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Gaining the upper hand: Comparison of alphabetic and keyboard positions as spatial features of letters producing distinct S–R compatibility effects ☆

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ABSTRACT

The present study explored which stimulus feature, alphabetic or keyboard position, primarily influences letter processing in different task settings. In Experiment 1 (alphabetic position judgment) a response side effect (faster responses when the location of letters within the alphabet or on the keyboard maps onto the response hand) could be observed for alphabetic position as task-relevant stimulus feature. In Experiments 2 and 3 participants responded to a non-spatial stimulus feature (uppercase–lowercase classification) so that both attributes can be characterized as task-irrelevant. The pattern indicated that a keyboard position–hand correspondence effect emerged independent of the time window (after stimulus onset) in which the response was given. However, an alphabetic position–hand correspondence effect only emerged when participants were forced to delay their responses by 450 ms. The overall pattern indicated that although both features were processed and translated into a spatial code reflecting their position within the alphabet vs. on the keyboard, the relevance of these features to the task as well as the time that elapsed since stimulus onset determined which attribute of the letters was effective in yielding a stimulus–response compatibility effect.

1. Introduction

Theories of embodied cognition (Barsalou, 1999; Semin & Smith, 2008; Wilson, 2002; Zwaan, 1999) suggest that stimuli automatically trigger activation in the sensorimotor systems that are associated with these specific stimuli in the sense that they are (in part) represented by covert simulation of the associated sensory processes. Consequently, associated motor responses are automatically covertly simulated when a specific stimulus is processed. For example, brain areas that are activated when actually moving the limbs also show higher activity when participants merely read associated action words such as *kick* (Hauk, Johnsrude, & Pulvermüller, 2004). Similarly, merely seeing a graspable object triggers activation in brain areas that are involved in actually grasping these objects (Chao & Martin, 2000). Even in the domain of typing it has been repeatedly shown that the representation of letters is grounded in action, such that the processing of letters automatically triggers activation of corresponding keystrokes (Beilock & Holt, 2007; Jasmin & Casasanto, 2012; Kozlik, Neumann, & Kunde, in press; Logan, 2003; Rieger, 2004; Van den Bergh, Vrana, & Eelen, 1990; Yang, Gallo, & Beilock, 2009). For example, letter dyads that are typed with different fingers were preferred over same-finger dyads because of less motoric interference (Beilock & Holt, 2007; Van den Bergh et al., 1990). Similarly, participants' preference for letter dyads is higher when their alphabetic order is compatible with the letter sequence on the keyboard (Kozlik et al., in press). Therefore, preference judgments for letter dyads are influenced by their keyboard position even when nothing is said about typing. Moreover, in experiments in which participants were instructed to simply type the information presented on the screen, a Simon effect was observed. Response times (RTs) decreased when the stimulus position on the screen corresponded to the location of the key on the keyboard (Logan, 2003). Thus, “left” and “right” seem to be part of the keypress schemata so that letters are associated with their corresponding hand due to their position on a computer keyboard. Consequently, letter processing and subsequent responses to letters are automatically influenced by their position on the computer keyboard via covert sensorimotor simulations of typing as the associated motoric response. However, keyboard position is not the only spatial

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feature of letters that might affect performance; they are also organized alphabetically.

In studies on S–R compatibility effects, it has repeatedly been shown that response selection is automatically influenced by overlap between spatial stimulus and response features. Typically responses are faster when the location of stimuli maps onto the responding hand (Fitts & Deininger, 1954; Kornblum & Lee, 1995; Lamberts, Tavernier, & d'Ydewalle, 1992; Umiltà & Liotti, 1987). This response advantage even occurs when participants responded to a non-spatial stimulus feature (such as color), a phenomenon that is known as the Simon effect (see Simon, 1990, for a review). Similar effects also occur when spatial aspects of the mental representation of stimuli overlap with spatial response features. In the domain of number processing it has been repeatedly shown that responses to small numbers are faster with the left compared to the right hand and vice versa for large numbers—a phenomenon known as the SNARC effect (see Gevers & Lammertyn, 2005 for an overview). This effect is generally interpreted as evidence for the mental representation of numbers analogous to a horizontal line. Therefore, responses are either influenced by associations between apparent spatial stimulus features and response features or by spatial aspects of mental representations of stimuli and response features. However, in studies on mental representations of ordinal sequences it has also been investigated whether even non-numerical ordinal information is spatially coded (Dehaene, Bossini, & Giraux, 1993; Gevers, Reynvoet, & Fias, 2003, 2004; Leth-Steensen & Marley, 2000; Zorzi, Priftis, Meneghello, Marenzi, & Umiltà, 2006). Especially in the domain of letter processing, it has been argued that letters, like numbers, are mentally represented on a horizontal line from left to right analogous to the alphabetic arrangement (Di Bono & Zorzi, in press; Gevers et al., 2003; Jou & Aldridge, 1999). For example, Jou and Aldridge (1999) reported to have found a distance effect when the task was to decide whether a letter dyad reflected alphabetic order or not, where response times increased as the alphabetic distance between the two letters of a dyad decreased. Moreover, according to Di Bono and Zorzi (in press), participants showed an early-letter bias in a random generation task, such that letters that occur before "M" in the alphabetic sequence were generated more often. Besides, Gevers et al. (2003) reported that responses to letters were significantly faster when the relative location within the alphabetic sequence maps onto the response hand. Typically, all these effects are interpreted as evidence for a horizontal representation of letters analogous to the alphabet (known as *mental letter line*). However, the conclusion that letter processing automatically primes activation of the alphabet leading to interactions with action-related processes remains controversial. Other than numbers, letter cues seem to be ineffective in orienting spatial attention (Casarotti, Michielin, Zorzi, & Umiltà, 2007). Furthermore, the processing of letters does not interact with action planning in handwriting (Perrone, de Hevia, Bricolo, & Girelli, 2010). Moreover, even though Gevers et al. (2003) also found a response side effect (i.e., faster responses when the relative location within the alphabetic sequence maps onto the response hand), when participants performed an order-irrelevant task (consonant–vowel classification), Dehaene et al. (1993) did not.

The purpose of the present study was to investigate the ways in which performance with regard to letters is influenced by the two stimulus features, i.e., alphabetic vs. keyboard position. In the literature there are two independent lines of research, suggesting that letter processing is automatically affected by (1) their keyboard position via covert sensorimotor simulations, or (2) their alphabetic position via associations between spatial aspects of mental representations and response features. Therefore, letters might evoke two different perception–action associations. However, it is an open research question whether these two processes operate simultaneously. Until now, there has only been one study showing that the two stimulus features of letters are indeed processed simultaneously, leading to a stimulus–stimulus compatibility effect (alphabet–keyboard compatibility effect; Kozlik et al., in press). The question that arises is this: Which of the two stimulus features predominates response selection? Hence, the first aim of the present research was to investigate which of the two stimulus features would produce a response side effect under different levels of relevance of the features to the task.

The second aim was to test whether seeing and responding to a letter automatically leads to activation of the alphabetic sequence when this feature is totally task-irrelevant because until now the results are inconsistent: Gevers et al. (2003) reported to have found an alphabetic position–hand correspondence effect, whereas Dehaene et al. (1993) did not. Although Gevers et al. (2003) questioned the statistical power of the Dehaene et al. (1993) study, there is another apparent difference between the two studies. Although participants in both studies performed the same task (consonant–vowel classification) mean RTs differed. However, prior to the present study the time course of this response side effect had not been investigated. Therefore, in the three experiments, we conceptually replicated and extended the Gevers et al. (2003) study by additionally controlling for keyboard position and decomposing the time course of the effects.

2. Experiment 1

In Experiment 1, we used the same paradigm used for Experiment 2a in the Gevers et al. (2003) study. Therefore, single letters were presented on the screen, and participants made a judgment of alphabetic position (target letter before or after "M"). Systematically varying alphabetic as well as keyboard position permitted us to test which of the two stimulus features is effective in yielding a response side effect (faster responses when relative position within the specific letter sequence maps onto the response hand). As relevant stimulus dimensions typically produce robust spatial compatibility effects (Fitts & Deininger, 1954; Kornblum & Lee, 1995; Lamberts et al., 1992; Umiltà & Liotti, 1987), we expected to replicate the response side effect for alphabetic letter position reported by Gevers et al. (2003). However, it remains an open question whether letters would produce a keyboard position–hand correspondence effect in an alphabetic judgment task (where keyboard position is a task-irrelevant feature). In the literature on S–R compatibility effects inconsistent findings have been reported. Among others, Umiltà and Liotti (1987) showed that in a paradigm where two spatial stimulus features were present (one egocentric and one relative spatial code), the irrelevant feature did not produce a spatial compatibility effect. However, for example Lamberts et al. (1992) did find a compatibility effect for the irrelevant spatial dimension. Hommel (1994a) tried to resolve this contradiction by arguing that whether the irrelevant feature produce a spatial compatibility effect or not depends on the difficulty of stimulus discrimination and a resulting decay of the irrelevant spatial response code (see also Hommel, 1994b). Therefore, only easy-to-discriminate stimuli (i.e., those that could be responded to relatively quickly with a mean RT of 473 ms) produced a robust Simon effect, whereas Hommel (1994a) failed to show a Simon effect for hard-to-discriminate stimuli (with a mean RT of 521 ms). Therefore, if letters automatically produce a response side effect with respect to their location on the keyboard, this spatial stimulus code might dissipate soon after stimulus onset. As Gevers et al. (2003) reported mean RTs between 550 ms and 653 ms in this kind of task, this stimulus code might have already decayed by the time the response was given. On the other hand, it is also conceivable that keyboard position as irrelevant stimulus feature is not automatically transferred into a response side effect, unless specific boundary conditions known from the literature were implemented. For instance, in studies that differentiated between expert and novice typists it has been shown that typing as the associated motoric response is automatically activated in expert typists but not in novices (Beilock & Holt, 2007; Rieger, 2007; Yang et al., 2009). Similarly, the activation seems to be modulated by the response device that is used to perform the experimental task, as the reported effects were more pronounced when participants used the keyboard instead of an external response box (Rieger, 2007).