	2,412	0.8
Difference	19	24	0.5

.05, and $F_2(1, 23) = 6.6$, $MSE = 793$, $p < .05$. To test if performance differed over the two halves of the experiment, an ANOVA including the variables experiment half, movement type, and semantic relatedness was performed on the latencies. Latencies in the first half of the experiment were, on average, 2 ms shorter than in the second half of the experiment. There was no significant main effect of experiment half and no significant interactions involving the variable experiment half were observed. The average latency across the four conditions was 815 ms, which is 66 ms shorter than the average latency observed in Experiment 1.

An ANOVA including the variables movement type and semantic relatedness was performed on the durations. Horizontal movement sentence durations were, on average, 114 ms longer than vertical sentence durations, and this gave rise to a significant main effect of movement type, $F_1(1, 23) = 67.3$, $MSE = 4{,}693$, $p < .01$, and $F_2(1, 23) = 51.2$, $MSE = 6{,}106$, $p < .01$. The analysis did not yield a significant main effect of semantic relatedness, $F_1(1, 23) = 0.1$, and $F_2(1, 23) = 0.03$. The interaction between movement type and semantic relatedness was marginally significant, $F_1(1, 23) = 4.1$, and $F_2(1, 23) = 5.0$, $MSE = 1{,}783$, $p < .05$. To test if performance differed over the two halves of the experiment, an ANOVA including the variables experiment half, movement type, and semantic relatedness was performed on the durations. Durations in the first half of the experiment were, on average, 117 ms shorter than in the second half, and this produced a main effect of experiment half, $F_1(1, 23) = 66.9$, $MSE = 9{,}432$, $p < .01$, and $F_2(1, 23) = 58.7$, $MSE = 11{,}560$, $p < .01$. However, no interactions involving the variable experiment half were observed.

Discussion

In Experiment 2, semantic interference effects were once again observed in relation to both same phrase and different phrase sentences. However, in contrast to Experiment 1, no interaction was observed between these two effects in the current experiments. Such a pattern of results suggests that the interaction observed in Experiment 1 was the result of the differing syntactic descriptions used in this experiment rather than the differing picture movements. Thus, Experiment 2 provides further support for the view that horizontal information flow is stronger between words in the same phrase rather than between words in separate phrases. It is also the case that Experiment 2 failed to replicate the semantic interference effects observed in the durations in Experiment 1. The most likely explanation for this is simply that these effects were not robust.

Experiment 3

Experiment 3 investigated whether the phonological planning of a lexeme can overlap temporally with that of another lexeme and whether phonological information can flow horizontally between them. To this end, we used a design that required participants to describe moving words and picture using same phrase sentences. In a *begin overlap* condition, the two consonant-vowel-consonant (CVC) nouns in the same phrase sentence possessed either a phonologically related or unrelated initial segment (defined as the onset and nucleus of a CVC noun), whereas in an *end overlap* condition, the two CVC nouns in the same phrase sentence possessed either a phonologically related or unrelated final segment (defined as the coda and nucleus of a CVC noun):

> *Begin overlap related*: "The cat and the cap move up"
> *Begin overlap unrelated*: "The cat and the rock move up"
> *End overlap related*: "The flag and the bag move up"
> *End overlap unrelated*: "The flag and the brick move up"

We reasoned that if phonological facilitation effects were observed in either the begin or end overlap condition, this would indicate that there is a temporal overlap in the activation of lexemes from within the same phrase and a flow of phonological information between them.

Method

Materials. In the current experiment, 44 pictures and 44 words from the set in Experiment 1 were used. The set of pictures was divided into a set of 20 experimental pictures and a set of 24 filler pictures. Moreover, the target words used to name the experimental pictures were all monosyllabic CVC nouns and had a frequency count of 72 occurrences per million. The set of 20 experimental pictures were also divided up into two sets of 10—one for use in the begin overlap condition and one for use in the end overlap condition. These two sets were matched across a number of relevant features as Table 3 shows.

The set of 44 words were also divided up into a set of 20 experimental words and a set of 24 filler words. The set of 20 experimental words were selected on the basis of their phonological relatedness to the target words corresponding to the experimental pictures. Thus, 10 of the experimental words were selected because their initial segment was phonologically identical to that of one of the experimental pictures used in the begin overlap condition (i.e., the word "doll" was chosen to match the picture "dog"), whereas the other 10 were selected because their final segment was phonologically identical to that of one of the experimental pictures used in the end overlap condition (i.e., the word "map" was chosen to match the picture "tap"). These two sets of experimental words were also matched in terms of their length and frequency. Thus, all of the experimental words were a single syllable in length and whereas the words in the begin overlap set had a log frequency of 2.2, the words in the end overlap set had a log frequency of 1.9. Combining the two sets of experimental pictures and words together yielded a set of picture and word pairs for use in the begin overlap condition and a set of picture and word pairs for use in the end overlap condition. To create the picture and word pairs for use in the unrelated conditions, begin overlap pictures were recombined with phonologically unrelated words from the end overlap set and end overlap pictures were recombined with phonologically unrelated words from the begin overlap set. In all conditions, experimental words were paired with experimental pictures whose target word they were semantically unrelated to.

Design. The experiment comprised two practice blocks of 16 trials and two experimental blocks of 44 trials. Each experimental block featured 20 experimental trials and 24 filler trials. The 20 experimental trials were divided up into four sets of 5 trials—one set for each of the four experi-

Table 3
Two Matched Sets of Experimental Object Pictures for Experiment 3

Variable	Begin overlap	End overlap
Naming latency (ms)	562	551
Standard deviation (ms)	143	135
No. of syllables	1.0	1.0
No. of phonemes	3.1	2.8
Log frequency	4.3	3.7

mental conditions. In all of the experimental trials, the picture and the word would move up or down in the same vertical direction. The two experimental trial movement types (e.g., “up” and “down”) were distributed so that participants would see equal numbers of the two movements in all of the conditions. In total, there were 40 experimental trials—10 for each of the conditions. In all other respects the design was the same as for Experiment 1.

Results

Outliers were excluded from the analyses using the same criteria as Experiment 1, as were data from trials with technical problems. This resulted in the loss of 2.3% of the data. Responses were categorized as errors as in Experiment 1 and were excluded. Mean latencies, mean durations, and percentage error rates are shown in Table 4.

Error rates were highest in conditions with the longest latencies, thus providing no evidence of a speed–accuracy trade-off. Analyses by subject and by item were carried out as in Experiment 1. An ANOVA including the variables overlap (begin overlap vs. end overlap) and phonological relatedness (phonologically related picture and word vs. phonologically unrelated picture and word) was performed on error rates but it yielded no significant effects.

An ANOVA including the variables overlap and phonological relatedness was performed on the latencies. The analysis did not yield a significant main effect of overlap, $F_1(1, 23) = 0.2$, and $F_2(1, 18) = 0.05$. However, latencies to phonologically related sentences were, on average, 32 ms shorter than latencies to phonologically unrelated sentences and this gave rise to a significant main effect of phonological relatedness, $F_1(1, 23) = 7.5$, $MSE = 3{,}061$, $p < .05$, and $F_2(1, 18) = 5.5$, $MSE = 2{,}009$, $p < .05$. The interaction between overlap and phonological relatedness proved to be nonsignificant, $F_1(1, 23) = 1.9$, and $F_2(1, 18) = 1.2$. Further analyses revealed that the difference between latencies to the related and unrelated begin overlap sentences was nonsignificant, $F_1(1, 23) = 0.9$, and $F_2(1, 9) = 0.7$, but that the difference between latencies to the related and unrelated end overlap sentences was significant, $F_1(1, 23) = 10.2$, $MSE = 2{,}425$, $p < .01$, and $F_2(1, 9) = 6.3$, $MSE = 1{,}885$, $p < .05$. To test if performance differed over the two halves of the experiment, an ANOVA including the variables experiment half, overlap and phonological relatedness was performed on the latencies. Latencies in the first half of the experiment were, on average, 14 ms shorter than in the second half but no main effect or interactions were observed. Similar ANOVAs were performed on the durations but no main effects or interactions were observed.

Table 4
Latencies and Percentage Error Rates for the Sentence Types of Experiment 3

Sentence type	Latency (ms)	Duration (ms)	Error rate (%)
Begin related	805	2,376	1.4
Begin unrelated	822	2,403	1.6
Difference	−17	−27	−0.2
End related	785	2,365	0.9
End unrelated	831	2,407	2.5
Difference	−46	−42	−1.6

Discussion

In Experiment 3, a phonological facilitation effect was observed in the end overlap condition. This effect indicates that there is a temporal overlap in the activation of lexemes from within the same phrase and a flow of phonological information between them. It is, however, difficult to be certain why a facilitation effect was observed in the case of the end overlap condition but not in the case of the begin overlap condition. A similar finding was observed in a study by Meyer and Schriefers (1991), which also used a picture–word interference task. In Meyer and Schriefers’s study, facilitation effects were observed to target words that shared an onset and nucleus with distractor words but only when the distractor words were presented auditorily within 150 ms of the appearance of the picture corresponding to the target word. In particular, when the distractor word was presented 300 ms prior to the appearance of the picture corresponding to the target word in the begin related condition, the facilitation effect disappeared. This suggests that facilitation effects may not arise when a sufficient temporal gap separates the activation of the shared segments of the target and distractor words. Unfortunately, it is difficult to be certain whether such an asynchrony is responsible for the failure to observe a facilitation effect in the case of the begin overlap condition in the current experiment because the time separating the presentation of the distractor word and the picture corresponding to the target word was not manipulated. Indeed, because distractor words were presented visually rather than auditorily in the current study, the time at which participants were required to attend to the distractor word was not fixed, and, consequently, the design of the current study does not allow the temporal relation between the processing of the target and distractor word to be independently determined. Thus, although we can infer from the facilitation effect in the case of the end overlap condition that there was a temporal overlap in the processing of the end segments of the target and distractor words, we cannot infer either that there was an absence of temporal overlap in the case of the begin overlap condition or that an absence of temporal overlap was responsible for the absence of a facilitation effect. A related effect of phonological form similarity has been demonstrated using methods in which both the prime and target words must be spoken (O’Seaghdha & Marin, 2000; Sevald & Dell, 1994; Wheeldon, 2003). These studies have showed that times to produce pairs of words decrease when those words share a final consonant but increase when they share an initial consonant. To explain this pattern of results, Sevald and Dell assumed that a word’s initial segment is produced before its final segment. Moreover, they assumed that when the second word in a pair is produced, the segment that it shares with the first word serves to reactivate the discrepant segment of the first word. In such a view, when the words in a pair share an initial segment, producing the initial segment of the second word reactivates the discrepant segment of the first word in time for it to inhibit the production of the final segment of the second word. In contrast, when the words in a pair share a final segment, producing the final segment of the second word reactivates the discrepant segment of the first word too late for it to inhibit the production of the initial segment of the second word. It is uncertain, however, whether such an account explains the results observed in the current experiment. In particular, although greater facilitation was observed with sentences in the end overlap condition than in the begin overlap condition as Sevald and Dell's model predicts, no inhibition was observed with sentences in the begin overlap condition. Unfortunately, the methodological differences between the design of the current study and that used by Sevald and Dell are so numerous that it is difficult to pinpoint the precise source of this empirical discrepancy. Clearly, then, further experimental work is required to determine why a facilitation effect was observed only in the end overlap condition in the current experiment.

Experiment 4

The purpose of Experiment 4 was to investigate whether there is a temporal overlap in the planning of lexemes from separate phrases and whether there can be a horizontal flow of phonological information between lexemes in separate phrases. To test this, the experiment probed for phonological facilitation effects in the following types of different phrase sentences:

Begin overlap related: "The cat moves above the cap"
Begin overlap unrelated: "The cat moves above the rock"
End overlap related: "The flag moves above the bag"
End overlap unrelated: "The flag moves above the brick"

We reasoned that if latencies to the related sentences were shorter than those to unrelated sentences in either the begin or end overlap condition, such a phonological facilitation effect would constitute evidence of a temporal overlap and a horizontal information flow between lexemes in separate phrases.

Method

The method was the same as for Experiment 2 except that the experimental trials featured pictures that moved up or down and words that remained stationary, and participants were instructed to describe these movements using different phrase sentences.

Results

Outliers were excluded from the analyses using the same criteria as Experiment 1, as were data from trials with technical problems. This resulted in the loss of 0.6% of the data. Responses were categorized as errors as in Experiment 1 and were excluded. Mean latencies, mean durations and percentage error rates are shown in Table 5.

Error rates were highest in conditions with the longest latencies, thus providing no evidence of a speed–accuracy trade-off. Analyses by subject and by item were carried out as in Experiment 1. An ANOVA including the variables overlap (begin overlap vs. end overlap) and phonological relatedness (phonologically related picture and word vs. phonologically unrelated picture and word) was performed on error rates but it yielded no significant effects.

Table 5
Latencies and Percentage Error Rates for the Sentence Types of Experiment 4

Sentence type	Latency (ms)	Duration (ms)	Error rate (%)
Begin related	810	2,411	1.3
Begin unrelated	807	2,405	1.0
Difference	3	6	0.3
End related	824	2,420	1.9
End unrelated	820	2,414	1.9
Difference	4	6	0.0

An ANOVA including the variables overlap and phonological relatedness was performed on the latencies. The analysis did not yield a significant main effect of overlap, $F_1(1, 23) = 1.6$, and $F_2(1, 18) = 0.4$, or a significant main effect of phonological relatedness, $F_1(1, 23) = 0.1$, and $F_2(1, 18) = 0.06$. In addition, the interaction between overlap and phonological relatedness proved to be nonsignificant, $F_1(1, 23) = 0.001$, and $F_2(1, 18) = 0.0$. Further analyses revealed that the difference between latencies to the related and unrelated begin overlap sentences was nonsignificant, $F_1(1, 23) = 0.05$, and $F_2(1, 9) = 0.02$, as was the difference between latencies to the related and unrelated end overlap sentences, $F_1(1, 23) = 0.08$, and $F_2(1, 9) = 0.07$. To test if performance differed over the two halves of the experiment, an ANOVA including the variables experiment half, overlap, and phonological relatedness was performed on the latencies. Latencies in the first half of the experiment were, on average, 14 ms shorter than in the second half of the experiment. However, there was no significant main effect of experiment half and no significant interactions involving the variable experiment half were observed. An ANOVA including the variables overlap and phonological relatedness was performed on the durations but no significant main effects or interactions were observed. This also proved to be the case for an ANOVA including the variables experiment half, overlap, and phonological relatedness.

Discussion

No phonological facilitation effects were observed in either the begin or end overlap conditions in Experiment 4. As such, the experiment failed to provide any evidence of a temporal overlap in the activation of lexemes from different phrases. Also, it failed to provide any evidence of a flow of phonological information between lexemes from different phrases. The most plausible interpretation of this pattern of results is that there is no temporal overlap and no flow of phonological information between lexemes in different phrases. Such an interpretation is supported by a number of online sentence-production studies, which have indicated that phonological planning is restricted to the first phonological word or the first phrase of a sentence prior to speech onset (e.g., Meyer, 1996; Wheeldon & Lahiri, 1997). Such studies have indicated that phonological planning would only have been conducted prior to speech onset for the target word in different phrase sentences and not for the distractor word. Consequently, these studies suggest that no temporal overlap and no flow of phonological information would have occurred between the lexemes within a different phrase sentence prior to speech onset and, thus, that no phonological facilitation effect should have been observed.

General Discussion

The purpose of the current study was to investigate the horizontal flow of information between words during spoken sentence production. Specifically, in the study we investigated whether there is a temporal overlap in the processing of the words of a sentence and whether information from one word can influence the access of another word in a sentence. To probe these issues, we ran experiments using a method that combined features of the picture–word interference task (e.g., Golinkoff & Rosinski, 1976; Rosinski, 1977) with features of a sentence-production task (e.g., Levelt & Maassen, 1981; Smith & Wheeldon, 1999). Such a design tests whether the distinct words of a sentence, like the target and distracter words of a picture–word interference task, give rise to semantic interference and phonological facilitation effects. Using this design, we can investigate whether there is a temporal overlap in the processing of the words in a sentence and a flow of information between them, just as there is a temporal overlap between the processing of the target and distracter words in a picture–word interference paradigm and a flow of information between them. Consistent with previous studies conducted using the picture–word interference paradigm (e.g., Damian et al., 2001; Jescheniak & Schriefers, 2001; Lupker, 1979; Starreveld & La-Heij, 1996), in the current study we demonstrated both semantic interference effects and phonological facilitation effects. Thus, in Experiments 1 and 2, semantic interference effects were repeatedly observed between lemmas in both same phrase and different phrase sentences. In addition, however, a phonological facilitation effect was observed between lexemes sharing end segments in same phrase sentences. Just as such effects indicate a temporal overlap in the processing of the target and distracter words in a picture–word interference task and a flow of information between them, such effects indicate a temporal overlap in the processing of the words in a sentence and a flow of information between them. Specifically, such effects are compatible with the view that there is a parallel and interactive horizontal flow of information between the words of a sentence at both the grammatical and phonological planning levels of speech production.

In providing support for the parallel processing of words within a sentence, the results of the current study contrast with those of a number of previous studies. In particular, the results contrast with those obtained in a series of eye-tracking studies by Meyer and colleagues (e.g., Meyer et al., 1998; Meyer & van der Meulen, 2000). In these studies, evidence was obtained that was compatible with a strictly serial approach to word access. Thus, it was found that when participants described two pictures using coordinated noun phrases such as, “the book and the pipe”, they would not attend to the picture corresponding to the second noun in the phrase until the phonological encoding of the first noun in the phrase had been completed. On the basis of such results, Meyer et al. concluded that the processing of the first noun is not initiated until that of the first noun is complete. In contrast to such a strictly serial view of the processing of words during speech, the semantic interference and phonological facilitation effects observed in the current study indicate that there has been a temporal overlap between the target and distractor word during grammatical and phonological planning. It is critical that such evidence for parallel processing is not necessarily incompatible with the results of Meyer and colleague’s eye-tracking studies. In particular, as the studies reported in Meyer and Dobel (2003) have suggested, the eye-tracking data do not necessitate a strictly serial model of word access because some processing of a picture can be conducted prior to fixation on it. More generally, the current results have implications for Levelt and Meyer’s (2000) claim that speakers pursue a serial processing strategy in lemma access to spread the cognitive load even when this risks incurring dysfluency. In particular, the current results suggest that speakers engage in at least some degree of temporal overlap in spoken word production, a strategy that is less likely to give rise to dysfluency than a strictly serial approach.

Moreover, the current study provides evidence not only of parallel processing but also interactive processing during word access. Specifically, the results of the current experiment are compatible with the view that there is a horizontal flow of semantic and phonological information from one word to another during spoken sentence production. Thus, to make sense of the phonological facilitation and semantic interference effects that occur in a standard picture–word interference task, it is necessary to assume that there is a flow of information between the target and distractor words (cf. theoretical accounts by Cohen et al., 1990; Phaf et al., 1990; Roelofs, 1992). Similarly, in the current paradigm, the occurrence of phonological facilitation and semantic interference effects compel us to believe that there has been a transfer of semantic and phonological information between the target and distractor words. As such, the current results reinforce the experimental evidence of horizontal information flow in the study by Rapp and Samuel (2002). However, the currents results extend those of Samuel and Rapp insofar as they indicate that it is not only phonological information but also semantic information that can flow horizontally during word access. In providing further experimental evidence of horizontal information flow, the current results further reinforce the view that the horizontal information flow that gives rise to speech errors such as perseveration and exchange errors is not simply a product of a disrupted speech system but may be a feature of a normally functioning speech system. Clearly, perseveration and exchange errors demonstrate that dangers do attach to an interactive approach to word access, dangers that could be avoided by a speech system using a strictly modular approach to word access. Nevertheless, the mounting evidence for horizontal information flow in sentence production suggests that the benefits of such interactive processing outweigh the costs. Indeed, as we argued in the introduction, such processing may be necessitated by the prevalence in language of grammatical dependencies between the words of a sentence and, in particular, between words within the same phrase.

In the current study we also probed the range over which such horizontal information flow obtains. Thus, Experiment 1 provided evidence of semantic interference effects both between words within the same phrase and between words within different phrases. This indicates that the range of semantic information is quite extensive insofar as such information can flow between words at opposite ends of the clause. Because there is evidence that semantic interference effects only arise during lemma access (e.g., Damian et al., 2001; Jescheniak et al., 2001) and not during conceptual planning (e.g., Schriefers et al., 1990), such a finding may suggest that there is a temporal overlap in the access of lemmas at opposite ends of the clause. This in turn would seem to contradict the many recent studies that have provided evidence for incremental lemma access (e.g., Griffin, 2001; Griffin & Bock, 2000; Levelt & Maassen, 1981; Martin, Katz, & Freedman, 1998; Meyer et al., 1998; Meyer & Van der Meulen, 2000; Schriefers, de Ruiter, & Steigerwald, 1999; Schriefers & Teruel, 1999; Schriefers, Teruel, & Meinshausen, 1999; Smith & Wheeldon, 1999, 2001; although see Ferreira & Swets, 2001, for evidence of non-incremental access). In fact, however, such findings are not irreconcilable. It could be, for example, that semantic interference effects arise between words in different phrases when semantic information generated during the conceptual planning of one word interferes with the lemma access of the other word. In such a scenario, lemma access need not be conducted simultaneously for words in different phrases, and thus this scenario is consistent with studies that have found that lemma access is incremental. In addition, however, because such a scenario assumes that semantic interference effects arise during lemma access rather than during conceptual planning, it is consistent with studies that have found that semantic interference effects arise during lemma access. Such an account may even allow us to make sense of the finding that the semantic interference effects observed between words in the same phrase are significantly stronger than those obtained for words within different phrases reported in Experiments 1 and 2. Thus, it is possible that semantic interference effects are strong for words within the same phrase because both the conceptual and lemma information from one word is interfering with the lemma access of another word. It is also possible that semantic interference effects are weak for words within different phrases because only the conceptual information from one word is interfering with the lemma access of another word.

Experiments 3 and 4 indicated that, in contrast to semantic interference effects, only lexemes from within the same phrase give rise to phonological facilitation effects. As argued above, the most plausible explanation for this pattern of results is that although there is a temporal overlap in the activation of lexemes in the same phrase and a flow of phonological information between them, lexemes in separate phrases are processed neither in parallel nor interactively. Such a view is consistent with the data from studies of speech error corpora. Thus, Garrett (1980a) has observed that erroneous exchanges of phonological segments tend to involve lexemes from the same phrase (as in Example 1 above). In addition, this observation is reinforced by experimental studies showing that the scope of phonological planning is smaller than that of grammatical planning and may be as small as a phonological word (e.g., Meyer, 1996; Wheeldon & Lahiri, 1997). However, the results of the current study fit less easily with those of Rapp and Samuel (2002). As noted above, Rapp and Samuel showed in a sentence-completion task that participants tend to select words that are phonologically similar to a word in a prior clause. Thus, they tend to choose "neck" in response to a sentence such as "He'd gone to deposit his check and nearly broke his ______". Clearly, such a finding indicates, in contrast to the current study, that the horizontal flow of phonological information is not restricted to lexemes from within the same phrase but can involve lexemes from different clauses. One way to reconcile these findings is to assume that they reflect different directions of horizontal information flow. Thus, in the Rapp and Samuel study, information from a distractor word flows from left to right across the sentence to influence word access. A similar information flow is observable in perseveration errors in which phonological segments from lexemes in prior clauses interfere with lexeme access as in the following (Example 22 in Berg, 1987):

3. Das war nicht mein Lebenskreis. Ich verbringe die meiste Kreis-Zeit zu Hause in Freisbach.
That is not my life circle. I spend the (f.) most circle (m.) – time (f.) at home in Freisbach.
"That is not my normal social circle. I spend most of my time at home in Freisbach."

It is possible that the current study in placing the distractor word to the right of the target word is tapping into the flow of information from right to left across a sentence. Such a flow of information is observed in sound exchange errors in which the production of a lexeme is interrupted by a lexeme that follows it in the sentence (as in Example 1 above). Crucially, unlike sound perseveration errors, sound exchange errors tend to be restricted to lexemes from within the same phrase. As such, they provide support for the view that the right to left flow of phonological information is restricted to lexemes from within the same phrase and, thus, that the phonological interference effect observed in the current study arises from a right to left flow of phonological information.

Overall, then, in the current study we provide evidence that there is a temporal overlap in the activation of words during speech and a flow of information between them. Moreover, in the current study we probed both the range and the speech production stages at which such parallel and interactive processing occurs. Despite our findings, however, much more experimental work is still required. Most obviously, further work is required to probe the transfer of grammatical information as opposed to the semantic and phonological information flow probed in this study. This could be achieved, for example, in a study that looked at the kinds of effects that arise when multiple words in sentences either share or differ in their grammatical gender marking. In addition, it would be valuable to explore horizontal information flow in a range of other experimental paradigms. Although the variant of the picture–word interference task we used in the current study is quite different to the sentence completion task used in Rapp and Samuel's (2002) study, for example, the studies resemble each other insofar as they both make use of distractor words. As such, it is possible that both studies may have tapped into comprehension as well as production processes. Therefore, it would be desirable to conduct an experiment that probed only production processes by using, for example, a picture as a distractor rather than a word (although this runs the risk of a visual similarity confound). Further work is also required to determine why lexemes sharing a nucleus and coda give rise to facilitation effects when lexemes sharing an onset and coda do not. Although there are various possible explanations of this contrast (e.g., Meyer & Schriefers, 1991; O'Seaghdha & Marin, 2000; Sevald & Dell, 1994), additional experiments manipulating factors such as the frequency of the lexemes and the asynchrony in the presentation of the target and distractor word are required to test between them. More generally, further studies are needed to address the issue of why horizontal information flow occurs and, in particular, whether it confers any functional benefits on the speaker. In addition, given the link between horizontal information flow and speech errors such as exchanges and perseverations, future studies need to address the issue of how speakers are able to maintain a horizontal flow of information while minimizing dysfluency.

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Appendix

Picture-Word Pairs Used in Experiments 1–4

12 Living Semantically Related Picture-Word Pairs Used in Experiments 1 and 2

snake-eel	pig-cow	camel-goat
finger-toe	nose-mouth	elephant-hippo
dog-cat	fish-whale	rose-tree
rabbit-hamster	frog-lizard	arm-leg

12 Nonliving Semantically Related Picture-Word Pairs Used in Experiments 1 and 2

flag-badge	dice-card	ladder-stairs
saw-axe	anchor-ship	watch-clock
tie-scarf	scissors-knife	tap-hose
bottle-jug	table-chair	boot-shoe

10 “Begin Overlap” Phonologically Related Word-Picture Pairs Used in Experiments 3 and 4

watch-wand	gate-game
arm-arch	hand-hat
dog-doll	sock-song
bridge-brick	fish-fig
cat-cap	rose-robe

10 “End Overlap” Phonologically Related Word-Picture Pairs Used in Experiments 3 and 4

car-jar	nose-hose
dice-rice	shoe-glue
door-floor	tap-map
flag-bag	tie-fly
fork-cork	clock-rock

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