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Exploring the role of verbal-semantic overlap in response-effect compatibility

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ABSTRACT

According to ideomotor accounts, actions are cognitively represented by their sensory effects. The response-effect compatibility (R-E compatibility) paradigm investigates this notion by presenting predictable effect stimuli that are produced by the response ("response effects"). The R-E compatibility effect denotes the finding of better performance in R-E compatible conditions than in incompatible conditions, suggesting that anticipation of the effect stimulus primes the response. Most previous studies employed perceptual R-E overlap manipulations (e.g., spatial, temporal or phonological overlap of response and predictable response effect). In the present study, we examined verbal-semantic response-effect overlap. In Experiment 1, we used category words as vocal responses and semantically associated vs. non-associated exemplar words for auditory response effects (or exemplar words as responses and category words as effects, respectively) to manipulate verbal-semantic R-E overlap without perceptual-phonological similarity. In Experiments 2A and 2B, we used the response word also as an "identical" auditory effect word (i.e., both verbal-semantic and perceptual-phonological R-E overlap). An R-E compatibility effect was observed only when there was both verbal-semantic and perceptual-phonological R-E overlap. These data suggest that anticipation of perceptual response features may be critical in the R-E compatibility paradigm, whereas the role of verbal-semantic processes in response-effect anticipation still needs to be established more firmly. We discuss how perceptual and conceptual processes can interact in ideomotor control of action.

Responses can be activated both by a physically present stimulus (i.e., exogenous priming; Rosenbaum, 2010) and when the stimulus is only mentally present due to mental imagery (endogenous response priming; Janczyk et al., 2020; Keller & Koch, 2006; Kunde, 2001; Tlauka & McKenna, 1998). According to the ideomotor principle, voluntary actions are represented in terms of the anticipated perceptual effects of the motor response ("response effects"). In this sense, the anticipation of response effects would be the mental cue that primes the motor activity that most likely brings this effect about (e.g., Ansorge, 2002; Greenwald, 1970; Hommel, 2013; Kunde et al., 2007; Kunde et al., 2017; for reviews see Badets et al., 2016; Shin et al., 2010).

The investigation of the factors that influence motor response activation has a long tradition in research on stimulus-response (S-R) compatibility. This research suggests that compatibility does not rely on specific characteristics of the stimuli or of the responses themselves but that it is based on stimulus-response ensembles (Fitts & Deininger, 1954; Fitts & Seeger, 1953). In their *dimensional overlap* model, Kornblum et al. (1990) proposed that S-R ensembles are represented as categories with dimensions that may or may not overlap, such as when both the set of stimuli and the set of responses share a spatial dimension. Importantly, action-control research based on the ideomotor principle suggests that anticipated effect stimuli should be able to prime a response in a similar way as an actually presented stimulus, that is, like in SRC (Keller & Koch, 2006; Kunde, 2001). Based on this notion of dimensional overlap, the response-effect (R-E) compatibility paradigm has been developed (Koch & Kunde, 2002; Kunde, 2001) to examine how anticipated action effects play a role in action control when there is dimensional R-E overlap.

For example, in Kunde's (2001) study, participants pressed a key either softly or forcefully, which resulted in soft or loud auditory tone effects. The critical manipulation referred to the mapping of the responses to the effects. In the R-E compatible condition, the effect

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predictably corresponded to the response in terms of intensity (e.g., both soft or both strong/loud), whereas in the incompatible condition, response and effect mismatched on the overlapping dimension of intensity. The trials in the compatibility conditions were blocked, so that participants could reliably anticipate their response effects. Kunde (2001) found shorter reaction times (RTs) in the compatible condition compared to the incompatible condition. Note that the response-effects were presented only after RT had been measured in the given trial, so that the compatibility effect must have been due to *anticipated* effects that facilitate action selection and execution (see also Kunde et al., 2004).

Many studies demonstrated R-E compatibility effects. However, most studies defined R-E compatibility based on perceptual relations between response and effect, such as sensory intensity (Kunde, 2001; Kunde et al., 2004), visual-spatial correspondence (Janczyk & Lerche, 2019; Müller, 2016; Pfister & Kunde, 2013; Shin & Proctor, 2012; Yamaguchi & Proctor, 2011), spatial height-auditory pitch overlap (Keller & Koch, 2008) or duration (Kiesel & Hoffmann, 2004; Kunde, 2003; Müller, 2016). All these relations are defined based on *perceptual* features that do not necessarily require verbal-semantic processes.

In comparison, the potential role of *verbal-semantic* R-E overlap in action control has received only little attention so far. Yet, a verbal-semantic representation of anticipated response-effects would seem to enhance flexible action control. For example, saying the word *two* leads to the anticipation of seeing the digit *2* written (Badets et al., 2013) or hearing it spoken, while all representations of the concept of "two" might be activated, too, such as seeing the written number word *two* or hearing two beeps, or even reading the word *shoes* (i.e., because shoes come in pairs). Thus, the ability to generalize anticipated response-effects to the semantic level would endow action control with more flexibility compared to anticipating the mere *sensory* outcome of one's actions.

Koch and Kunde (2002) investigated the verbal-semantic R-E compatibility. In their Experiment 2, participants were instructed to respond vocally, saying one of four color words, to visual digit stimuli 1 to 4. The vocal color word (R) led to a written color word (E) in neutral print color. Note that the instructed S-R (i.e., digit to color word) mapping was arbitrary, so that there was no dimensional S-R or S-E overlap but only R-E overlap. The authors found shorter RTs in the R-E compatible condition, with matching R and E word, than in the R-E incompatible condition, and suggested a verbal-semantic basis for effect anticipation in the R-E compatibility paradigm (see also Badets et al., 2013; Paelecke & Kunde, 2007). However, it is possible that the observed R-E compatibility effect in Koch and Kunde's (2002) study was not due to the verbal-semantic overlap but instead to a perceptual-phonological overlap between the vocalized response word and an auditory effect representation based on automatic grapheme-phoneme conversion (i.e., recoding) of the anticipated visually presented effect word, which is likely to occur in skilled readers (e.g., Rubenstein et al., 1971).

In an attempt at confirming the verbal-semantic R-E compatibility effect, Földes et al. (2018) introduced a bilingual version of the task which did not allow for phonological overlap between response and effect words. In their Experiment 1, in a monolingual condition, participants responded to visually presented digit stimuli (1 and 2), saying the words "Hund" or "Schwein" (German for *dog* and *pig*). Saying the response word resulted in the presentation of effect words either in a compatible, matching manner (e.g., "Hund" ➔ *Hund*) or an incompatible manner (e.g., "Hund" ➔ *Schwein*). In a bilingual condition, participants received the English translation-equivalents of these words as effects (e.g., "Hund" ➔ *dog*). This way, Földes et al. (2018) compared the R-E compatibility effect in a condition with both perceptual-phonological and verbal-semantic overlap (monolingual condition) with that in a condition in which there was only verbal-semantic overlap (bilingual condition) without perceptual-phonological similarity. The authors found a significant R-E compatibility effect in the monolingual condition (Badets et al., 2013; Koch & Kunde, 2002) but not in the bilingual condition. Importantly, in their Experiment 2, the authors replicated the absence of a bilingual R-E compatibility effect in a well-powered sample with 48 participants, confirming the finding of their Experiment 1. In their third experiment, they replicated the monolingual R-E compatibility effect with the words *Pferd* and *Stuhl* (German for horse and chair). Together, the data suggested no verbal-semantic generalization in this particular bilingual version of the R-E compatibility paradigm.

However, the bilingual setting employed by Földes et al. (2018) included a language switch between response word and effect word, which might have disrupted the verbal-semantic effect-anticipation process (Declerck & Philipp, 2015; for a review on language switching). Therefore, while such a bilingual R-E mapping represents a specific example of semantic generalization, it is still unclear whether effect anticipation would (or would not) extend more generally to verbal-semantic effects in the R-E compatibility paradigm.

Interestingly, Hommel et al. (2003) used the response-effect learning paradigm, which represents a different experimental approach to examining effect anticipation (e.g., Elsner & Hommel, 2001; Herwig et al., 2007; Herwig & Waszak, 2009; Janczyk et al., 2012; Pfister et al., 2011; Ziessler et al., 2004). Hommel et al. (2003) found evidence for a role of verbal-semantic representations in effect anticipation. Unlike the R-E compatibility paradigm, the learning paradigm does not exploit pre-experimentally existing dimensional overlap relations between responses and effects but is based on a previous training that forms an associative link between potentially arbitrary responses and effects. Specifically, this paradigm consists of two phases. In the initial learning (or training) phase of Hommel et al.'s (2003) Experiment 1, participants were taught that a specific manual response was going to be followed by a specific category word (e.g., after a right keypress the written word *animal* appeared on the monitor, and after a left keypress the written word *furniture* was presented). Note that there is no verbal-semantic relation between, say, a right key press and the effect word *animal*, but the previous training phase should have created an associative link. Subsequently, in the transfer (or test) phase, participants were instructed to respond to exemplar words of the earlier presented categories (i.e., *dog*, *chair*). Performance was better when participants were instructed to respond to the exemplar word referring to the category with which the response had been previously associated to (e.g., compatible with the acquisition phase, such as when the word *dog* required a right keypress) compared to when they were instructed with the opposite mapping (e.g., when the word *dog* required a left keypress). Thus, participants learned that specific responses led to specific verbal word effects in the training phase, and later a conceptually related word that is presented as a target stimulus facilitated selecting the action that was previously associated with the corresponding verbal concept (see also Badets & Pesenti, 2011). This may be evidence for conceptually generalized response-effect representation based on verbal-semantic processes.

Note, however, that the learning paradigm requires participants first to go through an associative learning training phase in which they develop a R-E association and later retrieve this association in the test phase when the previous effect (or a conceptually related effect) is *physically* presented as a target stimulus, but it still carries its previous association with the response. In comparison, similar effects in the R-E compatibility paradigm would mean that participants had the ability to generalize before any specific experimental training and that it refers to pure endogenous response priming because the effect can be anticipated but is never in any experimental trial physically presented prior to the response.

The aim of the present study was to further examine verbal-semantic response-effect anticipation in the R-E compatibility paradigm, using a setting that avoids methodological issues of earlier studies such as phonological R-E overlap and language-switching-related influences (Badets et al., 2013; Földes et al., 2018; Koch & Kunde, 2002). To this end, we implemented verbal-semantic R-E overlap by using category words and exemplar words as responses and effects (or vice versa), so that there was no phonological overlap between response and effect words because these were semantically related but different words (see Hommel et al., 2003). In addition to the monolingual condition we also implemented a bilingual condition in order to re-assess Földes et al.'s (2018) finding of no bilingual R-E compatibility effect using a different set of response and effect words. If there is verbal-semantic R-E compatibility, and if the language switch in the bilingual condition would have disrupted the R-E compatibility effect, then the R-E compatibility effect should be present only in the monolingual setting.

1. Experiment 1

1.1. Method

1.1.1. Participants

Thirty-four German-speaking students from RWTH Aachen University (M_{age} = 22.59 years; 10 males) participated. They reported normal or corrected-to-normal vision. The sample size was determined in line with previous R-E compatibility studies, ranging mostly between 16 and 24 (see Földes et al., 2018). Data of two participants, who indicated afterwards that they did not understand the instruction, were excluded from the analysis. For reasons of better generalization, participants were randomly assigned to two groups (i.e., $n = 16$ in each group): Group 1 responded by saying category words and received auditory exemplar words as effects ($R_{category} \rightarrow E_{exemplar}$), while we used the other mapping for Group 2 ($R_{exemplar} \rightarrow E_{category}$). All participants gave written consent and received partial course credit or small monetary compensation.

1.1.2. Apparatus and stimulus material

The apparatus consisted of a PC equipped with a 17 in. LG Flatron computer screen with a 75 Hz refresh rate and a microphone, both approximately 60 cm from the participant. As target stimuli, the digits *1* and *2* were used; each digit was presented visually in black color (with Courier New font, font size 24) on white background.

As vocal responses to the digits, participants responded either with the category words *Tiere* (German for *animals*) and *Möbel* (German for *furniture*) or the two corresponding exemplar words *Pferd* (German for *horse*) and *Stuhl* (German for *chair*).[1] The responses were to be given always in German. RT was measured from stimulus onset. A voice-key (Serial Response Box; Psychology Software Tools, Inc., 2017) detected the onset of participants' vocal responses, and accuracy was coded online by the experimenter.

For each participant, the complementary set of these two sets of two words were also used as auditory effect words that were presented 300 ms after vocal response onset. That is, participants who responded with category words to the digit stimuli received the exemplar words as effects, and those who responded with exemplar words received the category words as auditory response effects. Like in Földes et al. (2018), the auditory effect words were generated with an online text-to-speech converting program[2] and further edited using Audacity® (Mazzoni, 2015) to obtain equally long (700 ms long) audio files. The auditory effect words were presented in German in the monolingual condition and in English in the bilingual transfer condition.

1.1.3. Procedure

The experimenter instructed the participants orally (the instruction was later repeated on the computer screen before each experimental block as a reminder) and verified that participants were familiar with the English words that we used as response-effects in the bilingual variation of the task (e.g., "Please name the word *Möbel* in English!"). Participants were instructed to respond to the visual digit stimuli *1* and *2* as quickly and accurately as possible with the assigned response words. Stimuli were presented until response onset. The vocal response onset triggered, with a delay of 300 ms, an auditory word as response-effect, which was either compatible or incompatible to the response (e.g., in a compatible trial if the participant responded with the word *Stuhl* the corresponding category word *Möbel* was presented auditorily, and in an incompatible trial and a non-corresponding category word [e.g., *Tiere*] was presented). As established in a previous study using auditory response effects (Földes et al., 2017, 2018), we introduced the delay of 300 ms between response and effect to avoid mutual acoustic masking of the produced sound of the vocal response and the auditory effect word (see Fig. 1). The experimenter remained in the lab throughout the experiment to register incorrect responses.

Participants first performed 10 practice trials without auditory response effects and afterwards performed two R-E compatible blocks followed by two R-E incompatible blocks, with R-E compatibility conditions counterbalanced across participants. Each of the four test blocks consisted of 100 trials. In each R-E compatibility condition, there was one monolingual block (responses and effects in German) and one bilingual block with effect words in English, again in counterbalanced order (e.g., monolingual/compatible, bilingual/compatible, monolingual/incompatible, bilingual/incompatible). Both compatibility and bilingual transfer conditions were varied in a block-wise manner to ensure maximum predictability of response effects in all conditions.[3]

1.1.4. Design

The independent within-subjects variables were R-E compatibility (compatible vs. incompatible) and transfer type (monolingual vs. bilingual). To explore the generality of verbal-semantic effect anticipation, we included mapping group as a between-subjects variable (category ➔ exemplar vs. exemplar ➔ category). The dependent variable was RT. Very few errors occurred in the present experiments (0.4% on average), and because we suspected the case of a floor effect, we did not analyze error data (similarly to Földes et al., 2018; Wirth et al., 2015; see also Dixon, 2008, for a discussion on ceiling and floor effects in error data).

1.2. Results

RTs below 100 ms (6.8%) were discarded from the analysis assuming that these were due to technical voice-key irregularities (such as coughs, background noises, etc.). Further exclusions were made concerning errors (0.4%), trials after errors (0.4%), RTs with more than 2.5 SDs above or below each participant's mean (1.4%), RTs longer than 2000 ms (0.8%), and the first trial in each experimental block (1%). In total,

[1] According to the CELEX data base (Baayen et al., 1995), the category word "Tiere" is more frequent than the exemplar word "Pferd" while the difference in word frequency for "Möbel" and "Stuhl" goes in the opposite direction (see Appendix).

[2] From text to speech: Free online Text To Speech (TTS) service with natural sounding voices. German words were spoken by "Denise", while English words were spoken by "Alice" (i.e., American English pronunciation; see http://www.fromtexttospeech.com/).

[3] Because we sought to exploit semantic relations between category and exemplar words, we also implemented a short manipulation check after the experiment. In this manipulation check, a category (prime) word was presented for 100 ms, and after 300 ms blank screen an exemplar (target) word appeared for 100 ms, and participants had to indicate whether prime and target have a semantic match or mismatch. Notably, semantic priming effects in such lexical decision tasks have also been observed even when the prime and target words were presented in two different languages (Dufour & Kroll, 1995; Francis, 2005). This task consisted of 48 trials both in the monolingual and bilingual condition. For the present purpose, we would simply like to note that the lexical decision task showed highly significant priming effects based on exemplar-category membership, suggesting strong semantic relations among our items used, but we do not report these data in more detail.

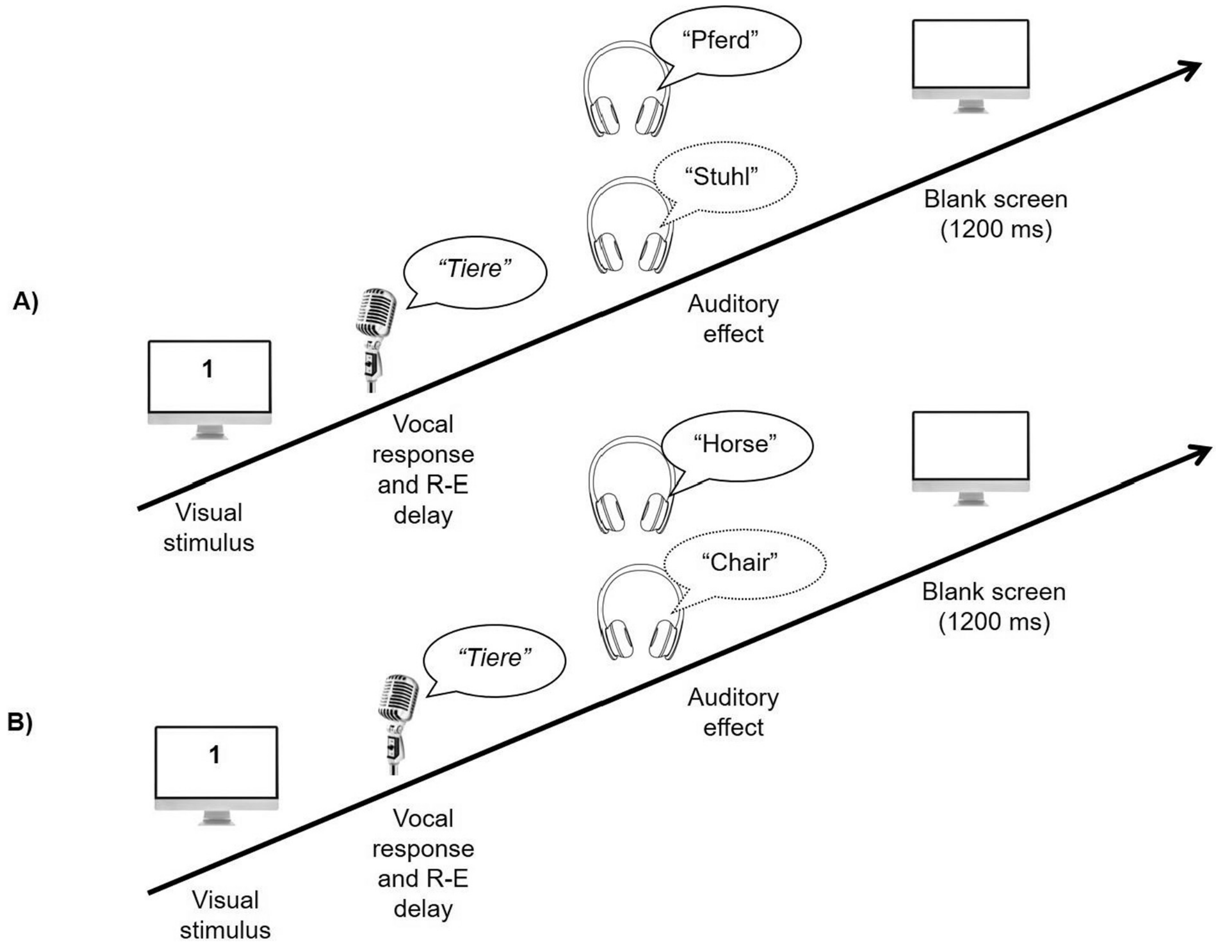

Fig. 1. Procedure in the monolingual (A) and bilingual (B) conditions. The figure depicts the course of a trial for the category ➔ exemplar R-E condition: In the case of the exemplar ➔ category condition, the response words were exemplar words (i.e., *Pferd*, *Stuhl*) and effect words were category words (i.e., *Tiere*, *Möbel*, or translation-equivalents in English). The dashed lines indicate an incompatible response-effect while continuous lines indicate a compatible response-effect. Vocal RT (in ms) was measured from stimulus onset. The auditory effect stimulus was presented 300 ms after onset of the vocal response.

91.4% of the RT data was analyzed. Results are reported as significant at an alpha level of $p = .05$.

We submitted the RT data to a 2 × 2 × 2 mixed analysis of variance (ANOVA) with R-E compatibility (compatible vs. incompatible) and transfer type (monolingual vs. bilingual) as within-subjects variable, and mapping group (category ➔ exemplar, exemplar ➔ category) as between-subjects variable (Fig. 2). Overall, no effect was significant. The main effects of R-E compatibility (552 ms vs. 548 ms for compatible vs. incompatible conditions, indicating a R-E compatibility effect of −4 ms) and mapping group (555 ms vs. 546 ms for category ➔ exemplar vs. exemplar ➔ category) were not significant, $Fs < 1$. There was a non-significant trend toward a main effect of transfer type, $F(1,30) = 3.613$, $p = .067$, $\eta_p^2 = 0.107$, showing numerically shorter RTs in the bilingual condition than in the monolingual condition (544 ms vs. 557 ms), but the response language was German in both transfer conditions. Also the other interactions were not significant (transfer type × mapping group, $F[1,30] = 1.994$, $p = .168$, $\eta_p^2 = 0.062$, R-E compatibility × mapping group, $F < 1$, transfer type × R-E compatibility, $F[1,30] = 1.295$, $p = .264$, $\eta_p^2 = 0.041$, three-way interaction, $F[1,30] = 1.029$, $p = .318$, $\eta_p^2 = 0.033$).

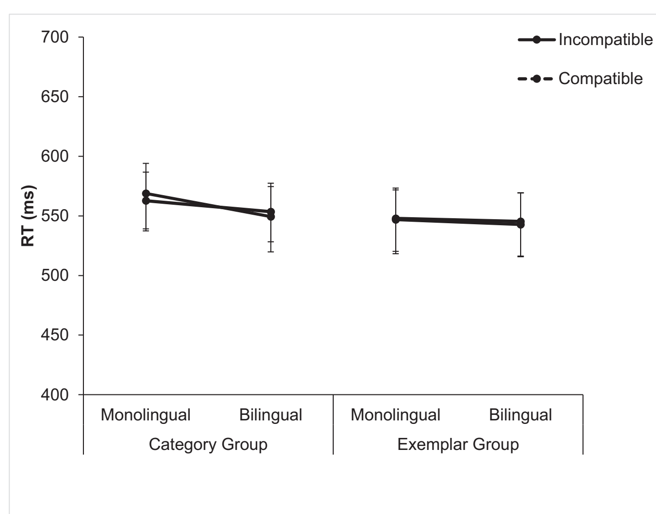

Fig. 2. Reaction Times (RTs; in ms) of Experiment 1 as a function of R-E compatibility (compatible vs. incompatible) and bilingual transfer conditions (monolingual vs. bilingual) for the two R-E compatibility conditions (category ➔ exemplar group vs. exemplar ➔ category group). Error bars depict standard error of means.

1.3. Discussion

In Experiment 1, we replicated Földes et al.'s (2018) finding of no R-E compatibility effect for the bilingual condition using a different set of response and effect words. Importantly, there was also no significant R-E compatibility effect in the monolingual condition, showing that the employed category-exemplar relationships did not provide a sufficient basis for a verbal-semantic R-E compatibility effect. Hence, the data do not support the notion that verbal-semantic R-E compatibility effect can occur in the complete absence of perceptual overlap between response and effect word (cf. Koch & Kunde, 2002). Note though that this statement is based on a null effect. In Földes et al. (2018), we replicated the null effect for the bilingual condition across two experiments, and the replication experiment used a rather large sample size of $n = 48$. The present experiment used a sample size of $n = 32$ (divided in two counterbalancing groups differing whether the response word was a category or an exemplar word). To get an estimate of the statistical power of the present experiment, we considered the critical comparison of R-E incompatible vs. compatible (i.e., a test of a difference of two within-subjects conditions) using the *t*-test (matched pairs) procedure of Gpower (Faul et al., 2007) for a post-hoc power calculation. Using alpha = 0.05, we achieved a power of >0.99 for predicted (i.e., one-tailed testing) large effects (i.e., $d_z = 0.8$) and still a power of >0.86 for medium-sized effects (i.e., $d_z = 0.5$). Even if we tested the R-E compatibility effect separately in each of the two groups of $n = 16$, we would have a power of ≈0.85 for detecting large effects. Hence, our power to detect large to medium-sized effect appears sufficient. Yet, based on the present data we could claim only that large verbal-semantic R-E compatibility effects are rather unlikely in the monolingual condition while not being able to exclude smaller effects. Yet, in light of previous findings by Földes et al. (2018) with much larger power we can be more confident with regard to the present null effect of bilingual verbal-semantic R-E compatibility.

2. Experiment 2A and Experiment 2B

Given the null effect of verbal-semantic R-E compatibility in conditions without perceptual R-E overlap, we also assessed control conditions that included such perceptual overlap. To this end, we used only the monolingual condition, in which the effect word was the same as the response word in the R-E compatible condition (e.g., in the category word condition: "hund" ➔ *Hund*), so that there was not only verbal-semantic overlap but also perceptual-phonological overlap. Here we expected to find an R-E compatibility effect.

In Experiment 2A, participants had blocks with category words and blocks with exemplar words nested in the manipulation of R-E compatibility. In Experiment 2B, we tested the R-E compatibility effect as a function of word type (category vs. exemplar) in two separate groups of participants in order to avoid potential carry-over effects across word types.

2.1. Participants

In Experiment 2A, twenty-four native German students from RWTH Aachen University ($M_{age} = 28.1$ years; 18 females) were recruited in the same manner as in Experiment 1. In Experiment 2B, twenty-five native German students from RWTH Aachen University ($M_{age} = 22.5$ years; 14 females) were recruited and randomly assigned to one of two groups ($n = 12$ for the category word group and $n = 13$ for the exemplar word group).

2.2. Apparatus, stimuli, procedure and design

The experimental setting was like in Experiment 1, but we used only German words and the set of response words was used also as effect words. Each participant practiced the task in 12 trials followed by four test blocks with 100 trials each. In Experiment 2A, participants performed each time two blocks of R-E compatibility condition (counterbalanced order of R-E compatibility conditions). In Experiment 2B, the difference to Experiment 2A was that we tested the R-E compatibility conditions for category words and for exemplar words in two separate groups.

2.3. Results

2.3.1. Experiment 2A

The same exclusion criteria were applied as in the previous experiments. In total, 97.5% of the raw data was analyzed. The ANOVA on RT with R-E compatibility and word type revealed no R-E compatibility effect, $F < 1$, but there was a significant effect of word type, $F(1,23) = 4.679$, $p = .041$, $\eta_p^2 = 0.169$, indicating overall faster responses with exemplar words. In addition, there was a non-significant trend toward an interaction between R-E compatibility and word type, $F(1,23) = 2.341$, $p = .140$, $\eta_p^2 = 0.092$. There was a 17 ms R-E compatibility effect with category words and a slightly reversed R-E compatibility effect of −3 ms with exemplar words (see Fig. 3), but when tested separately, the 17 ms R-E compatibility effect with category words was not quite significant: $t(23) = 1.225$, $p = .116$, $d_z = 0.250$ (just as the −3 ms effect with exemplar words: $t[23] = 0.302$, $p = .382$, one-tailed testing).

2.3.2. Experiment 2B

The same exclusion criteria were applied. In total, 96.7% of the RT data was analyzed. The ANOVA on RT with R-E compatibility and word type (between-subjects: category vs. exemplar word) revealed no significant effect of R-E compatibility ($F < 1$) and word type ($F[1,23] = 3.021$, $p = .096$, $\eta_p^2 = 0.116$), but there was a significant interaction between R-E compatibility and word type, $F(1,23) = 6.631$, $p = .017$, $\eta_p^2 = 0.244$ (see Fig. 4). Testing the R-E compatibility effect separately for each word type (i.e., group) with a one-sample *t*-test revealed a significant R-E compatibility effect of 24 ms (602 ms vs. 578 ms for incompatible vs. compatible condition) for the category word-group ($t[11] = 2.236$, $p = .047$, $d_z = 0.645$), which supports the non-significant 17 ms trend ($p < .12$) with category words in Experiment 2A. However, for the exemplar words the R-E compatibility effect was again not significant (528 ms vs. 547 ms for incompatible vs. compatible conditions; $M = -19$ ms, $t[12] = 1.506$, $p = .158$).

2.4. Discussion

In Experiment 2A and 2B, a R-E compatibility effect was found with category words (even though the 17 ms R-E compatibility effect in Experiment 2A was not quite significant), but not with exemplar words. That is, for category words we could confirm the corresponding findings in Földes et al. (2018) using a different set of words as well as findings by Koch and Kunde (2002), who used visually presented effect words. This is consistent with the notion that conditions with semantic and additional perceptual R-E overlap produce R-E compatibility effects. Yet,

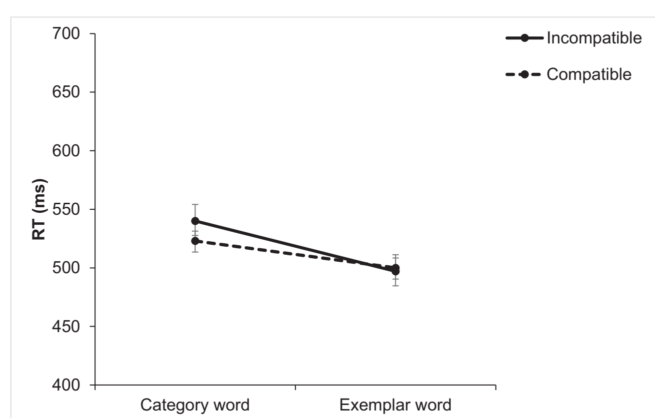

Fig. 3. Reaction Times (RTs; in ms) of Experiment 2A as a function of R-E compatibility (compatible vs. incompatible) and word type (category vs. exemplar). Error bars depict standard error of means.

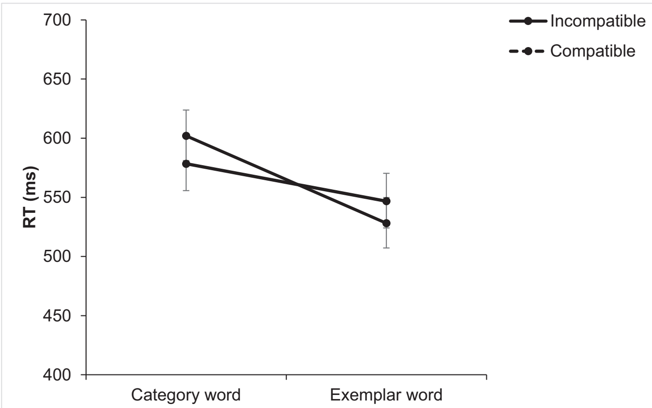

Fig. 4. Reaction Times (RTs; in ms) of Experiment 2B as a function of R-E compatibility (compatible vs. incompatible) for the two word types (category word group vs. exemplar word group). Error bars depict standard error of means.

unexpectedly, we did not find the R-E compatibility effect with the present set of exemplar words. We return to this issue below.

3. General discussion

In the present study, we investigated conceptual generalization in the process of response-effect anticipation by exploring verbal-semantic overlap in the R-E compatibility paradigm. To this end, we re-assessed a bilingual version of the paradigm using exemplar and category words as responses and effects in different languages, and we supplemented this with a monolingual condition, in which there was a category-exemplar semantic relation but no phonological R-E overlap because response word and effect word were phonologically dissimilar. We found no evidence for verbal-semantic R-E compatibility, confirming previous data from Földes et al. (2018) on bilingual R-E compatibility and extending this to the monolingual condition. Földes et al. (2018) speculated that bilingual switches might have disrupted the R-E compatibility effect because anticipating the English word might have inhibited the production of the German word (see Declerck & Philipp, 2015, for a review). However, even in the monolingual condition the verbal-semantic associations did not produce the R-E compatibility effect. Hence, the data suggest that verbal-semantic associations alone, when being isolated experimentally, do not readily show R-E compatibility effects that would indicate that the semantic relation to the response is part of the effect anticipation.

However, we have to deal with two caveats. First, we have a null effect, which is always somewhat difficult to interpret because absence of evidence is not evidence for its absence. Yet, in this regard we would like to note that Földes et al. (2018) replicated the null-effect in the bilingual R-E compatibility manipulation even with a large sample size of $n = 48$, giving sufficient power to detect at least medium-sized effects. Therefore, the present finding of no bilingual R-E compatibility effect simply generalizes the existing null effect to a different set of items for vocal responses and auditory effects and thus seems very credible. With respect to the present new monolingual verbal-semantic overlap manipulation based on category-exemplar relations, the data basis appears less firm statistically, even though considerations of statistical power suggest that we would have been able to detect at least large effects if they existed. That is, it stands to future tests whether possibly existing smaller effects could be assessed in much larger samples and whether the null effect is specific to the present monolingual R-E compatibility manipulation as well as to the bilingual version. Future studies with new manipulations of verbal-semantic R-E compatibility might change this picture. Yet, at this point it is important to note that the present findings using the R-E compatibility paradigm are not in line with the effect that Hommel et al. (2003) found in their learning and transfer paradigm using almost identical category words (*animal*, *furniture*) and exemplar words (*dog*, *chair*). Given the difference in experimental methodology, it is possible that a conceptual effect anticipation can occur more readily when the conceptual relation is trained in a preceding associative learning phase, whereas verbal-semantic R-E compatibility effects do not arise spontaneously.

The second caveat refers to Experiment 2A and 2B, in which the auditory effect word was identical to the vocal response word in the R-E compatible condition and was different in the R-E incompatible condition (Földes et al., 2017, 2018; Koch & Kunde, 2002). This leads to perceptual-phonological overlap between vocal response and auditory effect words in the R-E compatible condition (for discussion of the influence of different modality mappings see Földes et al., 2017; Fintor et al., 2018; Greenwald, 1972; Stephan & Koch, 2010) in addition to verbal-semantic overlap. Therefore, finding a R-E compatibility effect in this condition while finding no R-E compatibility effect in Experiment 1 would support the role of perceptual similarity in response effect anticipation. In fact, R-E compatibility effect of 17 ms and 24 ms was found with category words, consistent with the notion of perceptual similarity and in line with previous studies using similar experimental designs with different stimulus material (e.g., visual words, Földes et al., 2017, 2018; Koch & Kunde, 2002; or visual digits, Badets et al., 2013). Yet, unexpectedly, we did not find a R-E compatibility effect with our exemplar words. This finding weakens our empirical basis, but we deemed it important to report those non-significant results nonetheless, so that R-E compatibility effects with vocal responses and auditory effects do not go overestimated due to publication bias (Francis, 2012; Pashler & Wagenmakers, 2012).

We can only speculate on possible explanations for this unexpected finding. One explanation might be that the category words contained two syllables, whereas the exemplar words contained only one. Thus, the category words took more time to pronounce, and thus enunciate them overlapped more in time with the auditory effects that occurred 300 ms after vocal onset. In fact, an important difference to a previous study that observed clear effects of R-E compatibility with perceptual-phonological overlap using vocal responses (Koch & Kunde, 2002) is that these authors used immediate visual effects, whereas in the present study the auditory effects were delayed by 300 ms after vocal onset. While delays between actions and consequences are mentally represented when generating an action (Dignath et al., 2014), such delays rendered the self-produced auditory feedback of the participants and the experimentally manipulated auditory response effects more clearly distinguishable in our study. Temporal overlap of self-produced and manipulated response effects might be important to produce the sort of facilitation and interference of mutually phonologically compatible or incompatible auditory feedback we were looking for.

However, another explanation might be that we simply failed to detect actually existing effects with our sample sizes with exemplar words because statistical power was not large enough (note that the exemplar word group in Experiment 2B had only $n = 13$). This consideration becomes even more plausible if we consider the data in the context of the conditions tested in Földes et al. (2018). In that study, focusing on the monolingual conditions, Experiment 1 used the word “Hund” (German for *dog*) and “Schwein” (German for *pig*) and found a significant R-E compatibility effect of 12 ms. In their Experiment 3, they used the words “Pferd” and “Stuhl” (which we also used in the present study as exemplar words) and found a significant R-E compatibility effect of 16 ms. Hence, with a very similar setup, we replicated Földes et al.'s (2018) findings in two cases, resulting in four conditions with R-E compatibility effects, while we failed to replicate this effect in two other conditions, possibly due to lack of statistical power. Yet, we still believe that we can derive some empirical generalizations from the data set. Fig. 5 gives an overview of the R-E compatibility effects observed by Földes et al. (2018) and in the present study. It is notable that we never observed a R-E compatibility effect in those conditions that isolated

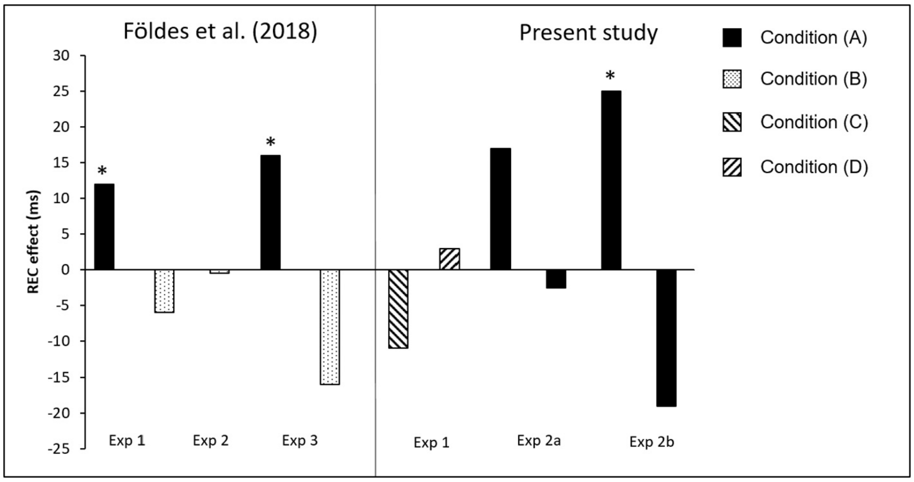

Fig. 5. Summary of findings on conceptual generalization of Földes et al. (2018; left panel) and of the present study (right panel). In the "identical R-E" mappings (both panels, black columns, Condition A), there is phonological R-E overlap (identity of vocal response and auditory effect word in the R-E compatible condition), whereas in the other mappings (both panels, white panels with black dots or lines, Conditions B, C and D) there is only verbal-semantic R-E overlap. Condition B: response set = Hund & Schwein; Condition C (bilingual): response set = Tiere & Möbel (category words) vs. Pferd & Stuhl (exemplar words); Condition D (monolingual): response set = Tiere & Möbel (category words) vs. Pferd & Stuhl (exemplar words). *$p < .05$.

verbal-semantic R-E overlap. However, with perceptual-phonological overlap, we observed the R-E compatibility effect in the two relevant conditions in Földes et al. (2018) and here with the category words (significant in Experiment 2B and as a trend [$p < .12$] in Experiment 2A), even though not with exemplar words.

Hence, in light of previous evidence on conceptual influences on action-effect anticipation, we can now speculate about possible limitations of conceptual processing during action-effect anticipation. Previously, it has been reasoned that the basic ideomotor mechanism underlying motor control, which is mainly space-based and time-based, might also be used for other processing domains, such as numerical cognition (see, e.g., Badets et al., 2016). Number processing is strongly connected to spatial cognition, as suggested by findings indicative of a spatially aligned "mental number line" (Dehaene, 1997; see also Walsh, 2003). Spatial and temporal relations have conceptual aspects in the sense that they are abstract and can be scaled (in terms of ratios), and they can be transferred from one effector to the other effector (see, e.g., for a review on motor-program generalization, Boutin et al., 2012; Krakauer et al., 2006; Rosenbaum, 2010). In this sense, these relations combine both perceptual and semantic elements. When we attempted to isolate the verbal-semantic element in the present study using a verbal task with linguistic material and examining bilingual transfer as well as exemplar-category priming, we might be leaving the representational domain that has sufficiently strong links to spatial action control and that can result in significant priming of the response-effect anticipation process. Hence, while perceptual relatedness of response and effect may be able to prime action across a wide range of domains, the link between linguistic cognition and action-effect anticipation seems to be weaker than the one defined by perceptual-conceptual (e.g., spatial or temporal) anticipation.

Koch et al. (2004) mention distal, abstract response effects that are not directly movement-related (e.g., patting a teammate on the shoulder). It is possible that perceptual effect features are more beneficial for immediate, online action control, while verbal-semantic effect features might be abstract and more indirectly influential for offline action control, such as to create an emotional state (e.g., doing gestures or saying specific things to motivate somebody; Koch et al., 2004), in effector generalization (Boutin et al., 2012), or in high-level human-specific cognitive skills such as word processing or arithmetics (Badets et al., 2016). Hence, we believe that future research should take into consideration a differentiation between *direct* response effects (perceptual, directly movement-related) and *indirect* response effects, which are neither perceptual, nor directly movement-related but mediated by verbal-semantic processing.

Future studies would need to examine the conditions under which linguistically defined conceptual relations, such as categorical relatedness of response word and effect word, can influence the process of action-effect anticipation. Hommel et al. (2003) showed such an effect using the learning paradigm. It is possible that previous specific association learning is the requirement for obtaining such "abstract-conceptual" anticipation effects, which would not occur if not preceded by this specific pre-training, such as in the present verbal-semantic R-E compatibility paradigm. In any case, further exploration of the representational basis of action-effect anticipation seems to be an important avenue for future research on the mechanisms underlying action control.

Compliance with ethical standards

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Ethical approval

All procedures performed in the present study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standard.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Declaration of competing interest

The authors declare that there is no conflict of interest (financial or non-financial). Moreover, we have full control of all primary data and we agree to allow the journal to review the data if requested.

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Appendix A

Table A
Word frequency of the response/effect words (per million).

	Combined word frequency	Oral word frequency	Written word frequency
German words			
Pferd	65	34	68
Stuhl	38	19	40
Tier	128	179	122
Möbel	23	14	23
English words			
Horse	152	40	139
Chair	136	26	145
Animal	260	104	272
Furniture	39	31	39

Note. Source: CELEX Lexical Database (Baayen et al., 1995).

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