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ORIGINAL ARTICLE

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Evidence for effects of phonological correspondence between visible speech and written syllables

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Abstract The present study investigated compatibility effects between written and spoken syllables. Participants saw the syllables "Ba" or "Da" printed on a speaker's mouth that was articulating either /b∧/ or /d∧/. Participants classified either the printed syllable or the mouth movement by pressing a left or right key. Responses were faster when mouth movement and letters were congruent regardless of imperative stimulus dimension. As the two stimulus dimensions (mouth movements and letters) showed dimensional overlap, but did not overlap with the response, stimulus-response compatibility was ruled out according to some models. It is argued that the compatibility effect was due to the competition of phonological codes at a stage preceding response selection. Also, the results lend support to the view that Stroop-like tasks are ambiguous with regard to the locus of compatibility effects. Stimulus-response and stimulus-stimulus compatibility may be observed.

Introduction

In previous experiments (Kerzel & Bekkering, 2000), it was observed that reading written consonant-vowel syllables is affected by concurrently presented visible speech. The way in which visible speech is processed is important for theories of speech perception that either do (Liberman & Mattingly, 1985) or do not (e.g., Fowler, 1986; Massaro, 1987) use motor structures to analyze speech input. Kerzel and Bekkering investigated effects of compatibility between response-irrelevant mouth movements of a speaker pronouncing /b∧/ or /d∧/ and vocal latencies for /b∧/ and /d∧/ to different response-relevant stimuli. In one of their experiments, participants were required to read the printed syllables "Ba" and "Da" that were printed on the moving mouth. In this setup, relevant and irrelevant stimulus dimension are similar to each other because they refer to the same syllable, and they are readily translated into the same spoken utterance. Also, both irrelevant and relevant stimulus dimension were non-arbitrarily related to the response. This kind of perceptual or structural similarity between stimulus or response dimensions will be referred to as dimensional overlap (see Kornblum, Hasbroucq, & Osman, 1990). Thus, there was dimensional overlap between printed letters and visual mouth movements, and between the two stimulus dimensions and the verbal response. The results showed that reading a printed syllable was faster when it corresponded to a concurrently presented, irrelevant mouth movement. Two interpretations of this result are possible. On the one hand, it may be that dimensional overlap between the relevant and the irrelevant stimulus dimension accounted for the reaction time (RT) advantage in compatible trials. On the other hand, it may be that the dimensional overlap between the irrelevant stimulus dimension and the response accounted for the results. The latter interpretation would support the idea that speech stimuli lead quickly and inevitable (or automatically) to the activation of the corresponding motor response as postulated by the motor theory of speech perception (Liberman & Mattingly, 1985).

In the study of Kerzel and Bekkering (2000), evidence in support of such a tight coupling between perception and action was provided by eliminating similarities (i.e., overlap) between the stimulus dimensions. In one experiment, the overlap between irrelevant and relevant dimensions was eliminated by using arbitrary symbols ("&&" and "##") to instruct participants to respond either /b∧/ or /d∧/. Still, a compatibility effect was obtained. In another experiment, presentation of the relevant dimension preceded presentation of the irrelevant dimension, i.e., participants were instructed to utter a

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precued syllable when the mouth started to move. In this case, stimulus identification on the relevant dimension and response selection were completed such that compatibility effects could only result from motor activation from the irrelevant information contained in the go-signal (see also Hommel, 1995). The compatibility effect persisted, indicating that the mouth movement inevitably activated some response-related stage.

The results of the prior study were framed within the dimensional overlap model (Kornblum et al., 1990). Kornblum et al. suggested that in virtually any kind of compatibility paradigm two dimensions are involved: one relevant for response execution and the other irrelevant for response execution. In the experiments of Kerzel and Bekkering (2000), participants were instructed to read a syllable while watching irrelevant mouth movements: The relevant letter dimension was translated into a verbal response, whereas the irrelevant dimension, the mouth movement, had to be ignored. According to the dimensional overlap model, the irrelevant dimension may nevertheless activate the corresponding response. That is, the participant may have felt a tendency to imitate the visible speech gesture instead of reading the syllable, which speeded up responses in compatible trials and slowed down responses in incompatible trials. In general, dimensional overlap was assumed to be a precondition for compatibility effects.

The purpose of the present study was to examine possible arguments against a motor interpretation of the compatibility effects. To support such an interpretation, Kerzel and Bekkering's (2000) strategy was to eliminate similarities between relevant and irrelevant stimulus dimensions while maintaining overlap between irrelevant dimension and response. As compatibility effects arising from correspondence of irrelevant dimension and response persisted, they concluded that visible speech may involuntarily activate verbal responses. Here, the notion of a strong perception-action linkage is questioned by adopting a complementary strategy: If automatic response activation provided a complete account of these compatibility effects, then they should disappear when the similarity between stimulus and response is eliminated. To test this conjecture, participants were asked to press a left or right key in response to the same visual mouth movements and letters as in the experiments of Kerzel and Bekkering. As key presses have no perceptual or structural similarity to written or spoken syllables like "Ba" or "Da", compatibility effects between relevant and irrelevant dimensions would have to be attributed to phonological competition or facilitation but cannot be attributed to motor activation (at least not within the dimensional overlap model). If such effects are obtained, it is unlikely that motor activation may fully account for the compatibility effects in Kerzel and Bekkering's study: It may have been that phonological coding of the irrelevant stimulus dimension (mouth movements) facilitated or interfered with the selection of a phonological code needed for response production. Thus, a compatibility effect with key presses would suggest that phonological codes formed with respect to the relevant and irrelevant dimension may interact at a stage preceding motor programming. At first sight, such a result would question the original idea that visible speech leads to motor activation. However, the Discussion provides possible ways in which current models of stimulus-response translation may accommodate such findings without abandoning the idea of a close perception-action linkage.

In the present experiment, the movements of a speaker's mouth were used to convey phonological information. It has been shown that mouth movements alter the perception of auditory speech. The McGurk effect (McGurk & MacDonald, 1976) shows that the perception of an acoustic syllable is influenced by the visual information about the talker's articulation. For example, if the acoustical syllable /bʌ/is presented in synchrony with a face articulating /gʌ/, English speaking listeners typically perceive /dʌ/ and less frequently /gʌ/. Thus, one may assume that visible mouth movements convey phonological information. In the experiment, visible mouth movements were paired with written syllables that appeared on the speaker's mouth. Participants were asked to either classify the movement of the mouth as /bʌ/ or /dʌ/, or the written syllable as "Ba" and "Da" by pressing a left or right response key. Because the vowel of these consonant-vowel syllables was the same, any effects may be attributed to differences in the consonant. It is very likely that the written letters were recoded in a phonological format (sounds). Thus, both the lip movements and the letters may have been represented as phonological structures. Therefore, any interactions between the relevant and the irrelevant dimension would have to be attributed to competition or facilitation at the level of phonemes.

Method

Participants

Eighteen students at the Ludwig-Maximilians University of Munich were paid for their participation. All reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus and stimuli

Most of the methods were identical to those in the experiments of Kerzel and Bekkering (2000). The computer display had a resolution of 1,280 (H) × 1,024 (V) pixels on a 50-cm (diagonal) screen, and the refresh rate was 60 Hz. Viewing was unrestrained at a distance of 100 cm from the screen. Video recordings of a male speaker pronouncing /bʌ/ or /dʌ/were digitized and converted into a standard picture-file format. Participants saw the lower portion of the speaker's face in a 6.62°×4.95° window on an otherwise white screen. Only the mouth and parts of chin and cheeks were visible. The mouth was approximately centered on the screen. In its resting configuration, it was closed and had a maximal extent of 3.26°×1.09°. Visual presentation of speech gestures was accomplished by showing a sequence of 20 pictures at a rate of 30 Hz (667 ms). A gesture comprised the opening (10 pictures) and closing (10 pictures) of the mouth. In an animation showing a /bʌ/ the maximal vertical extent of the mouth decreased from its value at rest to a minimum of 0.23° after 133 ms (4 pictures) and then increased to a maximum of 2.58° after 333 ms (10 pictures). For sequences showing a /dʌ/, the vertical extent increased from the size at rest to a maximum of 2.86° after 333 ms (10 pictures). In both sequences, the closing movement from the maximal aperture to the rest configuration took 333 ms (10 pictures). The mouth at rest was visible during the intertrial interval. As imperative stimuli, the printed syllables "Ba" and "Da" were presented for 100 ms in the center of the mouth. The capital letters measured 0.29°×0.34°, the "a" measured 0.29°×0.29°. The font was with serifs and its color was white. Participants responded by pressing either the left or right shift key.

Design

There were 15 blocks composed of 16 trials each, which resulted from the factorial combination of visible speech gesture (/bʌ/, /dʌ/), printed syllable ("Ba", "Da") and time interval between the first frame of the animated sequence, i.e., the last frame of the mouth in rest position, and the appearance of the letter, i.e., the letters "Ba" or "Da". This time interval was 0, 167, 333, or 500 ms. The resulting 240 trials were administered in a single 30-min session. The imperative stimulus dimension (ISD) was varied between participants. In the mouth condition, ten participants classified the mouth movement as /bʌ/ or /dʌ/, whereas in the letter condition, eight participants classified the letters "Ba" or "Da". When the ISD was the mouth movement, the relevant stimulus was mostly presented before the irrelevant stimulus (the letter), which is denoted by negative stimulus onset asynchronies (SOAs; 0, –167, –333, and –500 ms). When the ISD was the letter, the relevant stimulus was mostly presented after the irrelevant stimulus (the mouth movement), which is denoted by positive SOAs (0, +165, +333, and +500 ms). The first block served as practice and was not evaluated any further.

Procedure

The experiment took place in a dimly lit room. During the intertrial period, the mouth was visible in its resting position. To avoid anticipatory responses at the onset of the lip movement, the intertrial period varied randomly between 1 s, 1.75 s and 2.5 s. A message was displayed when an error occurred or when the response time exceeded 2.5 s. The assignment of "Ba" and "Da" or /bʌ/ and /dʌ/ on left and right response keys was balanced across participants. In the letter condition, RT was measured from the onset of the letters; in the mouth condition, RT was measured from the beginning of the mouth movement.

Results

Pressing the wrong key was counted as choice error, and responses with RTs shorter than 100 ms or longer than 2.5 s were considered anticipations and missing trials, respectively. There were only a few anticipations and missing trials (0.5%). Conditions were grouped according to the compatibility of relevant and irrelevant dimension. In compatible conditions, the letter and the mouth movement referred to the same phoneme, which was not the case in incompatible conditions. For the mouth and the letter condition, separate two-way ANOVAs (compatibility × SOA) were conducted on mean correct RTs and errors. Means are presented in Fig. 1.

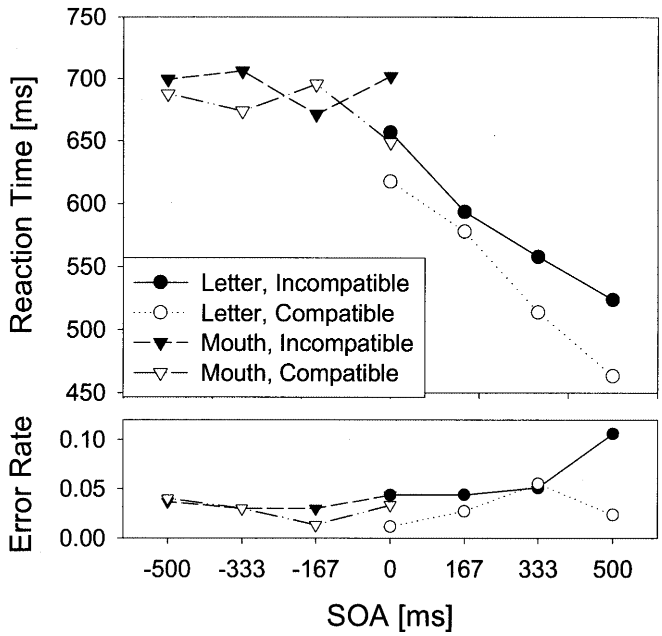

Fig. 1. Mean reaction times and error rates as a function of imperative stimulus dimension (mouth or letter), compatibility (incompatible or compatible), and SOA. Participants had to respond either to the letters or to the mouth movement. Negative SOAs indicate that the relevant dimension preceded the irrelevant dimension. Positive SOAs indicate that the relevant dimension followed the irrelevant dimension (*SOA* stimulus-onset asynchrony)

Mouth condition

Responses were faster when irrelevant and relevant dimensions were compatible (678 vs 697 ms), $F(1, 9) = 11.03$, MSE = 601.7, $P < 0.01$. The interaction of SOA and compatibility reached significance, $F(3, 27) = 4.04$, MSE = 1,351.25, $P < 0.05$. *t*-tests showed that the compatibility effect was reliable with the 0 ms SOA (702 vs 671 ms), $t(9) = 4.55$, $P < 0.01$, and –333 ms SOA (649 vs 696 ms), $t(9) = 3.38$, $P < 0.01$, but not with the remaining SOAs (*P*s > 0.1). An ANOVA on the error data did not yield significant effects.

Letter condition

Responses were faster when irrelevant and relevant dimensions were compatible (534 vs 583 ms), $F(1, 7) = 21.16$, MSE = 1,198.43, $P < 0.01$. RT decreased with SOA from 638 to 494 ms, $F(3, 21) = 153.16$, MSE = 403.16, $P < 0.01$. An ANOVA on the error data showed that fewer errors were made in the compatible than in the incompatible condition (2.9% vs 6%), $F(1, 7) = 9.5$, MSE = 1.6e–3, $P < 0.05$. The effect of SOA, $F(3, 21) = 2.99$, MSE = 4.46e–3, $P = 0.054$, and the interaction of SOA and compatibility, $F(3, 21) = 2.54$, MSE = 2.14e–3, $P = 0.084$, approached significance.

Combined analysis

The 0 ms SOA condition was examined in a combined ANOVA with imperative stimulus dimension as a between-participant factor and compatibility as within-subjects factor. An effect of compatibility, $F(1, 16) = 13.55$, MSE = 2,129.63, $P < 0.01$, showed that responses were faster in the compatible than in the incompatible condition (636 vs 692 ms). An ANOVA on the error data did not yield significant effects.

Discussion

Latencies in the letter condition decreased with SOA, indicating that the movement of the mouth served as a warning signal, such that responses at the later SOAs were better prepared. Further, SOA interacted with compatibility in the mouth condition. There may be two reasons for the interaction. First, the compatibility effect may have decreased with long SOAs in the mouth condition because with long SOAs (e.g., –500 ms) the letters may have been presented after identification of the mouth movement and response selection had been completed (mean RT was 689 ms). Second, it may be that the fast visual motion (mouth opening) at the beginning of the movement (mostly around the –167 ms SOA) diverted attention from the center of the mouth, such that the influence of the distracting letters was reduced (e.g., Besner & Stolz, 1999). Thus, the most adequate comparison between the two ISD conditions was the 0 ms SOA condition as the mouth was approximately static in this condition. In this condition, the compatibility effect was about the same size in both ISD conditions which shows that the stimulus dimensions were at least partially matched in terms of discriminability (see also Melara & Mounts, 1993).

A compatibility effect was obtained with mouth movements and letters as ISD. When the visible mouth movement corresponded to the written syllable, responses were faster compared to conditions with noncorresponding mouth movement and syllable. Because there was no structural or perceptual overlap between stimuli and response, the locus of the effect would be at the stage of stimulus identification according to the dimensional overlap model. Thus, evidence for phonological conflict unrelated to response-related stages was obtained in a paradigm that has previously been taken as evidence for motor activation from visible speech (Kerzel & Bekkering, 2000). At first sight, this finding casts doubt on the conclusion that visible speech is processed automatically up to a late, motor stage. However, both the dimensional overlap model, motor theories of perception, and cascaded processing models may accommodate the results without rejecting strong perception-action links.

Dimensional overlap

According to Kornblum et al.'s (1990) taxonomy, the present task is related to the Stroop phenomenon (Stroop, 1935) because the two stimulus dimensions overlap among themselves and also overlap with the response. In Stroop's experiments, participants were asked to either name the color of a color-word, or to read a colored color-word (for an overview see MacLeod, 1991). For instance, in the color naming condition of a Stroop experiment, the relevant color dimension is translated into a verbal response, whereas the irrelevant dimension, the color-word, is not related to the task. In general, the two stimulus-dimensions (e.g., color-word/color, or mouth movement/written syllable) in Stroop-like situations show dimensional overlap because they reference the same quality (e.g., a color, or a phoneme). Also, each of the two stimulus dimensions in Stroop-like situations overlaps to some degree with the response because both dimensions may activate a corresponding verbal response. As dimensional overlap is a precondition for compatibility effects, both stimulus-stimulus and stimulus-response compatibility effects are expected.

Existing evidence from Stroop experiments supports the notion of a conflict at perceptual, orthographic, lexical and semantic levels of stimulus identification or selection. For instance, when attending to only one colored letter in an otherwise neutral color-word, the Stroop effect is largely reduced or absent (e.g., Besner & Stolz, 1999), suggesting that interference is only observed when the word is processed in a holistic manner. Further, Stroop interference depends on the baseline discriminability of the two stimulus dimensions (Melara & Mounts, 1993). Also, further up in the processing stream, lexical and semantic factors have been shown to affect the Stroop effect (e.g., Glaser & Duengelhoff, 1984; Lupker, 1979, 1982; Rayner & Posnansky, 1978; Starreveld & La-Heij, 1995; Underwood & Briggs, 1984).

In addition to stimulus-stimulus compatibility effects, existing evidence supports the notion of a response-related conflict in Stroop tasks (Durgin, 2000; Flowers, Warner, & Polansky, 1979; McClain, 1983). For instance, Durgin (2000) used a pointing response which required participants to move a mouse cursor into a colored field on the screen instead of a color naming response and observed that the identity of the color-words had almost no effect on pointing latencies. Interpreted in terms of the dimensional overlap model, the absence of interference from the word with pointing responses was due to the lack of dimensional overlap between the irrelevant stimulus dimension (word) and the response (pointing). Therefore, the irrelevant dimension could not activate a conflicting response, such that no interference was observed.

In sum, the dimensional overlap model accommodates apparently conflicting findings on the locus of interference in Stroop-like tasks: Existing evidence supports both an early and a late locus of the conflict. This apparent contradiction is handled by assuming (a) that the stimuli overlap on one dimension and also overlap with the response, and (b) that dimensional overlap may produce compatibility effects. In the present experiment, a related situation was created that involved consonant-vowel combinations as stimuli. Thus, the present experiments provide evidence for combined contributions of stimulus identification and response-selection to compatibility effects at a sublexical (phonological) level of processing.

Motor theories of perception

A different interpretation of the present findings is offered by a strict version of the motor theory of speech perception (Liberman & Mattingly, 1985). The theory claims that any kind of speech perception is motor from the start because stimulus identification is achieved by means of (relatively abstract) motor structures. If one were to accept this view, the motor nature of speech perception precludes the occurrence of stimulus-stimulus interference because processes of phonological identification are motor, not perceptual, and the classical distinction between perception and action is abandoned. Although there may be evidence that this is the case (for a discussion see Mattingly & Studdert-Kennedy, 1991), this line of argument is at odds with the assumption of serial information processing that is dominant in research on compatibility (for an exception see Prinz, 1997) and that also underlies the dimensional overlap model by Kornblum et al. (1990). Although the present results are compatible with a strict version of the motor theory, further research involving electrophysiological methods such as the recording of event-related brain potentials (ERPs) would be needed to support the claim that the present effects are due to processes related to motor programming.

Cascaded processing

An alternative framework in terms of cascaded processing is provided by studies on unconscious semantic priming (e.g., Dehaene, Naccache, Le Clec, Koechlin, Mueller, Dehaene-Lambertz, van de Moortele, & Le Bihan, 1998; Reynvoet, Caessens, & Brysbaert, in press). When observers are asked to judge whether target numbers are larger or smaller than five by pressing a left or right response button, a subliminal prime number presented before the target number activated the corresponding response. In conditions in which the response required by the target number was different from the response required by the prime, responses were slower, and ERPs and function magnetic resonance imaging indicated activation over the motor cortex contralateral to the primed response (Dehaene et al., 1998). These effects were even observed when the prime stimuli did not feature as target stimuli (Naccache & Dehaene, 2001). Thus, response-relevant information was automatically processed up to a very late processing stage. Theses findings cast doubts on the assumption that dimensional overlap is necessary for interactions between stimulus and response. A semantic classification task like the one used by Dehaene et al. (1998) is completely unrelated to left or right responses. Thus, response relevant information may be processed all the way down to the motor system, such that direct motor activation from the stimulus depends on the arbitrary mapping between stimulus and response (Neumann & Klotz, 1994), but not on structural, semantic, or other kinds of similarities. Interference effects may therefore be due to conflicts at the level of motor response programming, and not, as suggested by the dimensional overlap model, by conflict at the level of stimulus identification.

For the present experiment, one would have to conclude that the usage of button presses does not ensure that compatibility effects are restricted to interference at a phonological stage, because direct activation from the phonemes to the assigned responses is possible. Without further brain imaging work, no firm conclusion with respect to the motor activation issue can be reached. Thus, the conceptual ambiguity of the Stroop effect that was described in the dimensional overlap model may be extended to the model itself: Effects of stimulus-response compatibility as reported by Kerzel and Bekkering (2000) do not prevent the occurrence of stimulus-stimulus compatibility. However, because stimulus identification may proceed in a rather cascaded manner from perception to response, it is not clear whether manipulation that are thought to ensure interactions at the level of stimulus identification may not actually be due to interactions of stimulus and response. This, of course, would provide further evidence for models that assume a direct, inevitable linkage between perception and action (Liberman & Mattingly, 1985; Prinz, 1997).

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