Task-Dependent Motor Representations Evoked by Spatial Words

by

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B.Sc., Psychology, University of Victoria, 2012
B.Sc., Mathematics, University of Victoria, 2015

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ABSTRACT

Embodied accounts contend that word meaning is grounded in sensory-motor representation. In support of this view, research has found rapid motor priming effects for words like eagle or shoe, which differ as to whether they are typically associated with an up or down spatial direction. These priming effects are held to be the result of motor representations evoked as an obligatory part of understanding the meaning of a word. In a series of experiments, we show that prime words associated with up or down spatial locations produce vertical perturbations in the horizontal movements of a computer mouse, but that these effects are contingent either on directing conscious attention to the spatial meaning of the word, or on the inclusion of the primed spatial direction in the response set, and that this is true even for strongly spatial words such as up and down. These results show that the motor representations associated with such words are not automatically evoked during reading. We discuss implications for claims that spatial representations reflect our embodied perception of the world.

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Chapter 1

Introduction

The meaning of spatial prepositions like above and below can influence the selection of an up/down movement. For example, the word above acting as a prime, induces faster and more accurate upward than downward responses, whereas the word below yields the opposite result (Ansorge et al., 2013). More surprisingly, analogous results have been reported for words like bird and submarine that, although not explicitly concerned with spatial location, nonetheless affect speeded responding in an up/down direction (e.g Dudschig et al., 2014, 2012; Lebois et al., 2015). We will refer to such words for convenience as UP/DOWN words. The evidence suggests that many words, at least under certain task conditions, trigger spatial representations associated with our experiences of objects;birds are often encountered above us in the sky, whereas submarines move below in the depths of the ocean.

Spatial compatibility effects induced by language are taken as support for the claim that meaning is grounded in sensory-motor representations, including representations dealing with an object's typical location in space. For example, Estes et al. (2008) found that participants were slower to react to a target presented above or below fixation after viewing an object word (e.g. *boot* or *hat*) typically associated with the corresponding direction. The authors conclude that "...an object word orients attention to and evokes a perceptual simulation in the denoted object's typical location ..." (p. 96). Others have suggested that the meaning of a spatial word exerts an obligatory influence on the programming of movement in a particular direction. Ansorge et al. (2010) used a set of six spatial prepositions like above and below, and two adjectives (high and deep) as both masked primes and as targets. Subjects were required to indicate by means of an upper or lower keypress made from a neutral starting point whether target words referred to an upward or downward spatial position or direction. Semantic congruency effects on speeded responding were found even though the primes were presented too briefly for conscious report. The authors inferred that their findings were consistent with the view that "... the semantic processing of words ... necessarily draws upon underlying sensorimotor representations" (p. 317). An analogous result was obtained by Dudschig et al. (2014) who found priming effects of subliminally presented UP/DOWN words on the speed and accuracy of upward/downward responses to color cues. They authors concluded that ... language-action interconnections are automatically activated... (when)... processing a very wide set of linguistic stimuli, even in paradigms that limit strategic language processing to a minimum (p. 156).

In contrast, Lebois et al. (2015) found no evidence that UP/DOWN words acting as primes influenced performance when the task simply involved speeded up/down responding to a color cue. Rather, an explicit decision about word meaning was needed to yield spatial priming effects. Because these authors repeatedly failed to find congruency effects under well-defined task conditions that involved no explicit attention to the meaning of words, Lebois et al. (2015) rejected the claim that spatial congruency effects are automatic. They argued instead that a variety of conditions might tacitly have increased the accessibility of spatial features in other studies. For example, the requirement to engage in up/down keypress responses to a color cue (e.g. Dudschig et al. (2014)) may well have oriented subjects to verticality as a response dimension, establishing a context that dynamically activated the spatial features of words. A version of this idea could even apply when the priming words are presented too quickly for conscious report. Task set influences the way unconscious stimuli are processed (e.g. Kunde et al., 2003), a consideration leading Dudschig et al. (2014) to acknowledge in their study that "... even the mounting of the response apparatus in the vertical dimension might activate specific response codes that... influenced how the words were unconsciously processed" (p. 156). Lebois et al. (2015) noted that their response apparatus was positioned on the right of the computer screen, a departure from the more conventional position centered along the midline. This spatial arrangement would force subjects to glance back and forth horizontally when producing a response. The need to engage in this left-right orienting may have rendered verticality a less salient dimension, triggered only by instructions to explicitly process the meaning of words.

In this article, we seek to further evaluate the conditions that determine the influence of spatial words on movement in a vertical direction. Our methodological approach reduces the influence of task demands emphasizing up versus down as the intended response, while still allowing us to measure subtle effects of a word on the vertical component of a movement. Consider moving a cursor horizontally on a screen by means of a computer mouse, from a central position to one of two locations placed some distance to the left or right of the starting point. Although the requirement is ostensibly to move the cursor along a horizontal axis, the trajectories will immediately reveal that the movements include a definite vertical component. In general, there are obvious deviations along the vertical axis as the hand moves the cursor horizontally. We assume that under certain task conditions, the extent of the deviation should be influenced by the priming of spatial features representing an upward or downward direction.

There is evidence to support our assumption. Tower-Richardi et al. (2012) measured computer mouse movements to one of four rectangular target boxes situated to the left, right, above, and below a central start box. Cued movements were produced in response to the words up, down, left or right and the words north, south, west or east acted as briefly occurring primes. The word east biased vertical target movement trajectories to the right, and west biased these trajectories to the left. The word north biased the trajectory of horizontal movements upward, whereas south biased the horizontal trajectory downward. Additional support for the idea that words can prime movement in a direction orthogonal to a cued trajectory was provided by Zwaan et al. (2012). These authors required subjects standing or seated on a Wii balance board to indicate whether a sentence was sensible or not by moving the board sideways (e.g. left for sensible, right for non-sensible). The sentences implied movement in a forward (e.g., John bent to tie his shoelaces) or backward direction (e.g., John braced himself in the tug of war). Because the balance board provided spatio-temporal coordinates that included forward/backward components of movement, it was possible to determine from the trajectories whether the sentences activated spatial representations consistent with their meaning, even though the task ostensibly involved leaning only to the left or right. Depending on the forward/backward direction implied by the sentences, the sideways trajectory of the response was indeed shifted in an anterior or posterior direction in accordance with the sentence content. Zwaan et al. (2012) inferred that understanding the sentences activated a forward or backward direction that was integrated with and altered the trajectory of left/right movements.

Clearly, the meaning of words or sentences can prime a vertical or horizontal component of movement orthogonal to the direction of an intended trajectory. What task conditions, given this evidence, are required for words like above and below, or UP/DOWN words like eagle and basement to evoke spatial representations that affect the vertical component of a left or rightward movement? In Experiment 1, we asked subjects to move a cursor left or right from a central position to a target area, using a computer mouse with direction cued by an arrow pointing to the left or right. Responding was contingent on the prime word being a spatial preposition, such as up or down; responses were withheld for other prime words. Movement trajectories were clearly altered in a vertical direction. In Experiment 2, when words were passively viewed as primes, no biasing effect was observed. However, when subjects were cued (again by means of an arrow) to make vertically (up/down) as well as horizontally (left/right) directed movements of the cursor (Experiment 3), UP/DOWN words evoked spatial representations that affected horizontal responses, even under passive viewing conditions. We discuss the role of task context in triggering spatial components of meaning that affect ongoing motor activity. In addition, we consider the wider implications of our results for claims about the nature of semantic representations for spatial words.

Chapter 2

Experiments

2.1 Experiment 1

In Experiment 1, we looked for further evidence that spatial prepositions (e.g. above, below) and other explicit descriptors of vertical position (e.g. high, low) can influence the up/downward component of a horizontally directed movement. The semantics of prepositions dealing with space are highly complex; for example, Tyler & Evans (2003) discussed no less than 15 distinct senses of the word *over* (compare, the *cat jumped over the wall* and *dinner time is over*). Nevertheless, as Tyler and Evans point out, many of these different senses of over are directly concerned with or linked to the notion of a focal object being higher than, but within potential contact with, some background element. We assume therefore, as do others, that "*. . . spatial features are central for words whose meanings depend heavily on spatial position*" (Lebois et al., 2015), and that this assumption is uncontentious for words like over, under, high, and low. More controversial, as we have already observed, is whether explicit attention is needed to the spatial meaning of these words to cause priming effects on the upward/downward component of a horizontally directed movement. Our first step, before turning to this question, was to establish that priming indeed occurs when subjects attend to the directionality of the words while carrying out a cued left/right movement.

2.1.1 Method

Participants

Forty students at the University of Victoria participated to earn extra credit in an undergraduate psychology course. The experiments reported here were approved by the University of Victoria Human Research Ethics Committee.

Procedure

Participants performed a go/no-go task requiring them to move a mouse cursor from the center of a computer screen to one of two circular target regions on the left and right sides. Trials began with the presentation of a prime word selected from one of eight spatial prepositions connoting up or down (e.g. *up, down, above, below*) or eight abstract nouns (e.g. *justice, crime*). A complete listing of the prime words used for each experiment can be found in the appendix. Prime words were presented for 50 ms in a lowercase, monospace font, and were followed by a 100 ms blank screen, after which an arrow cue appeared in the center of the screen, alongside two circular target regions on the left and right sides. Each target region subtended a visual angle of approximately 2°, and was separated from the center of the screen by an angle of 16°. Participants were instructed to move the cursor to the corresponding target region if the word was directional (*go* trial), and to simply click the left mouse button otherwise (*no-go* trial). The arrow cue remained on-screen until the cursor entered one of the target regions. After reaching the target region, a circular target appeared in the center of screen, and participants were required to move the cursor back to the center and click the mouse button to begin the next trial. Prior to performing the task, participants were shown a list of the prime words and instructed that it was not necessary to memorize them, but to simply note what is meant by "directional" and non-directional".

Target regions subtended approximately 1.9° of visual angle, and were separated from the center of the screen by 15.9°. Participants were seated approximately 2 feet away from the computer screen, and performed the task using their dominant hand. Moving the cursor from the center of the screen to the target region required moving the hand approximately 28 cm on the computer desk. In total, the task consisted of 40 practice and 320 experimental trials. The design of the experiment was fully randomized, so that each combination of prime word and response direction occurred equally often.

The experiment was programmed using the Psychophysics Toolbox extension for Matlab (Brainard, 1997), and was performed on a 27-in Apple iMac. The position of the cursor on the screen was captured at 60 hz during the movement phase of the task. Cursor speed was set to its lowest setting, and cursor acceleration was disabled. Note that the 60 hz refresh rate of the iMac monitor implies a screen refresh interval of 16.667 ms, which allows for the precise specification of a $50 = 3 * 16.667$ ms prime duration.

2.1.2 Results and Discussion

All data handling and preprocessing was done using the R statistical language (R Core Team, 2014), and Bayesian models were fit using Stan 2.7 (Stan Development Team, 2015).

We defined the beginning of the trajectory to be the instant that cursor velocity exceeded zero, and the end to be the instant that the cursor reached one of the two target regions. Each trajectory was then resampled to 100 equally spaced time points using linear interpolation. Trajectories were not smoothed or filtered, as they were sampled without noise, and the low cursor velocity resulted in already smooth trajectories. Trajectories were coordinatized by specifying the origin $(0, 0)$ to be the center of the screen.

Incorrect trials (those in which the cursor entered the incorrect target region), as well as trials with movement initiation time greater than 3 standard deviations greater than the mean for each participant, were excluded from analysis. In addition, we excluded trials in which the trajectory length was greater than 1.5 times the distance from the center of the screen to the target region. This was done because several trials exhibited wandering behaviour, in which the cursor seemed to travel back and forth across the screen. The 1.5 threshold was selected arbitrarily so as to exclude the most severe wandering behaviour, while being conservative enough to retain the vast majority of trials. In total, fewer than 5% of trials were excluded for each participant.

Previous research has found stimulus-response compatibility effects even when stimulus and response sets vary along orthogonal dimensions (so-called *orthogonal* stimulus-response compatibility effects; see Lippa & Adam, 2001). For example, an up-right down-left advantage is often observed in Simon type tasks (Cho & Proctor, 2003). For this reason, we performed a preliminary analysis in order to rule out

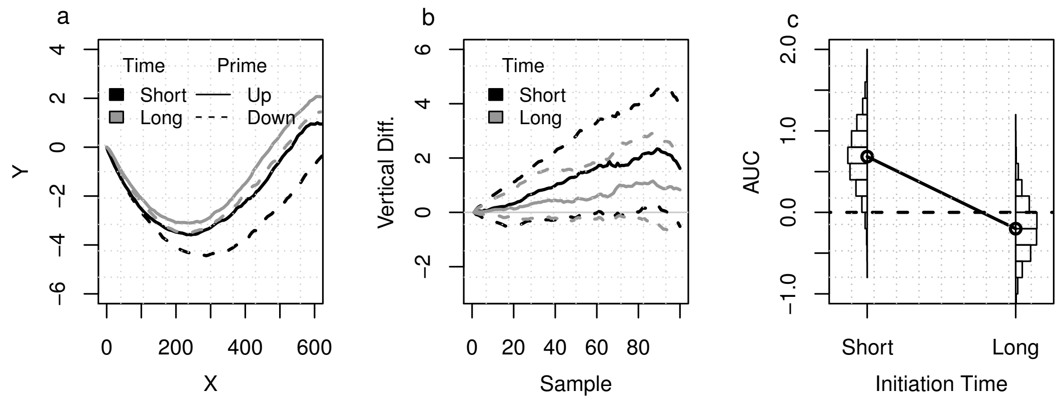

Figure 2.1: Analysis of mouse trajectories for Experiment 1. (a) Mean X-Y trajectories (in pixels) for up and down prime conditions as a function of initiation time (based a median split of movement initiation times). (b) Vertical difference between up and down trajectories (up - down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories. The AUC effect for short initiation times is positive with probability 0.97.

differential effects of UP/DOWN words on leftward and rightward responses. We found no evidence of such effects, and indeed leftward and rightward trajectories were highly similar, and so we collapsed both response conditions together by mirroring leftward responses along the y-axis.

Priming effects are often seen to preferentially affect fast or slow responses. For example, the Simon effect, in which an irrelevant spatial correspondence between stimulus and response affects reaction time, is strongest in fast responses (Ridderinkhof, 2002). For this reason, we conducted a median split of the response trajectories based on movement initiation time. The split was conducted for each prime condition and each participant. In this and subsequent experiments, all analyses are reported separately for short and long initiation times.

Mean trajectories for each response latency and prime condition are presented in Figure 2.1a. For the difference trajectories, we computed bootstrapped 95% confidence bands. We also computed difference trajectories for each response latency by subtracting the mean trajectory for downward primes from the mean trajectory for upward primes (Figure 2.1b). For each response latency, we summarized the vertical difference between prime conditions by integrating the difference trajectories using the trapezoid approximation (denoted by AUC, for *Area Under the Curve*). Mean AUCs for each response latency were estimated by fitting a t-distribution to the participant values, and posterior distributions are presented in Figure 2.1c. A complete description of the model used to obtain the posterior distributions, as well as model code, is provided in the appendix.

Analysis revealed reliably higher y-coordinate values (indicating a more "upward" trajectory) for responses in the upward prime condition than in the downward prime condition. This effect was only observed in responses with a short initiation time; consistent with the results of Buetti & Kerzel (2008, 2009). It is likely that attention to the spatial prime results in the activation of a corresponding spatial representation. The resulting interference produces the effects observed in fast responses, but is resolved before the execution of a slower response.

2.2 Experiment 2

The results of the previous experiment suggest that (vertical) spatial primes can, under certain conditions, produce perturbations in a horizontal trajectory, and that our method is sensitive to such effects. We turn now to the question of the conditions under which these effects appear. In the previous experiment, conscious attention was drawn to the spatial meaning of the prime words by forcing participants to classify them as either *directional* or *non-directional*. In contrast, an embodied account, which holds that the motor representations evoked by spatial words are an obligatory part of their meaning, would predict similar effects even under passive viewing. Such effects have indeed been observed for other stimuli; for example, Kuhn & Kingstone (2009) found that arrows perturb eye movement trajectories under passive viewing condition. Similarly, Hermens & Walker (2010) find that passively viewed arrows, pointing left or right, produce deviations in eye movement trajectories directed towards targets above or below fixation.

We wished to determine whether the same effects can be observed in response to a passively viewed spatial preposition, or whether the effects are dependent on conscious attention to the spatial meaning of the word, as in Experiment 1. We address this question through a pair of experiments requiring participants to generate horizontal responses to an arrow cue, preceded by a word prime. The key difference between the following experiments and experiment 1 is that participants are instructed to ignore the prime word and respond to the arrow on all trials. In Experiment 2a, we use prime words adapted from Dudschig et al. (2014), consisting of words such as *mountain* and *shoe*, which are typically associated with an up or down spatial direction. In Experiment 2b, we use the spatial prepositions described in Experiment 1. Note that, although prime words are associated with up or down spatial directions, the task itself requires only horizontal movements. This design, in contrast to the design of Dudschig et al. (2014), eliminates the possibility that priming effects are due to a response set requiring the generation of vertical responses.

2.2.1 Method

Participants

Eighty students at the University of Victoria participated to earn extra credit in an undergraduate psychology course. Forty students participated in each version of the experiment.

Materials and Procedure

The procedure for Experiments 2a and 2b was identical to that of Experiment 1, with the exception that the prime words were passively viewed, and participants were required to respond on every trial. The prime words in Experiment 2a were adapted from Dudschig et al. (2014), and consisted of words such as *eagle* and *shoe*, which are typically associated with an up or down spatial direction. In total, 10 up and 10 down words were used. In Experiment 2b, the prime words were identical to the directional primes used in Experiment 1. The experiments each consisted of 40 practice and 320 critical trials, with all combinations of prime word and spatial direction occurring equally often.

2.2.2 Results and Discussion

Data were analyzed identically to Experiment 1. Mean and difference trajectories are reported in figures 2.3a and 2.3b, while posterior distributions for the AUC are reported in 2.3c.

We found no evidence for an effect of prime condition on AUC for either short or long response latencies for either experiment, suggesting that passive viewing is not sufficient to produce perturbations in the horizontal trajectory of the movement, even with strongly spatial words such as *up* or *down*. These results stand in conflict with results obtained by Tower-Richardi et al. (2012), who found that the words *north, south, east* and *west* induced perturbations of a computer mouse under passive

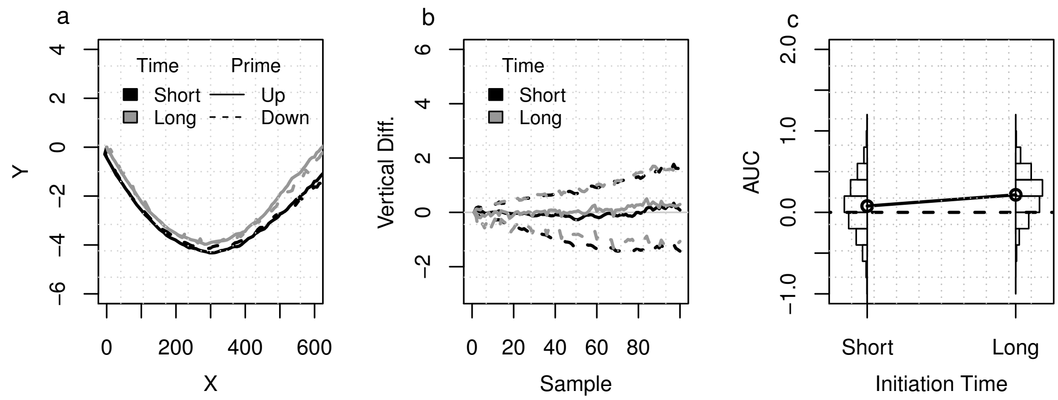

Figure 2.2: Analysis of mouse trajectories for Experiment 2a. (a) Mean X-Y trajectories (in pixels) for up and down prime conditions as a function of initiation time (based a median split of movement initiation times). (b) Vertical difference between up and down trajectories (up - down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories.

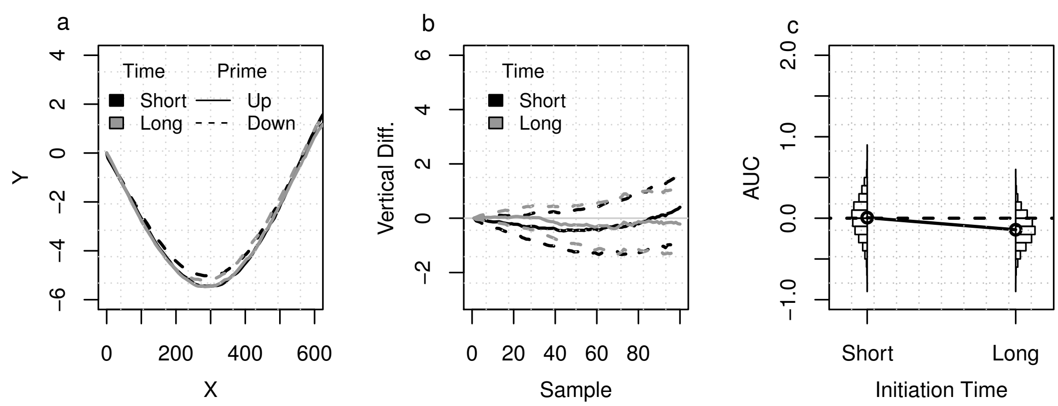

Figure 2.3: Analysis of mouse trajectories for Experiment 2b. (a) Mean X-Y trajectories (in pixels) for up and down prime conditions as a function of initiation time (based a median split of movement initiation times). (b) Vertical difference between up and down trajectories (up - down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories.

viewing condition, or Ansorge et al. (2010) and Dudschig et al. (2014), who found motor priming effects for masked primes.

A crucial difference between our experiment and other experiments reporting priming effects for passively viewed primes is that, in our experiment, the spatial directions implied by the prime words do not overlap with the spatial directions in the response set. It is possible that the intention to generate movements along a vertical axis is necessary for the evocation of spatial representations in response to UP/DOWN words, which would stand in contrast to the embodied position, which holds that the evocation of such spatial priming effects is obligatory. The same conclusion was reached by Lebois et al. (2015), who claimed that ”If the semantic access of spatial features had been automatic and context-independent, a congruency effect should have occurred regardless of whether participants were told explicitly about spatial features or not. The failure for congruency effects to occur . . . indicates that spatial features did not become active automatically.” (pp. 27-28). Indeed, Memelink & Hommel (2013) argue that the preferential processing of task-relevant stimulus dimensions constitutes a fundamental property of cognitive control; a process which they term ”intentional weighting”. In this way, a task requiring vertical movement may result in greater activation of vertical stimulus features than a task requiring only horizontal movement, as argued by Meiran et al. (2000). If this is true, then the requirement to generate vertical responses may result in the evocation of spatial features from UP/DOWN words, even under passive viewing conditions. We address this question in Experiment 3.

2.3 Experiment 3

We conducted a modified version of Experiment 2a in which participants were cued to move in all four cardinal directions (up, down, left, and right). If the inclusion of the vertical dimension in the response set is sufficient to elicit spatial representations from UP/DOWN words, we should observe vertical perturbations of left/right trajectories similar to those observed in Experiment 1. Additionally, we would expect to see an influence of UP/DOWN words on the initiation times for vertical movements, similar to previously reported effects of passively viewed words on response times.

2.3.1 Method

Participants

Forty students at the University of Victoria participated to earn extra credit in an undergraduate psychology course.

Materials and Procedure

The procedure for Experiment 3 was identical to that of Experiment 2a, with the exception that participants were cued to move in all four cardinal directions (up, down, left, and right). Two additional target regions were added at the top and bottom of the computer screen at the same distance from fixation as the left/right targets. Similar to Experiment 2a, participants were cued to move the cursor to one of the four target regions by an arrow. All four movements were cued equally often across 40 practice and 360 critical trials. The two types of prime words (connoting up or down locations) were presented equally often with each of the four directional cues.

2.3.2 Results and Discussion

We examined the initiation times of vertical movements in response to UP/DOWN prime words. Figure 2.4 displays the mean initiation times for congruent and incongruent responses in each prime condition. As the motor priming effects observed in Experiment 1 were observed only for trials with the shortest initiation times, up/down initiation times were analyzed after performing a median split. We generated mean estimates and highest density intervals by fitting a normal distribution to the subjects' mean congruency effects (mean congruent trial minus mean incongruent trial) with a non-informative N(0,100) prior on the mean and a weakly informative Cauchy$(0, 15)$ prior on the variance. The resulting congruency effect on vertical movements was -6.2 ms (95% highest posterior density interval = $[-9.9, -2.1]$) for short initiation times, and for long initiation times the effect was -3.1 ms ($[-8.4, 2.8]$), indicating that the priming effect is rather short-lived and has begun to decay during the preparation or execution of the slower responses. Nevertheless, we have a clear replication of previous reports that passively viewed words connoting up or down directions induce spatial priming effects on vertical movements.

We analyzed horizontal trajectories using the procedure described for Experiment 1. Mean and difference trajectories, as well as an analysis of the AUC, are presented in figure 2.5. The results provide strong evidence of a motor priming effect of UP/DOWN words in responses with short initiation times, in which trajectories primed by *up* words were consistently higher on the vertical axis than trajectories primed by *down* words.

These results confirm that the inclusion of vertical movements in the response set

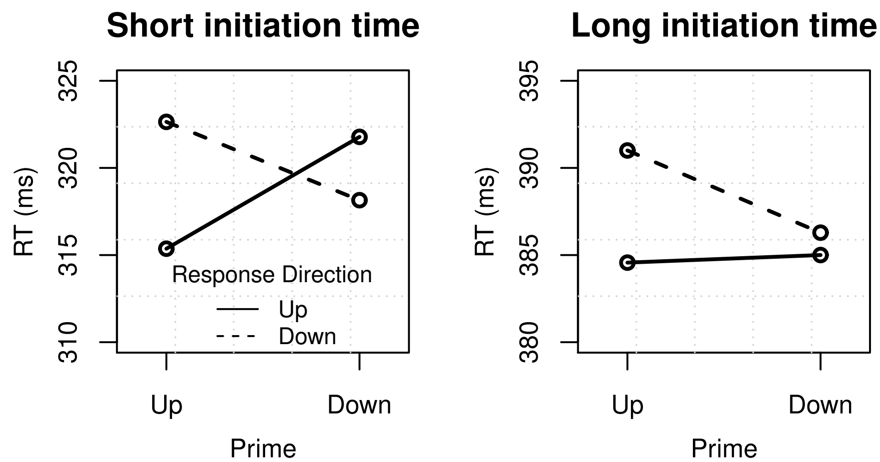

Figure 2.4: Mean response initiation time for upward and downward responses in each prime condition. Initiation times were categorized as either short or long based on a median split.

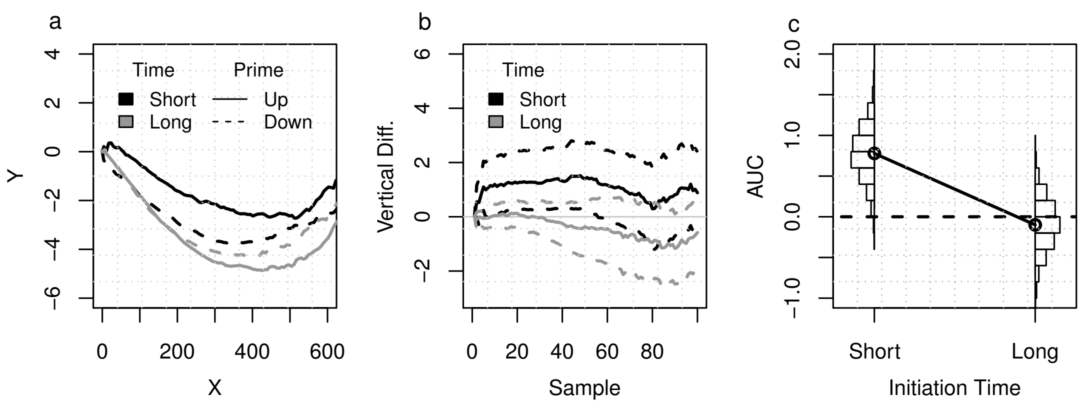

Figure 2.5: Analysis of mouse trajectories for Experiment 3. (a) Mean X-Y trajectories (in pixels) for up and down prime conditions as a function of initiation time (based a median split of movement initiation times). (b) Vertical difference between up and down trajectories (up - down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories. The AUC effect for short initiation times is positive with probability 0.99.

is sufficient to evoke a spatial representation from words like *eagle* and *shoe*, resulting in motor activation which alters the trajectory of horizontal movements. The principle of intentional weighting offers an elegant explanation for these effects: The intention to produce a vertical movement generates a stronger weighting of stimulus and response features related to the vertical dimension. Even on trials cueing a left/right responses, the participant is required to select from a response set including vertical movements. Further, the computer screen includes target regions that previously afforded vertical movements, and the prime words themselves are associated with spatial representations that include a vertical dimension, triggered on previous trials requiring vertical responses. Thus, even on trials requiring a left/right movement, there are cues that enable an effect of the vertical dimension on horizontal trajectories. For a similar example of these effects, see Eder et al. (2010), who found that intentional acts of approach and avoidance in an evaluation task influence the involuntary activation of approach and avoidance tendencies even when stimulus valence is irrelevant.

Chapter 3

Discussion

Defining the background conditions that allow words like *above*, *below*, *eagle*, and *worm* to prime up/down movements is important if we are to better understand the nature of the spatial representations triggered during semantic access. According to some researchers (Ansorge et al., 2010; Dudschig et al., 2014) the meaning of spatial words necessarily triggers sensorimotor representations. A word like up should therefore exert an obligatory impact on vertical movement even under passive viewing conditions, much like the correspondence effects automatically induced by an arrow pointing in a particular direction (Kuhn & Kingstone, 2009). A rival claim is that task context and the subject's intentions play an important role in evoking priming effects. As a number of authors have noted (Dudschig et al., 2014; Lebois et al., 2015; Thornton et al., 2013), assessing the impact of spatial words on movements generally involves the arrangement of response keys along a vertical axis. This cue, along with the intention to respond vertically (Memelink & Hommel, 2013), may inevitably draw attention to the spatial features of words associated with an up/down direction.

We wished to eliminate task demands and response options that emphasize up versus down as a contributing factor to the priming effect of a spatial word on vertical movements. At the same time, because compatibility effects require a degree of overlap between stimulus and response dimensions (Ansorge & Wühr, 2004; Kornblum et al., 1990), any task must include a vertical feature component that can potentially be affected by a word acting as a prime. Our approach required speeded movements of a cursor by means of a computer mouse, directed left- or rightward from a central location. Given the nature of cursor movements, proprioceptive feedback in this task comprises a mixture of both left/right and up/down sensations. Although task context (and the subject's intentional set) would determine that this feedback is categorized as a left or rightward response, it remains possible that spatial words can increase the activation of vertical feature codes, thereby altering the shape of the movement trajectory.

Both theory and prior evidence support this background assumption. According to a recent computational model of the interaction between perception, action, and task goals, feature dimensions can generate concurrently active but competing stimulus-response mappings (e.g., left/right and forward/backward), even though the task instructions favor one mapping over another (Haazebroek et al., 2013). In addition, the trajectory of left/right movements can indeed be modulated by words or sentences acting as primes that imply an up/ down (Tower-Richardi et al., 2012) or forward/backward direction (Zwaan et al., 2012).

We validated our methodological approach in Experiment 1 by requiring subjects to carry out a speeded go/no-go task involving left/right cursor movements primed by spatial prepositions denoting an up/down direction. Attention to the meaning of each prime was ensured by requiring subjects to respond only if the prime was a directional word (abstract words served as the no-go items). We observed consistently higher Y-axis values (indicating a more upwardly oriented trajectory) for horizontal cursor movements primed by words denoting an upward compared to a downward direction. This effect appeared only for responses with short initiation times, an outcome that converges with previously documented effects of spatial primes on the trajectory of left-right pointing movements (Buetti & Kerzel, 2008, 2009).

The next question was whether the spatial representations evoked by words are obligatory. If so, cursor trajectories should be affected even when subjects are merely instructed to passively view each prime before responding to an arrow cue. We know that other spatial cues do indeed exert this kind of obligatory influence on components of movement orthogonal to an intended direction. For example, eye movements to a target above or below fixation deviate away from the direction indicated by centrally presented arrows pointing to the left or right, even when the arrows merely serve as passive distractors (Hermens & Walker, 2010). Our results indicate that the spatial representations evoked by words do not show this degree of automaticity. Under passive viewing conditions the trajectory of cued left/right movements is unaffected by spatial prepositions, or by UP/DOWN words.

As we have seen, priming effects on left/right movement trajectories occur when attention is explicitly directed to a word's spatial meaning. In addition, however, the task of carrying out vertical movements is itself sufficient to induce priming effects even if words are just passively viewed. In Experiment 3, the initiation time of up/down cursor movements was affected by spatial words as passive primes, consistent with previous work reporting a similar effect on cued vertical movements (Dudschig et al., 2012, 2014). Furthermore, the spatial features of passively viewed words affected left/-right cursor movements when up/down movements were included in the response set. Left/right movement trajectories primed by a word like *eagle* were higher on the vertical axis than trajectories primed by a word like *submarine*.

Clearly, passively viewed words influenced horizontal trajectories, despite the fact that the intention to produce a left/right movement does not place any emphasis on verticality. For this priming effect to occur, however, subjects must also engage in up/down movements. We can distinguish two possible reasons for this constraint. One possibility denies any automatic status to the spatial representations evoked by words. Instead, it is assumed that the task of carrying out vertical movements explicitly draws subjects' attention to a word's spatial constituents.

Attending to spatial features also affects the trajectory of horizontal movements, just as we observed when semantic classification of words was required in Experiment 1. The alternative possibility, which we favor, is that up/down movements enhance the intentional weighting of vertical features, generating a "prepared reflex" (Eder et al., 2010; Hommel, 2000) that is automatically triggered by spatial words. Although the vertical dimension would not receive a high intentional weight for left/right cursor movements, Lavender & Hommel (2007) note that the weighting of a task-irrelevant dimension need not fall to zero. Indeed, these authors suggest that ... the more a dimension is directly or indirectly related to the task goal, or its interpretation by the subject, the more weight its codes will carry" (p. 1291). Intrinsic to left/right cursor movements are deviations of the intended trajectory in an up/down direction. Accordingly, we suggest that up/down features continue to remain active and can be influenced by spatial words so as to perturb the vertical component of horizontal trajectories.

For a number of reasons, we infer that the evocation of a word's spatial features a partially automatic, even though UP/DOWN words and spatial prepositions do not have the same kind of obligatory impact on the trajectory of left/right movements as does an arrow on the trajectory of eye movements (Hermens & Walker, 2010). First, we note that spatial words can prime up/down movements even when presented too briefly for conscious identification (Ansorge et al., 2010; Dudschig et al., 2014), a result consistent with the view that priming effects can occur without the contribution of strategic attention to meaning. A second point against the notion that priming effects are the result of explicit attention is that in Experiment 3, under passive viewing conditions, up/down movements yielded congruency effects on movement initiation time that were stronger when subjects made faster responses. According to Kinoshita & Hunt (2008), motor priming driven by word meaning is typically greater for faster than slower responses (see also Ansorge et al., 2013, for confirmatory evidence). By contrast, priming effects driven by attention to the semantic category of a word (including, presumably, the category up versus down) do not vary with the speed of responding. We infer, given this evidence, that UP/DOWN words directly induce motor rather than semantic priming effects on the initiation time of up/down responses in Experiment 3.

A third reason in favor of the claim that intending to move up or down automatically triggers the spatial features of UP/DOWN words is the following. It does not appear to be the case that under passive viewing conditions, motor intentions are sufficient to induce priming for any kind of word associated with up/down features. More specifically, emotionally valenced words despite their linkage to vertical features (e.g. elation → up, despair→ down), do not prime up/down movements unless subjects explicitly attend to or base their responses on positive versus negative affect (e.g. Rotteveel & Phaf, 2004). In a recent meta-analysis of the literature, Phaf et al. (2014) concluded that: "... A consistent finding across all analyses was a non-significant overall effect when instructions did not require conscious evaluation of the affective valence of stimuli ... In general, there seems to be little evidence for a direct or automatic link between affective information processing and arm flexion and extension, irrespective of whether the movements are made in the horizontal or vertical direction" (p. 13).

The available evidence gives rise to a taxonomy of stimuli, indexed by the task conditions that induce spatial priming effects on motor responses. Recall the three task conditions described in the experiments reported above: A stimulus presented as a passive distractor, a stimulus whose spatial meaning is consciously attended to, and a stimulus whose spatial dimension overlaps with the response set required by the task. A centrally presented (say, upward) arrow influences the trajectory of a response even under passive viewing conditions (Kuhn & Kingstone, 2009), and when the task requires only left/right responses (Hermens & Walker, 2010). Thus, the effect of the arrow appears to be obligatory, and requires neither conscious attention, nor the intentional weighting of its spatial features to exert an effect on movement.

A UP/DOWN word like *eagle* (and presumably a spatial preposition like up) influences movement under passive viewing conditions, but this effect is contingent on the intention to engage in up/down responses (Experiment 3). In addition, semantic judgements of directionality trigger the spatial features of a preposition like *up* (Experiment 1) and of UP/DOWN words (Lebois et al., 2015). Some evidence indicates that UP/DOWN words also prime up/down movements when attention is directed to a non-spatial conceptual attribute, for example when judging whether or not the word refers to a concrete object (Lebois et al., 2015). To trigger a spatial representation for UP/DOWN words requires either attention to meaning or an intention to engage in up/down movements.

An emotionally laden word like *joy* influences up/down movements only if subjects pay attention directly to valence, either as an immediate aspect of the task (Phaf et al., 2014) or before some other judgment that does not include valence as a relevant dimension (Eder et al., 2010). Attention to the valence of a word generates spatial representations that can influence the trajectory of a horizontally oriented movement (Gozli et al., 2013). In contrast to UP/DOWN words, though, a decision task based on a semantic feature other than valence does not yield any effect on up/down movement (Rotteveel & Phaf, 2004). The intention to process emotional valence is therefore crucial to obtaining any effect on up/down responses (Krieglmeyer et al., 2010).

3.0.1 Implications for Embodied Accounts of Meaning

What does this ordered pattern of effects imply about spatial features as embodied constituents of meaning? We turn now to this controversial issue. The claim that the meaning of a word is grounded in sensory-motor representations is sufficiently general that as Anderson (2008) notes, ". . . there are nearly as many theories of grounding - what it is, and what it means as there are theorists" (p. 423). This diversity is hardly productive if we wish to uncover the relationship between the meaning of a word and its effect on action. How is one to interpret a negative result as evidence regarding the notion of grounded representations?

Stimulus-response compatibility effects are often assumed to provide information about the construction of meaning, but this interpretation is difficult when the effects are highly task dependent. For example, the well known Simon effect, under certain conditions, can be reversed, so that a stimulus presented to the right of fixation produces a faster left-handed response. As Lebois et al. (2015) argue: "As these results illustrate, extracting the meaning of a symbolic cue is dynamic and context-dependent, not automatic and context-independent" (p. 7). But what does this reversal actually tell us about the meaning of the cue? Certainly, it does not imply that observers actually perceive a right-sided object as being on the left. As another example, under certain task conditions the Stroop effect can be reversed (e.g. Durgin, 2000), so that incongruent color/word pairs produce faster responses than congruent pairs. But this surely doesn't imply that participants misunderstand the meaning of the word, or have mistaken the identity of the color. Similarly, spatial compatibility effects induced by UP/DOWN words do not necessarily imply that spatial representations are an intrinsic component of their meaning, as in the embodied view.

Consider, by contrast, how context affects our understanding of the word up (as opposed to the meaning of an arrow pointing upward). *A bird flew up the chimney* indicates movement in a particular direction whereas *I read up on embodied cognition* implies the gaining of some knowledge. What if any, is the relationship between these different interpretations of up? The fact that understanding depends on context, and that spatial prepositions and UP/DOWN words do not automatically prime up/down movements (in that priming is task dependent rather than obligatory) has prompted a rejection of the idea that the meaning of a word includes a core semantic representation. Thus, according to Lebois et al. (2015): "... conceptual cores do not exist in word meanings... [T]he spatial features of these words are dynamic and context- dependent, with their availability varying across task contexts. Many findings, across literatures, now demonstrate clearly that features potentially viewed as core are actually context-dependent".

We have already noted that there is at best an indirect relationship between the task- dependency of priming effects and the context-dependence of word meaning. In addition, the fact that a spatial preposition like *up* has a variety of senses depending on context need not imply that such variation is unprincipled. An important subset of meanings may be linked via a unifying semantic device. In what follows, we discuss how the complex polysemy of *up* and *down* is grounded in what Tyler & Evans (2003) term a spatial "proto-scene" embodying the notion of verticality. We briefly provide some examples of how experiential correlations based on this proto-scene generate a number of meanings that are entirely non-spatial (see Tyler & Evans for many more ingenious analyses). We then apply this theoretical framework to clarify the nature of the influence that spatial prepositions and UP/DOWN words exert on vertical and

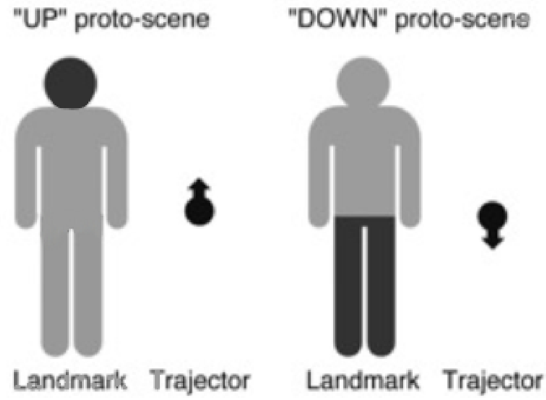

Figure 3.1: Illustration of spatial proto-scenes for up and down, adapted from Figures 6.1 and 6.2 of Tyler and Evans (2003)

horizontal movement.

The proto-scene for *up*, according to Tyler & Evans (2003), involves a background element a landmark or LM conceptually partitioned into a top and bottom. A moving object or trajector (TR) is conceptualized as being oriented in an upward direction relative to the LM. These authors suggest that the human body itself is used to develop a schematization of the LM into *top* versus *bottom*, the head being our highest body part when we are standing upright (see Figure 3.1). As they note, in a study of fifty-five languages, over half applied the word for head to indicate the spatial relation denoted by *up* (Svorou, 1994). When we say the head of an organization, we likewise draw upon the notion that the head is located at the top of the human body. The proto-scene for *down* stands in a contrastive relationship with *up*; it is now the lower half of the human body that is emphasized in the schematization of the LM, and the TR is oriented downward.

The sentence *A bird flew up/down the chimney* describes a TR (bird) oriented upward/ downward in relation to a LM (chimney). The chimney is symmetrical in appearance, but has a vertical asymmetry projected onto it from the proto-scene (we can refer to the top or bottom of a chimney). In addition to *up* and *down* as directions, a cluster of meanings referring to quantity (e.g., *prices are going up/down*) is grounded in our experience that an increase/decrease in quantity correlates with an increase/decrease in vertical elevation (also see Lakoff, 1987). Moreover, a change in our posture from vertical to horizontal always requires a stable surface that halts our downward path; lying down implicates the end of a trajectory, so that down can also be taken to mean complete, as in *two down and one to go*.

We now introduce the following ideas: The activation of an up or down proto-scene is directly responsible for the priming effect of a word or symbol on vertically oriented components of movement. An arrow pointing up or down automatically activates the corresponding proto-scene; the object is schematized as an upward or downward TR against the background of the computer screen acting as the LM. The priming effect of an arrow on movement trajectories is therefore obligatory even when the task set does not include up/down movements.

Attending to the direction along a vertical axis implied by a spatial preposition also activates an up/down proto-scene. Thus, we find that directionality judgements on a spatial preposition acting as a prime affects the vertical component of a horizontal movement in Experiment 1. Similarly, any intentional (task) set of carrying out up versus down movements automatically enlists the corresponding proto-scenes which can then be triggered by an UP/ DOWN word (and presumably by a spatial preposition) under passive viewing conditions (Experiment 3). However, in the absence of an up/down intention (when the task requires moving only along a horizontal axis), neither spatial prepositions nor UP/DOWN words activate any proto-scene (Experiment 2).

Finally, an up/down proto-scene, even when induced by the task set of engaging in up/ down movements, is not automatically triggered by an emotionally valenced word like *happy* (feeling up) or *sad* (feeling down). Instead, the representation that gives rise to a priming effect on up/down movements requires an intentional set that codes up/down as functional elements having a positive/negative value, in accordance with our semantic representation of valence (happy is a positive feeling whereas sad is negative). As Clark (1973) wrote, a view endorsed by Tyler & Evans (2003): "...positive is taken in its natural sense to be the presence of something and negative the absence... (and)... since everything above ground is perceptible and nothing below it is, upward is naturally positive and downward naturally negative" (p. 33). Without the explicit schematization of *up* as positive and *down* as negative, however, emotional words will not affect vertically oriented components of movement. Consistent with this claim, Ansorge et al. (2013) found no effect of subliminally presented positive or negative emotional words on the classification of spatial prepositions into up versus down categories. However, when the task required classifying emotional target words as positively or negatively valenced, reliable priming effects were induced by subliminal spatial words denoting an up/down direction or position. Thus, the valence of emotional words is primed by spatial words if the task set involves a recoding of up/down as spatial elements into functional elements with a positive or negative value. Unlike the spatial attributes of UP/DOWN words, however, valence is not triggered just by the intention to carry out an up/down movement.

We conclude by returning to the importance of the human body as a reference point for a number of crucial spatial representations. According to Wierzbicka (1985), the judgment of an object's relative size is often established by consulting our ability to pick it up with our hands. We conjecture that representing the prototypical height of an object or its location in terms of *up* or *down* is similarly dependent on a schematization of the upright human body. Objects that are conceptualized as *up* are at head height or higher, objects that are construed as *down* are near or below our feet. Under the right task conditions, and given this anthropocentric viewpoint, the words *aeroplane* as well as hat will trigger the proto-scene for up, while *submarine* as well as floor will trigger the proto-scene for down. Although the evocation of these spatial attributes, as we have seen, depends on intentional set, their presence is directly linked to our embodied perception of the world.

Appendix A

Additional Information

A.1 Prime Words

A.1.1 Experiment 1

UP: up, top, high, over

DOWN: down, bottom, low, under

NEUTRAL: crime, peace, honor, shame, joy, anger, victory, defeat

A.1.2 Experiment 2a

UP: eagle, balloon, roof, ceiling, kite, airplane, peak, sun, summit, sky, plateau, north[1], height, top, crown, moon, tower, bird, star, cloud

DOWN: ground, earth, soil, foot, floor, cellar, ditch, street, carpet, worm, root, south, valley, canyon, under, puddle, stone, low, tunnel

A.1.3 Experiment 2b

UP: up, top, high, over

[1]Note that, due to an oversight, the spatial words *north*, *south*, *low* and *under* were included in experiments 2a and 3, even though these would be considered "strongly" spatial words. In principle, the strongly spatial nature of these words could coerce the generation of spatial representations from the remaining words where they might otherwise not appear. Due to the null result in experiment 2a, this does not appear to be the case, and we do not believe that this oversight affects the interpretation of our results.

DOWN: down, bottom, low, under

A.1.4 Experiment 3

Same as experiment 2a.

A.2 Statistical Models

A.2.1 Model for the AUC

The following describes the model used in experiments 1, 2, and 3 to estimate the mean AUC of the difference between up and down prime conditions.

For each participant i, we computed the area between the difference curve and the x-axis by integrating the trajectory using the trapezoid approximation. Specifically, if $(x_1, y_1, x_2, y_2, \ldots, x_n, y_n)$ is a trajectory, then the AUC is computed as

$$\text{AUC} = \frac{1}{2}\sum_{k=1}^{n-1}(x_{k+1} - x_k)(y_{k+1} + y_k) \tag{A.1}$$

Due to the high pixel density of the display, AUC values are generally extremely large, making specification of a prior distribution difficult. For this reason, we scaled all AUC values by 1000 prior to analysis, producing values of roughly single digit magnitude.

Preliminary analysis revealed outlying AUC values which we could not justify excluding, as there was no evidence that these values were erroneous. For this reason, we estimated the mean AUC using a non-standardized t-distribution – selected as a robust alternative to the normal distribution, as the fat tails of a t-distribution allow it to accommodate a small number of outlying values. The non-standardized t-distribution is specified by three parameters: A location parameter μ, a scale parameter σ, and a degrees of freedom parameter ν, which governs the fatness of the tails. Note that the t-distribution does not have a mean (resp. variance) for $\nu \leq 1$ (resp. $\nu \leq 2$), and so caution must be used when interpreting μ and σ.

A weakly-informative $\text{N}(0, 10)$ prior was selected for the location μ, in order to provide a small degree of regularization due to the outlying values. A $\text{Cauchy}(0, 1)$ was placed on the scale σ^2, and an $\text{Exp}(1)$ prior was placed on the degrees of freedom

ν. The full model is thus

$$
\begin{aligned}
\mathrm{AUC}_i &\sim \mathrm{t}(\mu, \sigma^2, \nu) \\
\mu &\sim \mathrm{N}(0, 10) \\
\sigma^2 &\sim \mathrm{Cauchy}(0, 1) \\
\nu &\sim \mathrm{Exp}(1)
\end{aligned}
\tag{A.2}
$$

The model was fit by the Hamiltonian Monte-Carlo routine implemented in Stan 2.7 (Stan Development Team, 2015) using 3 chains of 1000 samples, of which the first 500 were discarded as burn-in. Convergence was assessed by verifying that the potential scale reduction factor (Gelman & Rubin, 1992) was less than 1.1, and through visual inspection of the chains.

A.2.2 Model for Congruency Effect in Experiment 1

The following describes the model for the mean congruency effect on initiation time in experiment 3.

We consider only initiation times for vertical (up/down) responses. Prior to analysis, we performed a median split of initiation times, and fit the model to short and long responses separately. For each participant i, we calculated the congruency effect θ_i by subtracting the mean initiation time in incongruent trials from the mean initiation time in congruent trials. We estimated the mean congruency effect by fitting a normal distribution to the effects θ_i. The model was as follows:

$$
\begin{aligned}
\theta_i &\sim \mathrm{t}(\mu, \sigma) \\
\mu &\sim \mathrm{N}(100) \\
\sigma &\sim \mathrm{Cauchy}(0, 15)
\end{aligned}
\tag{A.3}
$$

Bibliography

Anderson, M. L. (2008). On the grounds of (x)-grounded cognition. In P. Calvo & T. Gomila (Eds.), *The handbook of cognitive science: An embodied approach* chapter 21, (pp. 423–435). San Diego: Elsevier.

Ansorge, U., Khalid, S., & König, P. (2013). Space-valence priming with subliminal and supraliminal words. *Frontiers in psychology*, 4:21. doi: 10.3389/fpsyg.2013.00081.

Ansorge, U., Kiefer, M., Khalid, S., Grassl, S., & König, P. (2010). Testing the theory of embodied cognition with subliminal words. *Cognition*, 116(3), 303–320.

Ansorge, U. & Wühr, P. (2004). A response-discrimination account of the simon effect. *Journal of Experimental Psychology: Human Perception and Performance*, 30(2), 365.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial vision*, 10, 433–436.

Buetti, S. & Kerzel, D. (2008). Time course of the simon effect in pointing movements for horizontal, vertical, and acoustic stimuli: Evidence for a common mechanism. *Acta Psychologica*, 129(3), 420–428.

Buetti, S. & Kerzel, D. (2009). Conflicts during response selection affect response programming: reactions toward the source of stimulation. *Journal of Experimental Psychology: Human Perception and Performance*, 35(3), 816.

Cho, Y. S. & Proctor, R. W. (2003). Stimulus and response representations underlying orthogonal stimulus-response compatibility effects. *Psychonomic Bulletin & Review*, 10(1), 45–73.

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of verbal learning and verbal behavior*, 12(4), 335–359.

Dudschig, C., de la Vega, I., De Filippis, M., & Kaup, B. (2014). Language and vertical space: On the automaticity of language action interconnections. *Cortex*, 58, 151–160.

Dudschig, C., Lachmair, M., de la Vega, I., De Filippis, M., & Kaup, B. (2012). Do task-irrelevant direction-associated motion verbs affect action planning? evidence from a stroop paradigm. *Memory & cognition*, 40(7), 1081–1094.

Durgin, F. H. (2000). The reverse stroop effect. *Psychonomic Bulletin & Review*, 7(1), 121–125.

Eder, A. B., Rothermund, K., & Proctor, R. W. (2010). The prepared emotional reflex: Intentional preparation of automatic approach and avoidance tendencies as a means to regulate emotional responding. *Emotion*, 10(4), 593.

Estes, Z., Verges, M., & Barsalou, L. W. (2008). Head up, foot down object words orient attention to the objects' typical location. *Psychological Science*, 19(2), 93–97.

Gelman, A. & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical science*, (pp. 457–472).

Gozli, D., Chow, A., Chasteen, A. L., & Pratt, J. (2013). Spatial bias induced by semantic valence: Evidence from eye movement trajectories. *Journal of Vision*, 13(9), 512–512.

Haazebroek, P., Van Dantzig, S., & Hommel, B. (2013). How task goals mediate the interplay between perception and action. *Frontiers in psychology*, 4:247. doi: 10.3389/fpsyg.2013.00247.

Hermens, F. & Walker, R. (2010). Gaze and arrow distractors influence saccade trajectories similarly. *The Quarterly Journal of Experimental Psychology*, 63(11), 2120–2140.

Hommel, B. (2000). The prepared reflex: Automaticity and control in stimulus-response translation. In S. Monsell & J. Driver (Eds.), *Control of Cognitive Processes* chapter 11, (pp. 247–273). Cambridge, MA: MIT Press.

Kinoshita, S. & Hunt, L. (2008). Rt distribution analysis of category congruence effects with masked primes. *Memory & Cognition*, 36(7), 1324–1334.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus-response compatibility–a model and taxonomy. *Psychological review*, 97(2), 253.

Krieglmeyer, R., Deutsch, R., De Houwer, J., & De Raedt, R. (2010). Being moved valence activates approach-avoidance behavior independently of evaluation and approach-avoidance intentions. *Psychological Science*, 21(4), 607–613.

Kuhn, G. & Kingstone, A. (2009). Look away! eyes and arrows engage oculomotor responses automatically. *Attention, Perception, & Psychophysics*, 71(2), 314–327.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, 88(2), 223–242.

Lavender, T. & Hommel, B. (2007). Affect and action: Towards an event-coding account. *Cognition and Emotion*, 21(6), 1270–1296.

Lebois, L. A., Wilson-Mendenhall, C. D., & Barsalou, L. W. (2015). Are automatic conceptual cores the gold standard of semantic processing? the context-dependence of spatial meaning in grounded congruency effects. *Cognitive Science*, 2, 1764–1801.

Lippa, Y. & Adam, J. (2001). Orthogonal stimulus–response compatibility resulting from spatial transformations. *Perception & Psychophysics*, 63, 156–174.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive psychology*, 41(3), 211–253.

Memelink, J. & Hommel, B. (2013). Intentional weighting: a basic principle in cognitive control. *Psychological Research*, 77(3), 249–259.

Phaf, R. H., Mohr, S. E., Rotteveel, M., & Wicherts, J. M. (2014). Approach, avoidance, and affect: a meta-analysis of approach-avoidance tendencies in manual reaction time tasks. *Frontiers in psychology*, 5:378. doi.org/10.3389/fpsyg.2014.00378.

R Core Team (2014). R: A language and environment for statistical computing. r foundation for statistical computing, vienna, austria, 2012.

Ridderinkhof, R. K. (2002). Micro-and macro-adjustments of task set: Activation and suppression in conflict tasks. *Psychological research*, 66(4), 312–323.

Rotteveel, M. & Phaf, R. H. (2004). Automatic affective evaluation does not automatically predispose for arm flexion and extension. *Emotion*, 4(2), 156.

Stan Development Team (2015). Stan: A c++ library for probability and sampling, version 2.8.0.

Svorou, S. (1994). *The grammar of space*, volume 25. John Benjamins Publishing.

Thornton, T., Loetscher, T., Yates, M. J., & Nicholls, M. E. (2013). The highs and lows of the interaction between word meaning and space. *Journal of Experimental Psychology: Human Perception and Performance*, 39(4), 964.

Tower-Richardi, S. M., Brunyé, T. T., Gagnon, S. A., Mahoney, C. R., & Taylor, H. A. (2012). Abstract spatial concept priming dynamically influences real-world actions. *Frontiers in psychology*, 3:361. doi.org/10.3389/fpsyg.2012.00361.

Tyler, A. & Evans, V. (2003). *The semantics of English prepositions: Spatial scenes, embodied meaning, and cognition*. Cambridge University Press.

Wierzbicka, A. (1985). Lexicography and conceptual analysis.

Zwaan, R. A., Van der Stoep, N., Guadalupe, T., Bouwmeester, S., et al. (2012). Language comprehension in the balance: the robustness of the action-compatibility effect (ace). *PloS one*, 7(2), e31204. doi: 10.1371/journal.pone.0031204.