Sense and Sensitivity – Using Spatial Response-Compatibility Effects to Investigate Ambiguous Word Meaning: The Case of the German Particle *Ab*

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Abstract

We investigated sensitivity for the vertical meaning of the German particle *ab* by means of stimulus-response compatibility effects. In German, the particle *ab* is ambiguous and can take on a vertical meaning (downward) as in *Auf und Ab* (engl. *up and down*), but it can also take on non-vertical or non-spatial meanings as in *Ab und An* (engl. *from time to time*). We show that the particle *ab* only creates a spatial compatibility effect relative to the German particle *auf* (Experiment 1) but not relative to the particle *an* (Experiment 2). Furthermore, as participants executed upward versus downward responses in both Experiments 1 and 2, the mere vertical antagonism of the responses was insufficient to instill a verticality-based compatibility effect. In addition, the compatibility effect was restricted to the transparent version of the particle. If a letter sequence corresponding to the particles was presented in a semantically and morphologically opaque way (e.g., the letters *ab* were embedded in the German word *kn**ab**e*, engl. *boy*), no compatibility effect was found, underlining that the effect was due to word meanings rather than visual features. Results underscore the boundary conditions for using compatibility effects in investigating lexical and semantic spatial processing in humans.

Understanding human processing of spatial relations is important for a variety of sensory and motor performances, ranging from the orientation within an environment to the navigation through the environment. A crucial part of the involved spatial processes is language-based, such as space-based instructions or explanations. Among the many procedures that are available to investigate and understand these linguistic processes of comprehending and producing spatial semantics, stimulus-response (SR) compatibility effects of word meaning on motor performance have recently sparked more interest (cf. Ansorge et al., 2018; Ahlberg et al., 2018; Dudschig & Kaup, 2017; Glenberg & Kaschak, 2002; Landau et al., 2010; Luo et al., 2014; Proctor & Vu, 2002). An example are SR influences of spatial word meaning on the efficiency of motor responses in two-choice selection tasks (e.g., Luo et al., 2014; Proctor & Vu, 2002). For example, responses to discern the colors red versus green (e.g., red = left button press vs. green = right button press) of the words *right* and *left* are faster under SR compatible conditions (e.g., the word *left* in red) than under SR incompatible conditions (e.g., the word *left* in green) (Proctor & Vu, 2002). Such SR compatibility effects have the potential to complement the conclusions of classical studies of semantic and lexical word and sentence processing such as reading, pronunciation, picture-word tasks, semantic priming studies, and lexical-decision tasks, as SR compatibility effects in motor performance are potentially sensitive to influences of word meaning that escape the aforementioned tasks that primarily investigate higher level linguistic processing or are not sensitive to spatial language-motor links.

In particular, following Luo et al. (2014), Ansorge et al. (2018) have recently used such an SR compatibility effect to test if the German particles *auf* and *ab* show influences of their vertical spatial meanings in SR compatibility effects, although at least the particle *ab* does have a number of alternative spatial and non-spatial meanings, as it does not only mean *downward* as in words such as *Abstieg* (engl. *decline*) but also has non-vertical spatial meanings such as *off* as in *abnehmen* (engl. *to* *take off* or *to loose weight*) or even non-spatial meanings such as in *Absicht* (engl. *intention*). Much as in Luo et al., Ansorge et al. found that upward versus downward responses to discriminate the target colors green and red were faster if the task-irrelevant meaning of the target was compatible to the response than when it was not. Ansorge et al. speculated that the fact that upward versus downward responses were vertically discriminated could have been sufficient to elicit an SR compatibility effect based on these particles' vertical meanings. In the present study, however, we set out to test another possibility. Across Experiments 1 and 2, we tested if the context of the alternative target was critical for the spatial SR compatibility effect of the German word *ab*. While we used the German particles *ab* and *auf* in Experiment 1 to provoke the interpretation of the word *ab*'s vertical spatial meaning, in Experiment 2 the same target *ab* was used in the context of the non-vertical alternative target particle *an* – meaning approximately the same as the English word *at* and often implying the spatial relation of a movement *towards* a reference object as in the German words *ankommen* (engl. *to arrive*) or *anheften* (engl. *to post* [*on*]). We reasoned that in Experiment 2, the spatial meaning of *an* (engl. *at*) should suggest an interpretation of *ab* in terms of an alternative spatial meaning, here: roughly as *off*, the opposite pole of *at*. If access to the vertical meaning of the German particle *ab* depends on the presence of vertically opposite response options, we expected to see the vertical SR compatibility effect of the particle *ab* in Experiments 1 and 2, as the response options did not vary between experiments. However, if the presence of the vertically opposite meaning of the target *auf* in the context of the experiment is (also) critical for the SR compatibility effect of the particle *ab*, we expected to replicate the spatial SR compatibility effect of the target word *ab* in the present Experiment 1 but not in Experiment 2.

In addition, we tested a possibility following from Luo et al. (2014). These authors found SR compatibility effects based on vertical meanings of Chinese ideogrammic compounds even under semantically opaque conditions (see Table 1). We tested if this is possible in German by using the letter sequences of the particles *ab* (Experiments 1 and 2), *auf* (Experiment 1), and *an* (Experiment 2), embedded in a semantically and morphologically opaque way as in German words such as *kr**ab**be* (engl. *crab*), *l**auf**en* (engl. *running*), or *m**an**del* (engl. *almond*). If the letter sequences corresponding to the German particles *auf* and *ab* exerted their vertical-meaning based influences regardless of their transparency, we expected to see the SR compatibility effect in the opaque conditions in Experiment 1 and, if it only depended on the vertically antagonistic responses, maybe even in Experiment 2.

	transparent		opaque	
Chinese character	上	下	忐	忑
meaning	up	down	nervous	nervous

Table 1. A selection of characters used in Luo et al. (2014). Note that the ideogrammic Chinese compounds represent the vertical meanings much more analogously than Latin letters.

Experiment 1

Methods

Participants. Forty-six participants were tested in our Experiment 1 (33 female, M_{age} = 21.3 years, SD_{age} = 3). Participants were psychology students from the University of Vienna and were sufficiently skilled in the German language. They all had normal or corrected-to-normal visual acuity (according to self report). Participants received course credit for their participation and signed an informed consent form. While the SR compatibility effect reported by Ansorge et al.'s (2018) Experiment 1 of η_p^2 = .82 would have necessitated four participants for a replication with the power of 0.95, we decided for a considerably larger sample size for two reasons: Firstly, a sample size of 46 allowed us to detect a medium effect of *Cohen's d* = 0.5 with a power of slightly over 0.90, allowing us to detect potential SR compatibility effects in the opaque condition even if they are considerably smaller than the originally reported effect. Secondly, a sufficiently large sample size allowed us to more sensitively control for potential carry-over effects between transparent and opaque conditions.

Apparatus. The stimuli were presented on 24.5 inch LCD monitors in a dimly lit room. The monitors had a screen resolution of 1,920 × 1,080 pixels and a vertical refresh rate of 100 Hz. Viewing distance was kept stable at 57 cm via chin and forehead rest. Participants gave their responses on the number pad of a conventional QWERTZ computer keyboard. Stimulus presentation and response collection were both managed by OpenSesame (Mathôt et al., 2012). All responses were given with the participants' right index finger.

Stimuli and procedure. All visual stimuli were presented at screen center against a black background. We used a similar procedure as Ansorge et al. (2018). These authors used primed targets to study if priming influenced SR compatibility effects (– it did not –) and to ensure processing of the meaning of all presented words. Ensuring processing of target word meanings was also important in the present study. Therefore, the primes and the lexical-decision task were also used in the present study. The fixation cross, the (non-)word prime and feedback were presented in white (L = 140 in L*a*b color space). The target words were both equiluminant (L = 70) red (a = 99, b = 90) and green (−70, 67). The letters in the words were 0.34° wide and 0.57° high. The fixation cross extended 0.46° by 0.46°.

Our procedure was identical to the one used by Ansorge et al. (2018). At the beginning of each trial, participants saw a white fixation cross. In order to ensure that participants' hands were at the same distance from both response keys, participants initiated each trial by pressing the Key #5 on the number pad of the keyboard. After initiating the trial, participants saw a white word prime for 300 ms.

Participants first had to decide whether the prime was a real word or not. We used the German words *fahre*, *gebe*, *halte*, *lege* (meaning *drive*, *give*, *hold*, and *lay*, respectively) and non-words *fahse*, *gede*, *halfe*, and *lepe*, which were meaningless and were created by exchanging one of the letters of the word primes. If the prime was a non-word (1/6 of the trials), participants were required to press Key #*5*, whereas no response was required for word primes. Between the prime and the target word, another fixation cross appeared at screen center for 200 ms. (In Ansorge et al. [2018], we used different prime words to study if forming a full imperative sentence consisting of prime word and target that supported the spatial-vertical interpretation of the target word [i.e., the primes *tauche*, meaning *dive*, and *steige*, meaning *ascend/descend*, depending on the German suffix *an* vs. *ab* used with the word stem *steigen*] versus not supported the spatial-vertical interpretation of the target word [i.e., the primes *halte*, meaning *hold*, and *gebe*, meaning *give*] influenced the SR compatibility effect of the targets. It did not.) After this fixation cross, the target word was presented, which was equally likely printed in red or in green. No further response to the target word was required when the prime was a non-word. If the prime was a word, however, participants responded to the target word's color. For half of the participants, for red target words, a downward response (Key #*2* on the number pad) and for green target words, an upward response (Key #*8* on the number pad) was required. For the other half of the participants the opposite SR mapping rule applied.

Participants completed two types of blocks. In the transparent block, the German particles *auf* and *ab* (*up* and *down*, respectively) were presented in isolation. In the opaque block, the same letter sequences that correspond to the respective particles were presented not as particles, but within longer words without a clear vertical meaning such that the meaning of the word sequences corresponding to the particles was opaque. The target words in the opaque condition were *ankauf*, *fabrik*, *gabeln*, *haufen*, *kabine*, *kaufen*, *knaben*, *krabbe*, *labern*, *labors*, *laufen*, *taufen*, *traben*, *traufe*, *umlauf*, *zuhauf* (meaning *acquisition*, *factory*, *forks*, *pile*, *cabin*, *buy*, *boys*, *crab*, *babble*, *laboratories*, *run*, *baptizing*, *trot*, *eave*, *circulation*, and *galore*, respectively), and did not have any obvious inherent vertical meaning. By randomly varying the target word and the target colors, half of the trials were SR-compatible (e.g., *up* and an upward response) and the other half was SR-incompatible (e.g., up and a downward response).

Participants completed 300 trials per block (600 experimental trials in total) and 24 practice trials before each block. Self-paced breaks were possible after each block and after each 100 trials.

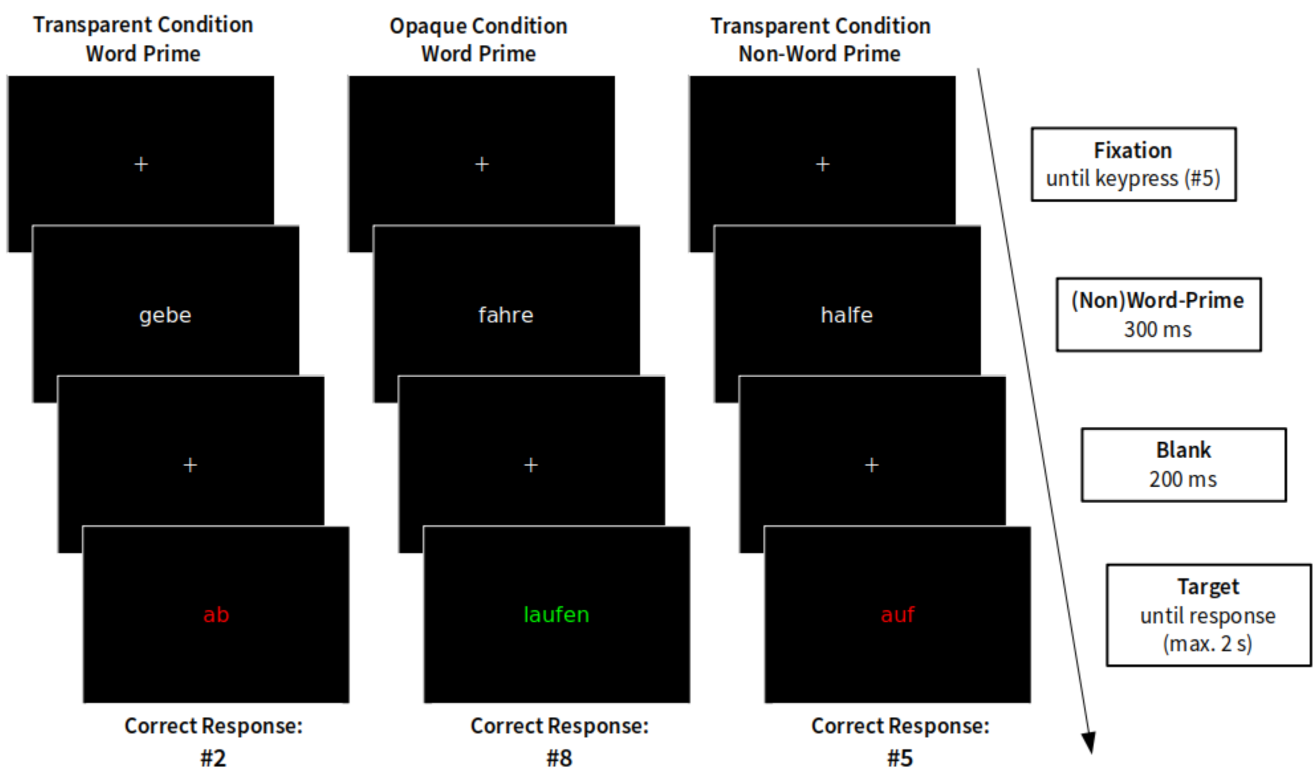

Figure 1. Examples of possible trial types. The left column provides an example for a transparent word trial (*ab*). The middle column illustrates a trial with an opaque target word (*auf*). The right

column represents a trial with a non-word as a prime (*halfe*), which required a "neutral" center response.

Results

Five participants with an error rate (ER) higher than one *SD* from participants' individual ERs (M_{ER} = 76.7%, SD_{ER} = 21.6%) were excluded from the analyses. Pseudo-word trials and trials with reaction times (RTs) deviating more than 2.5 *SD*s from participants' mean RT per condition were also excluded from the analyses (2.7%), as well as incorrect trials (additional 5.1%).

Response times.

Transparent condition. A mixed analysis of variance (ANOVA) on correct RTs from the transparent blocks, with the within-participant variable (transparent) particle (*auf*, *ab*) and response direction (*up*, *down*), and block order as a between-participants variable (*opaque before transparent*, *transparent before opaque*) was calculated. The main effect of response direction was significant, $F(1, 39) = 10.13$, $p = .003$, $\eta_p^2 = .21$, with faster upward (566 ms) than downward responses (585 ms). Response direction interacted with particle, $F(1, 39) = 7.99$, $p = .011$, $\eta_p^2 = .30$. Post-hoc paired *t*-tests revealed that upward responses were 18 ms faster for the particle *auf* (*up*; 557 ms) than for the particle *ab* (*down*; 575 ms), $t(40) = 2.79$, $p = .008$, $d = 0.26$, reflecting a compatibility effect between word meaning and response direction. Similarly, a significant compatibility effect for downward responses to the particle *ab* (*down*; 579 ms) compared to downward responses to the particle *auf* (*up*; 592 ms) was found, 13 ms, $t(40) = 2.74$, $p = .009$, $d = 0.18$, see Figure 2. Block order was neither significant, nor did it interact with any other variable (all *p*s > .13).[1]

Opaque condition. An identical mixed ANOVA with RTs from opaque blocks was calculated. We found a strong main effect of response direction, $F(1, 39) = 27.13$, $p < .001$, $\eta_p^2 = .41$, which was, again, due to 33 ms faster RTs for upward responses (577 ms) than for downward responses (610 ms). Furthermore, the main effect of block order was significant, with $F(1, 39) = 5.59$, $p = .023$, $\eta_p^2 = .13$. Participants who started the Experiment in the transparent condition were faster in the opaque condition (564 ms) than participants who started in the opaque condition (620 ms). Response direction interacted with block order, $F(1, 39) = 8.09$, $p = .007$, $\eta_p^2 = .21$. Upward responses (596 ms) were considerably faster than downward responses (646 ms) when participants began the Experiment with the opaque block, 50 ms, $t(20) = 4.67$, $p < .001$, $d = 0.55$, than when the opaque condition was the second block, 14 ms, $t(19) = 2.37$, $p = .029$, $d = 0.23$. As there was no significant interaction between response direction and (opaque) particle, there was no evidence of an SR compatibility effect (see also Figure 2).[2]

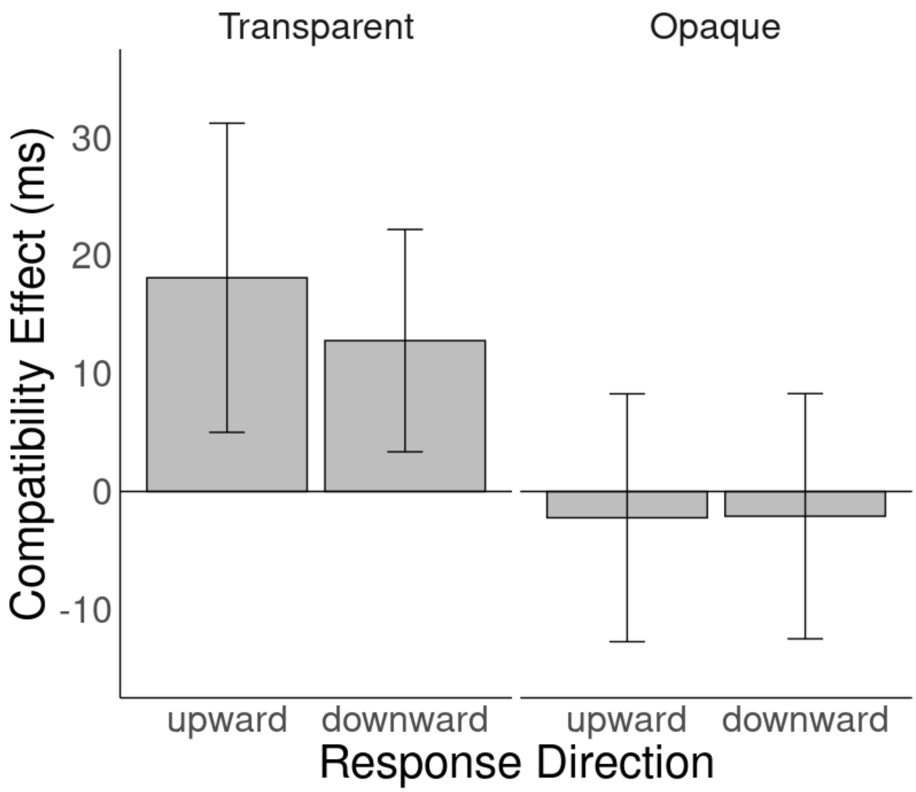

Figure 2. Compatibility effects in transparent (left) and opaque (right) conditions of Experiment 1. The compatibility effect for downward responses was calculated with reaction times for *auf* (RTs_{auf}) minus RTs for *ab* (RTs_{ab}). The compatibility effect for upward responses was calculated as RTs_{ab} minus RTs_{auf}. The error bars represent the 95% CI.

Error Rates. Arcsine-transformed ERs were fed into analogous mixed ANOVAs.

Transparent condition. The interaction between response direction and particle was significant, $F(1, 39) = 7.85$, $p = .008$, $\eta_p^2 = .17$. This interaction was due to significantly more errors for downward responses to the particle *auf* than the particle *ab*, 5.8% vs. 4.4%, respectively, $t(40) = 2.51$, $p = .016$, $d = 0.37$. However, no such compatibility effect was found for upward responses.

Opaque condition. No main effect or interaction was significant.

Discussion

We found clear-cut evidence for spatial compatibility effects based on the particles *auf* and *ab* when presented in a semantically transparent way (cf. Ansorge et al., 2018), but the letter sequences that corresponded to the particles did not lead to a spatial compatibility effect when they were shown in a semantically and morphologically opaque way – that is, if they were presented not as particles but embedded within longer words without a clear vertical meaning. The latter effect was not even found if the transparent condition preceded the opaque blocks. Thus, there was no transfer of the vertical meaning of the particles from the transparent blocks to the letter sequences in the opaque conditions.

In addition, we found the typical facilitation of the upward responses. However, this was only independent of block order in the transparent condition. In the opaque condition, facilitation for the upward responses relative to the downward responses was not present if participants started with the transparent condition. Taken together, these results suggest that the facilitation of the upward responses was not that robust in the opaque condition. Therefore, during reading of a target in the opaque condition, participants seemingly did not access the opaque lexical entries corresponding to the embedded spatial particles (cf. Zwitserlood, 1994). Otherwise, letter sequences corresponding to opaque particles in German should have led to a spatial SR compatibility effect just like the transparent targets of the current study and just like the spatial radicals embedded in Chinese ideogrammic compounds in Luo et al. (2014).

Experiment 2

Experiment 2 was almost identical to Experiment 1. The only difference concerned the choice of target words. In Experiment 2, the target words in the transparent condition were *ab* and *an* (*at*). Here, again *an* can theoretically denote vertically up (as in *ansteigen*, meaning *to ascend*), but, as with *ab*, it does only rarely so. In most other cases *an* rather denotes directionality toward a reference point if it takes on a spatial meaning at all, as in the German words *ankommen (to arrive)* or *aneignen* (*to acquire*). Accordingly, if presented as alternatives, in and by themselves, *ab* and *an* should evoke opposite meanings of directions away versus toward a point of reference (as in, e.g., *abziehen* vs. *anziehen*, meaning *to subtract* or *withdraw* vs. *to attract or take on clothes/dress*) rather than opposite vertical meanings. To our knowledge, however, the single idiom that juxtaposes *ab* and *an* in German would even suggest a temporal rather than a spatial meaning, as *ab und an* in German means *from time to time* or *occasionally*. To the extent that the vertical opposition of the targets is critical for the compatibility effect, we might therefore see a diminution of the verticality-based SR compatibility effect. However, in contrast, as discussed in Ansorge et al. (2018), the vertical opposition of the responses alone might be sufficient to elicit the particle-based compatibility effects, as the vertical meaning is the only spatial dimension shared by the respective particles and the responses. This condition was fulfilled in the present experiment.

Corresponding to the transparent condition, the target words in the opaque condition had to be changed, too, and were now *anfall*, *bangen*, *chance*, *danken*, *fabrik*, *fangen*, *gewand*, *hangar*, *hantel*, *kabine*, *knaben*, *krabben*, *labern*, *labors*, *mandel*, *tanzen*, *traben*, *vergab*, *zugabe* (*fit*, *tremble*, *chance*, *thank*, *factory*, *catch*, *garb*, *hangar*, *dumbbell*, *cabin*, *boys*, *crabs*, *babble*, *laboratories*, *almond*, *dance*, *trot*, *forgave*, and *encore*, respectively). Due to an error in creating the original version of this experiment, there was one opaque word more with *an* than with *ab*. This error was fixed after testing 23 participants.

Methods

Participants. Thirty-eight new subjects (29 female, M_{age} = 20.4 years, SD_{age} = 2.1) participated in this experiment. In all other respects (visual acuity, consent, course credit), they were (treated) as in Experiment 1.

Apparatus, *stimuli*, *and procedure*. Except for the aforementioned changes regarding the target words, Experiment 2 was identical to Experiment 1.

Results

Three participants were excluded from analyses due to the same criterion as in Experiment 1. Again, RTs deviating more than 2.5 *SD*s from subjects' mean per condition were removed from analyses (2.91%) as well as incorrect trials (4.77%).

Response times. As in Experiment 1, we calculated two separate mixed ANOVAs, one per transparency condition, both with the within-participant variables (transparent or opaque) particle (*ab*, *an*) and response direction (up, down), and the between-participants variable blocks order (*opaque before transparent*, *transparent before opaque*).

Transparent condition. Main effects of response direction and block order were found, with $F(1, 33) = 16.42$, $p < .001$, $\eta_p^2 = .33$, and $F(1, 33) = 4.83$, $p = .035$, $\eta_p^2 = .13$, respectively. The main effect of response direction was, as in Experiment 1, due to faster upward responses (547 ms) than downward responses (575 ms). The main effect of block order was due to faster responses for participants in the opaque before transparent block order (539 ms) than participants in the transparent before opaque condition (584 ms). While the interaction between response direction and particle was not significant ($p = .16$), we calculated pre-planned paired *t*-tests to investigate particle-based RT differences between response directions. While there was virtually no difference between downward responses between the particles *ab* (577 ms) and *an* (574 ms; difference: $p = .66$), the difference for upward responses towards the particles *ab* (551 ms) and *an* (543 ms) was slightly more pronounced and approached significance (p = .09).

Opaque condition. Again, a main effect of response direction was found, with $F(1, 31) = 25.66$, $p < .001$, $\eta_p^2 = .44$, which was due to 45 ms faster upward than downward responses (557 ms vs. 603 ms, respectively). The three-way interaction between block order, word particle and response direction was significant as well, $F(1, 33) = 4.77$, $p = .036$, $\eta_p^2 = .13$. In the transparent before opaque block order, upward responses were faster towards the particle *an* (542 ms), as compared to the particle *ab* (559 ms), $t(17) = 2.44$, $p = .026$, $d = 0.19$. No difference between word particles was found for downward responses (p = .29). No such differences were found in the opaque before transparent block order (*p*s > .52).[3]

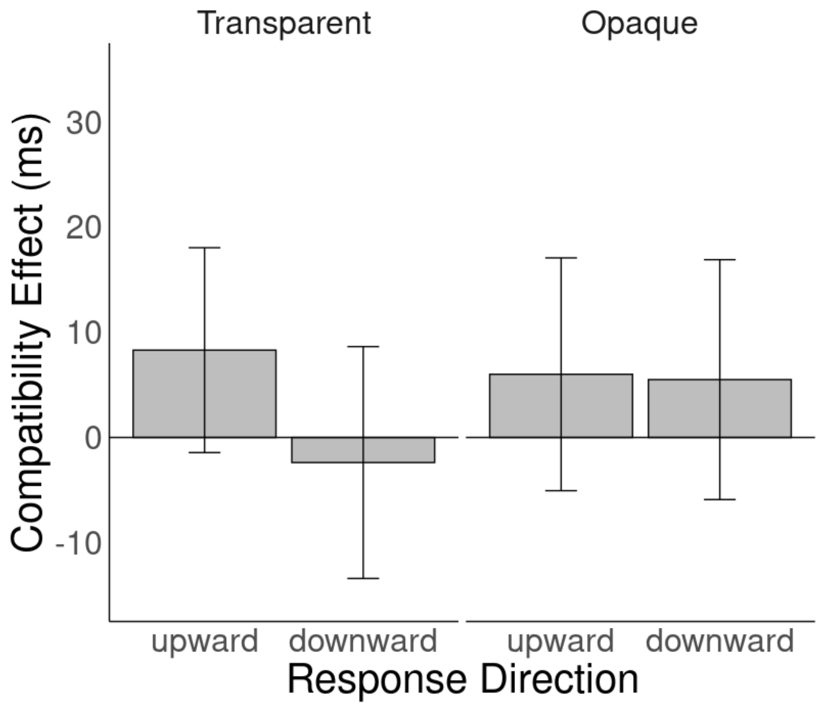

Figure 3. Compatibility effects in the transparent (left two bars) and opaque (right two bars) condition of Experiment 2. The compatibility effect for downward responses was calculated with reaction times for *an* (RTs_{an}) minus RTs for *ab* (RTs_{ab}). The compatibility effect for upward responses was calculated as RTs_{ab} minus RTs_{an}. The error bars represent the 95% CI.

Error Rates. Arcsine-transformed ERs served as the dependent variable in analogous mixed ANOVAs.

Transparent condition. No significant main effects or interactions were found. All *p*s > .2.

Opaque condition. Block order and (opaque) particle entered a significant two-way interaction, with $F(1, 31) = 5.27$, $p = .028$, $\eta_p^2 = .14$. However, no comparison of ERs with the word-particles *ab* or *an* yielded a significant result, neither for participants beginning the experiment with the transparent condition ($p = .65$), nor for participants starting the experiment with the opaque condition ($p = .4$). Additionally, the variables block order and response direction entered an interaction, with $F(1, 33) = 12.06$, $p = .001$, $\eta_p^2 = .27$. Post-hoc paired *t*-tests did not reveal significant, but directionally opposite differences between up- and downward responses in the transparent before opaque block order (3.7% vs. 4%, respectively; p = .5) and the opaque before transparent block order (6.1% vs. 5.1%, respectively; p = .33).

Discussion

Experiment 2 showed that if the relationship between the two particles used as targets was not dominated by their antagonistic vertical meanings, the words created no significant spatial compatibility effect based on verticality of the responses. The only evidence of such an effect were maybe the slower upward responses to the transparent target word *ab* than to the transparent target word *an*. Thus, the fact that the vertical meaning of only one of the two particles fitted to the spatial dimension of the executed responses was insufficient for the compatibility effect. This means that, in turn, the vertical opposition of the target words in Experiment 1 and in Ansorge et al. (2018) was critical for the compatibility effect.

In addition, as in Experiment 1, we found overall faster upward than downward responses, but again, in the opaque condition, this effect was less robust. This time it was restricted to the block order where the transparent block preceded the opaque block, but it only concerned words containing the opaque particle *an*. Given that the SR compatibility effect of the opaque particles was missing, this finding is the only evidence of participants' understanding of the spatial vertical meaning of the particles in the opaque condition.

General Discussion

In the current study, we set out to test some boundary conditions for the influence of the spatial meaning of words with ambiguous meanings on SR compatibility effects. We tested under which conditions the German particle *ab* facilitated a downward response. In particular, we tested if a context of vertically discriminated responses (up vs. down) was sufficient to elicit an SR compatibility effect based on the vertical (downward) meaning of *ab*, or whether a vertically antagonistic particle was (also) necessary to create the influence of the ambiguous word *ab*. To that end, across Experiments 1 and 2, the target word *ab* was presented with the antagonistic vertical target *auf* in Experiment 1, but with a non-vertical (but maybe spatially) antagonistic target *an* in Experiment 2. Across both experiments, the context of vertically discriminated upward and downward responses was kept the same. In line with the assumption that a second target needed to provide a vertically antagonistic semantic context for the disambiguation of the vertical meaning of the German particle *ab*, an SR compatibility effect was only found in Experiment 1's transparent conditions. This means that a context of vertically discriminated responses was insufficient to provoke a vertical interpretation of the word *ab*.

In addition, in both experiments, we tested if the sequence of letters corresponding to the different German particles *ab*, *auf*, and *an*, if embedded in a semantically and morphologically opaque manner within a word, would elicit an SR compatibility effect, too. We found little to no evidence for this possibility, a result that is in marked contrast to the findings of Luo et al. (2014). When using an ideogrammic but spatially opaque Chinese compound, Luo et al. observed an SR compatibility effect nonetheless. There are several possibilities to explain the discrepant results. One is that the ideogrammic Chinese compounds were much more analogous graphical depictions of their respective vertical meanings than the letter strings in German, which had no obvious analogue discriminating visual feature of their vertical meanings at all (see Table 1). Another difference is that we used semantically and morphologically opaque presentations of the German letter strings, while it is virtually impossible to conceive of the ideogrammatic signs used by Luo et al. as being morphologically opaque. Finally, another possible explanation for the lack of SR compatibility effects in our opaque conditions is that of experiential traces (cf. Ahlberg et al., 2018; Zwaan & Madden, 2005), which posits that, during language acquisition, new words and prepositions such as *an*, *ab*, and *auf* might be learned with corresponding actions, for instance, pointing downward when learning the word *ab*, and that every subsequent encounter with *ab* reactivates the experiential trace of a downward motion (embodied cognition), whereas words used in our opaque condition would not activate an experiential trace associated with an upward or downward movement.

Another interesting finding of the present study concerned a facilitation of upward responses compared to downward responses. Such facilitation has sometimes been linked to the polarity correspondence principle, meaning that upward responses would correspond to +pole responses – that is, representations (here: of responses) that participants access in a prioritized way (as compared to –pole responses, here: of downward responses; cf. Lakens, 2012; Proctor & Cho, 2006). It is very interesting to see that this +pole facilitation among the vertically discriminated responses itself was fostered by the presence of at least some meaning of the particles. Assuming that the spatial (not necessarily vertical) meanings of the particles were more readily available in the transparent conditions, this would explain why the facilitation of upward responses was stronger in transparent than in opaque conditions. However, the opaque conditions also consisted of longer words, had more syllables etc. Therefore, future research is needed to fully understand which of these factors accounted for the less robust upward facilitation in the opaque conditions. In any case, these results suggest that other influences of the spatial meanings of the words were also more or less restricted to the same conditions as the vertical SR compatibility effects.

Conclusion

The usage of SR compatibility effects and other effects of spatial semantics on non-linguistic motor performance as a complementary approach to the study of spatial word meaning is an interesting and fruitful approach to better understand human information processing in this important area. As we have seen in the current study, however, motor effects are not necessarily more sensitive to the various meanings of ambiguous words than other methods in all instances and situations. Even SR compatibility effects fail if a particle of a vertical meaning is presented in a morphologically and semantically opaque way and if the context suggests representation of a potentially vertical particle by one of its different (non-vertical) meanings.

Data availability statement

The raw data of this study are openly available in OSF at http://doi.org/10.17605/OSF.IO/KZNQB.

Footnotes

Footnote 1. We investigated the influence of individual prime-words on target-response based compatibility effects by including the variable "prime" (*gebe*, *lege*, *fahre*, *halte*) in our mixed ANOVAs. For the transparent condition, only the main effect of prime was significant, with $F(3, 117) = 3.10$, $p = .03$, $\eta_p^2 = .07$. Differences between prime-words were only found between *gebe* (571 ms) and *lege* (583 ms; *pBonferroni* = .09), and between *halte* (573 ms) and *lege* (*pBonferroni* = .1). All other interactions involving the factor prime were non-significant (*p*s > .2). Similarly, in the opaque condition of Experiment 1, only the main effect of prime was significant, with $F(3, 117) = 5.50$, $p = .024$, $\eta_p^2 = .12$. Again, significant differences were found between *gebe* (590 ms) and *lege* (605 ms; *pBonferroni* = .002), and between *halte* (586 ms) and *lege* (*pBonferroni* < .001).

Footnote 2. One reviewer noted that some opaque targets (e.g., the word *traufe*) could be associated with specific vertical meanings (e.g., *traufe* has a negative meaning in the German saying, *Vom Regen in die Traufe*, meaning about the same as, *from the frying pan into the fire*; thus, by means of a negative-down association, *traufe* could have been linked to *ab*). However, a post-hoc ANOVA on SR compatibility effects conducted with the single factor opaque target was neither significant in Experiment 1 nor in Experiment 2, $F(15, 600) = 0.87$, $p = .557$ and $F(18, 612) = 1.66$, $p = .096$, respectively. We thank the reviewer for raising this important question.

Footnote 3. As in Experiment 1, we took a closer look at potential influences of individual prime-words on target-response based compatibility effects. Again, we included the variable *prime* (*gebe*, *lege*, *fahre*, *halte*) in an otherwise identical ANOVA. In the transparent condition of Experiment 2, a significant main effect of prime, $F(3, 99) = 13.21$, $p < .001$, $\eta_p^2 = .29$, entered into a significant interaction with response direction, $F(3, 99) = 6.44$, $p < .001$, $\eta_p^2 = .16$. Looking at upward responses, the prime *fahre* (*drive*) accelerated responses by 31 ms, compared to the prime *lege* (*lay*), $t(34) = 3.59$, $p_{Bonferroni} = .038$, $d = 0.4$. For downward responses, only the difference between *lege* and *halte* (*hold*) almost reached significance, with 9 ms faster responses after the prime *halte* than after *lege*, $p_{Bonferroni} = .068$. Therefore, as in Experiment the prime did not significantly influence the SR compatibility effect, neither in the transparent condition, nor in the opaque condition ($F < 1$).

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