To appear in *Quarterly Journal of Experimental Psychology*

The temporal dynamics of effect anticipation in course of action planning

Michael Ziessler[1] & Dieter Nattkemper[2]

[1]Liverpool Hope University
[2]Humboldt University Berlin

Running head: Activation of effect codes in response planning

Key words: action planning, effect anticipation, ideomotor theory, motor control, flanker task

Address for correspondence:

Michael Ziessler
Department of Psychology
Liverpool Hope University
Hope Park
Liverpool
L16 9JD
UK

Dieter Nattkemper
Department of Psychology
Humboldt University Berlin
Rudower Chaussee 18
12489 Berlin
Germany

Email:
ziesslm@hope.ac.uk
dieter.nattkemper@cms.hu-berlin.de

Abstract

“Strong” versions of the ideomotor theory of action control claim that anticipations of the environmental effects actions bring about are mandatory for response selection. This is considered to be the one and only way of how actions can be voluntarily selected. We studied this notion in a series of four experiments where we adapted the flanker paradigm to investigate the involvement of effect codes in the preparation of motor responses. Participants first learned that their responses to stimulus letters were contingently followed by the presentation of a new letter on the screen. In the second phase of the experiments, the action-demanding letters were presented together with the effects of the correct response, effects of other responses or neutral letters. Varying the stimulus onset asynchrony (SOA) between target stimuli and the flanking effect stimuli provides the opportunity to investigate the temporal dynamics of the activation of effect codes. Hence, flanker stimuli were presented before, simultaneously with, or after the onset of the target. The results indicate that effect-related information from the flanker stimuli is involved in the preparation process, but mainly in later phases of response preparation. The observed pattern of results suggests that, at least under conditions where responses are determined by stimuli, effect codes are activated in course of response planning to enable the evaluation of the executed response and the monitoring of response execution, but they do not automatically activate the responses themselves.

Acknowledgements

The authors wish to thank Joachim Hoffmann, Bernhard Hommel, Wolfgang Prinz and three anonymous reviewers for their very helpful comments on an earlier draft of this manuscript.

The temporal dynamics of effect anticipation in course of action planning

Goal-directed behavior is only possible if we know in advance the possible effects of our actions. For example, when asked to illuminate a room, we press a light switch. Being able to do so implies knowing in advance that the action of pressing a light switch will turn on the light. Without this knowledge, we would have to go through all available actions to find out which one will produce the desired effect.

Consequently, early theories of motor actions such as the ideomotor principle assumed that randomly executed movements are associated with their environmental effects. The learned associations can then be used in the reverse direction, i.e. the activation of effect codes in mind will activate the corresponding motor behavior (Harleß, 1861; Herbart, 1824; James, 1890; Lotze, 1852; Münsterberg, 1888). Basically, these theories assume that actions are represented in terms of effect codes in memory. Münsterberg (1888) and James (1890) considered the anticipation of an action goal, i.e. the anticipation of the desired effect, to be a necessary precondition for executing a particular action. Lotze (1852) stated that the anticipation of a movement goal will make the body realize what the mind intends to do. Modern versions of the classical ideomotor principle have been suggested by Hommel, Müsseler, Aschersleben and Prinz (2001) and Prinz (1997). Following these theories, the activation of effect codes is a necessary step in action selection.

However, also other theories assume that effect codes are involved in action control. For example, the Schema Theory (Schmidt, 1975, 1988) assumes that effect codes are necessary to monitor action execution. Effects of the designed motor program are anticipated to enable the cognitive system to check whether the program has been executed correctly after the action has been performed. This can be achieved by comparing the actual effects with the anticipated effects (see also Adams, 1971). Another assumption, which is also part of the Schema Theory, is that anticipated effects can be used for an internal test of the motor program in advance of its execution. The action can be executed if the anticipated effect that depends on the specified motor program is identical with the desired effect. Thus, there are at least three functions that might require the activation of effect codes in the control of motor actions: selection of the action, internal testing of the motor program, and monitoring of action execution.

Recently, a number of experiments have shown that effect codes are indeed involved in the preparation and execution of motor actions (Hommel, 1993, 1996; Kunde, Koch, & Hoffmann, 2004). Elsner and Hommel (2001) performed an experiment in which participants first had the choice between a left and a right key-pressing response. Each response produced a particular tone. After a number of trials participants should have learned the connections between the responses and their effects. In a second phase of the experiment the former effects were presented as stimuli. If the stimulus response assignment corresponded with the previous response-effect assignment, the response times were shorter than with the other stimulus-response assignment. The authors took that as evidence that the effects activated the responses. Other experiments found that response times depended on the overlap between features of the required responses and their effects (Koch & Kunde, 2002; Kunde, 2001, 2003; Kunde, Hoffmann & Zellmann, 2002). This clearly indicates that effect codes are active during response preparation. If the effect codes as well as the responses share the same features then processing can be facilitated.

Ziessler and Nattkemper (2002; Ziessler, Nattkemper & Frensch, 2004) adapted the flanker paradigm introduced by Eriksen and Eriksen (1974) to investigate the involvement of effect codes in the preparation of a motor response. In the experiments participants first learned that their responses to stimulus letters were followed by the presentation of a new letter on the screen. The new letter was presented contingent to the response, i.e. as a response effect. In the second phase of the experiments, the stimulus letters were presented together with the effects of the correct response, effects of other responses or new letters. The effect letters or new letters flanked the stimulus letter on both sides. If the flanking letters were the effects of the correct response this was considered as the effect-compatible condition. Effects of other responses as flanking letters resulted in the effect-incompatible condition, new letters in the neutral condition. We found faster responses under the effect-compatible condition compared to the effect-incompatible and neutral conditions. To explain these findings, Ziessler and Nattkemper (2002, Ziessler et al., 2004) assumed that response preparation involves the anticipation of the response effects. In the effect-compatible condition the same effect codes are activated by the anticipation process as well as by external stimulation. In this way the correspondence between response-induced and flanker-induced effect codes might facilitate response planning and results in shorter response times.

These experiments demonstrate very well that the activation of effect codes is involved in response planning and execution; however it remains open what exactly their function is. Kunde et al. (2004) made a first attempt to investigate the role of effect codes in response planning. In their experiments participants responded to a green or red stimulus with a forceful or soft response. The responses produced either a loud tone or a quite tone. Responses were faster if a forceful response produced a loud tone and a soft response a quite tone compared to a reversed response-effect assignment. This effect of response-effect compatibility is evidence for the inclusion of effect anticipation in response preparation. To investigate if effect codes would be used for response selection or would play their role late in response initiation and response monitoring Kunde et al. introduced a cue into the paradigm informing the participants about the forthcoming response. A valid cue would allow response selection before presentation of the imperative stimulus. Participants were instructed to prepare the response but to withhold it until the stimulus was presented. If the effect of response-effect compatibility described above would disappear in trials with valid cues this would be evidence that effect codes were used for response selection, but not for the later processes of response initiation and monitoring. Results showed that the response-effect compatibility effect did not disappear after the valid cues. However, the compatibility effect was smaller after valid cues (35 ms on average) than after neutral cues (49 ms). The authors concluded that effect codes would affect the selection, initiation and execution of the response. The question is if the reduction of the compatibility effect is indeed evidence for the inclusion of effect codes in response selection. Valid cues lead to a facilitation of the responses compared to neutral cues. This can reduce the compatibility effect without any reference to underlying processes. Indeed, the mean response time after neutral cues amounted to 502 ms and the response time after valid cues to 348 ms. The compatibility effects of 49 ms and 35 ms had then a similar relative size of 9.8 % and 10 % of the mean reaction time. Thus, the conclusion that effect codes were involved in response selection is not very compelling.

Therefore, we believe that further experiments are necessary to investigate the role of effect codes in the control of motor responses. A way forwards consists in the investigation of the temporal dynamics of effect code activation in course of response planning. If the effect codes would be important for response selection, the activation of the effect codes should precede the selection of the motor program for the response. If the effect codes were necessary for an internal test of the motor program in advance of its execution, the effect codes would have to be activated prior or in parallel to the motor program, but it is not necessary that their activation precedes response selection. For response monitoring, the response effects would have to be predicted from the generated motor program. This would enable the cognitive system to compare the effects expected after correct program execution with the actual effects. Then the activation of effect codes should occur rather late in course of response planning, obviously after response selection. Thus, if we could show at which point in time effect codes are active in course of response planning, we should be able to conclude about their possible functions.

The flanker paradigm as described above gives a nice opportunity to investigate the temporal dynamics of the activation of effect codes by varying the stimulus onset asynchrony (SOA) between target stimuli and the flanking effect stimuli. The effect flankers can be present before, together with, or after the target stimuli. If the effect codes would be used for response selection under the given experimental conditions, then the presentation of the response effect in advance of the target stimulus should facilitate the response. On the contrary, if participants need first the motor program for the response to anticipate the effect (as described by the forward models, e.g. Jordan, 1996, Wolpert, Miall, & Kawato, 1998), presentation of the effects together with or shortly after the target stimulus determining the response should speed up the completion of response preparation and facilitate the response. In Experiments 1 we varied the point in time when the effect flankers were presented from 300 ms in advance of the target stimulus presentation to 300 ms after the target stimulus presentation. In Experiment 2 the SOA between targets and flankers was adapted to the individual mean reaction time (RT) of each participant and varied from 0 to 75% of the mean RT. Using this method, the time at which the flankers were presented should be more in accordance with individual stages of response planning compared to using the same fixed SOAs for all participants. In Experiment 3, in addition to the SOA variation the presentation time of the flankers was limited using a mask. Thus, the visual processing of the flankers had to be performed in a small time window. The interference between effect codes activated by external stimuli and effect codes activated as part of response preparation should be strongest, if both activation processes occur at the same time. Finally, Experiment 4 addressed the question whether the functional signature of effect-related compatibility effects is actually different from that of response-related compatibility effects of irrelevant flanker stimuli. By showing a difference between effect-related and response-related compatibility effects, the experiment provides additional validation of the first three experiments.

Experiment 1

The first experiment consisted in an adaptation of the flanker paradigm as described above. Flanking letters were shown prior or after the target letter. If the effects of the response were presented before the target, effect codes could be activated before the participant could actually select the response. Following the ideomotor principle, activation of the effect codes should automatically activate the motor response to produce this effect. Thus, response effects presented before the target stimulus should already activate the response and lead to shorter RTs. On the contrary, if presentation of response effects only after the target would lead to a facilitation of the response, in particular with long delays, this could hardly be due to response selection. The response should have already been selected depending on the target stimulus when the effect flanker appears. Then we would have to assume that the effect codes were involved in the internal test of the program or in monitoring of response execution.

Method

Participants

32 undergraduate students at the Psychology Department of the University of Sunderland (UK) served as participants. All students were first-year students and received course credits for their participation. They had normal or correct-to-normal vision.

Stimuli and Apparatus

Stimulus presentation and response recording were controlled by an IBM compatible personal computer. The computer was situated in a soundproofed booth in the cognitive lab. The capital letters *W*, *G*, *N*, *F*, *S*, *X*, *P*, and *H* were used as target stimuli and the letters *Y*, *C*, *B*, *R*, *T*, *K*, *M*, and *V* as effect stimuli. In the test phase of the experiment in addition the letters *D* and *Z* were used as neutral flanker stimuli. Stimuli were presented at the center of the computer screen. With a viewing distance of about 60 cm, one letter subtended a visual angle of 0.4 x 0.8º (width x height). In the test phase of the experiment the target letter was flanked by one of the other letters on both sides. The three-letter string subtended a visual angle of approximately 1.6º. Responses were key-presses with the index and middle fingers of each hand. Participants were asked to use the “\” and “z” keys for the responses with the left hand

and the "." and "/" keys for the responses with the right hand. The stimulus response-assignment and the response-effect assignment are shown in Figure 1.

Figure 1 about here

Design and procedure

The experiment was divided into two phases, an acquisition phase and a test phase. In the acquisition phase participants performed a speeded four-choice reaction-time task with eight stimulus alternatives (see Fig.1). Immediately after each correct response a letter was presented. This letter constituted the response effect. Its identity depended on the identity of the imperative stimulus. For example, if a *W* was presented as the target the correct response was a key-press with the left middle finger. This key-press was followed by a presentation of a *Y* as the response effect. However, if the same response was required to the target stimulus *S* a *C* was presented as effect. The purpose of the acquisition phase consisted in the learning of the stimulus-response assignment as well as the response-effect relations. At the beginning of the experiment participants were instructed as to the stimulus-response assignment, but they were not informed about the response-effect relations. They were only told that the appearance of the letter would indicate that the response was correct. Thus, participants should learn the response-effect relations just through the repeated experience that a certain response is always followed by a certain effect letter.

The acquisition phase consisted of 8 blocks of 56 trials each. In each block each of the 8 target letters was presented 7 times in random sequence. Each trial started with the presentation of a warning signal (+) for 500 ms. After the warning signal, the target stimulus was presented. Participants were required to respond as quickly as possible without making errors on appearance of the target. Immediately after a correct response the effect stimulus replaced the target and remained visible for 1000 ms. In case of an incorrect response a question mark was presented instead of the effect letter, accompanied by a beep signal for 50 ms. After a blank interval of 1500 ms the next trial started. After each block feedback was presented on the screen giving information about the mean RT and the number of errors in the previous block. Participants were encouraged to reduce RT and number of errors in the next block.

The test phase of the experiment followed immediately after the acquisition phase. In the test phase we presented the target letter together with another letter that flanked the target letter on both sides. This letter could either be the effect of the correct response following the given target (regular effect, e.g. *YWY*), the effect of the correct response following the alternate stimulus requiring the same response (alternate effect, e.g. *CWC*), the effect of a response with the other finger of the same hand (incompatible/ same hand, e.g. *RWR*), the effect of a response with the same finger of the other hand (incompatible/ other hand, e.g. *MWM*) or a neutral stimulus (e.g. *DWD)*. The variation of flanker types is the first independent variable of the experiment. Table 1 gives examples for each flanker type. In the present design the assignment of two stimuli and two effects to each response makes it possible to dissociate the target-effect relations and the response-effect relations. For example, if the target letter *W* was presented together with *Y*, the target was presented together with the regular effect of the correct response to W. In that case there is a target-effect relation as well as a response-effect relation that could have been acquired in the first phase of the experiment. Possible flanker effects on RTs could be due to both relations. However, if *W* was presented together with *C*, the target was also presented together with an effect of the correct response, but in this case there is only a response-effect relation because *C* never follows responses to *W*. In our former experiments (Ziessler & Nattkemper, 2002; Ziessler et al. 2004) both types of effect-compatible flankers had the same facilitating effect on the RTs to the targets.

Table 1 about here

Besides flanker type, a second independent variable was the time of flanker presentation. The flanking letters could either be presented before or after the target. To this end, the SOA between targets and flankers was varied in 5 steps: -300 ms, -150 ms, 0 ms, 150 ms, and 300 ms. In case of negative SOAs the flankers appeared before the target, in case of positive SOAs after the target. Both independent variables were varied within participants.

The test phase consisted of 320 trials. Each of the 8 target stimuli was combined 8 times with each of the five flanker types (neutral, effect-compatible/ regular, effect-compatible/ alternate, effect incompatible/ same hand, effect incompatible/ different hand) resulting in the 320 trials. The 64 trials with each flanker type were divided between the 5 SOAs. The -300, -150, 150, and 300 ms SOAs were used 13 times each, the 0 ms SOA 12 times. The particular stimulus letters assigned to the combinations of flanker type and SOA were balanced out over the sample. All conditions were randomly mixed. The 320 trials were separated into 4 blocks of 80 trials each to give participants occasions for a rest. Each trial started with the presentation of a warning signal (+) for 500 ms. In case of negative SOAs, the warning signal was followed by the presentation of the flanker at the left and right side of the central position on the screen. The central position was empty. After 0, 150, or 300 ms the target appeared at the central position between the flankers. The flankers remained on the screen. In case of positive SOAs, first the target was presented and 0, 150, 300 ms later the flankers. Participants were asked to respond as quickly and as accurately as possible to the target. As in the acquisition phase, on execution of the correct response the three-letter string disappeared and was immediately replaced by the effect letter for 1000 ms. If the response was not correct a question mark was presented and a beep indicated the error. RTs were measured from target onset to response onset.

The whole experiment lasted about 75 minutes.

Results

Only the results from the test phase are of interest regarding our research question. Therefore we will not report the results of the acquisition phase here. RTs longer than 2000 ms were considered as outliers and counted as errors (1.5% of all data). Participants with more than 25% of errors were excluded from the data analysis. Based on this criterion one participant was discarded. A second participant did not enter the data analysis because of missing values in two of the cells of the experimental design. The remaining 28 participants made on average 6.28 % erroneous responses including incorrect responses and outliers. The number of erroneous responses did not vary systematically with flanker type, $F(4, 108) = .706$, $p = .589$. Individual mean RTs were computed for each flanker type and SOA. The individual means entered the statistical analysis. Table 2 presents the RTs and error percentages for all experimental conditions.

Table 2 about here

The data were subjected to a repeated-measures 5 (flanker type) x 5 (SOA) ANOVA. In this and all following analyses the sphericity assumption was tested for the data. If sphericity could not be assumed, the df and subsequently the p-values were corrected using the Greenhouse-Geisser correction. The ANOVA yielded a significant main effect of the SOA, $F(2.5, 67.5) = 39.34$, $p < .001$. Shortest RTs were found if the flankers were presented 300 ms before the target. Flanker presentation together with or shortly after the target increased the RTs. More importantly, the results yielded that the main effect of flanker type was not significant, $F(3.0, 80.8) = 1.08$, $p = .364$. Overall there was only numerically an 8 ms advantage if the flankers were effect-compatible compared to the neutral and a 10 ms advantage compared to the incompatible conditions. However, the flanker effect interacted significantly with the SOA, $F(8.2, 221.5) = 2.14$, $p = .032$. To illustrate the flanker effects depending on SOA, Figure 2 depicts the RT differences between trials with effect-compatible and effect-incompatible flankers.

Figure 2 about here

Whereas for negative SOAs effect-compatible flankers never facilitated the response, at the 0 ms SOA a difference of 46 ms was found between effect-compatible and neutral and of 36 ms between the effect-compatible and incompatible flankers. Those differences were also observed for the 150 ms SOA and decreased at the 300 ms SOA. Separate ANOVAs for the five SOAs confirm this picture. For the two negative SOAs there were no flanker effects; $F(4, 108)$-values amounted to 1.24 (p = . 298) and 1.40 ($p = .238$) for the -300 ms and the -150 ms SOA, respectively. Significant effects of flanker type were only found for the 0 ms SOA, *F*(4, 108) = 3.32, *p* = .013, and the 150 ms SOA, *F*(2.6, 70.9) = 3.12, *p* = .037. At the longest SOA the significant flanker type effect disappeared, *F*(3.6, 82.1) = 1.01, *p* = .394. Post-hoc tests indicated that the flanker effect at the 0 ms SOA was due to faster RTs with both types of effect compatible flankers compared to neutral flankers (*t*(27) = 3.03, *p* = .005 for regular effect flankers, *t*(27) = 2.49, *p* =.019 for alternate effect flankers) and effect incompatible flankers (*t*(27) = 2.48, *p* =.019 for regular effect compared to incompatible/ same hand, *t*(27) = 2.19, *p* = .038 for alternate effect compared to incompatible/ same hand, *t*(27) = 2.31, *p* = .029 for alternate effect compared to incompatible/ different hand). At the 150 ms SOA, RTs were faster with the alternate effect flankers compared to all other flanker types (neutral: (*t*(27) = 2.74, *p* = .011, regular effect: *t*(27) = 2.61, *p* = .015, effect incompatible/ same hand: *t*(27) = 3.95, *p* = .001, effect incompatible/ different hand: *t*(27) = 3.05, *p* = .005). All other differences were not significant.

Discussion

Confirming the results of previous experiments, we found a facilitation of the responses if the targets were flanked by the effects of the correct response. If wrong effects or neutral stimuli were used as flankers RTs were longer. However, this facilitation was only found if the effect flankers were presented together with the target (0 ms SOA) or shortly after the target (150 ms SOA). No effect of flanker type was found if the effect compatible and effect incompatible flankers were presented in advance of the target (negative SOAs). Thus, the activation of effect codes by the flanker stimuli did not affect response times if this activation occurred before the response was determined by the target. This is clear evidence against the assumption of the ideo-motor principle stating that any activation of effect codes would automatically trigger the activation of the corresponding response. On the contrary, the significant flanker effects at SOAs of 0 ms and 150 ms suggest that the effect codes are activated only together with selected response. We can only speculate why the presentation of effect flankers affected the RTs within this short interval after target onset, but not before and after. We assume that response selection starts with the processing of the target. Selection and preparation of the response include the anticipation of the response effects. Responses are facilitated by flankers representing correct effects of the response, because in this case the response-induced activation of effect codes is supported by a stimulus-induced activation of the same codes. In line with this assumption, at the longest SOA of 300 ms the facilitation of the responses by effect-compatible flankers disappears because at this point in time the preparation of the response has reached an advanced stage including the anticipation of the effects so that this process cannot be additionally supported by external stimulation.

It is important that the facilitation of the responses was found for both types of the effect compatible flankers, the regular effect and the alternate effect. For the alternate effect it can be excluded that the flankers only supported the visual processing of the target. These effect letters were used never before in conjunction with the target letters. The only way they could affect the response is their property of being effects of the correct response to the target. Therefore, the fact that the presentation of the alternate effects together with or shortly after the target facilitated the response can only be explained by an involvement of effect code activation into response preparation.

The experiment also provides strong evidence that response-effect relations are learned even if the effects are completely irrelevant for the task except that their appearance indicated the correctness of the response. The activation of representations of the learned effects is part of the preparation of the response.

Apart from the interaction between flanker effects and SOA, the main effect of SOA was significant. This effect is mainly due to faster responses when the flankers appeared before the target. On average, RTs with the -300 ms SOA were 85 ms shorter than with the 0 ms SOA. Within the positive SOAs the effect is much smaller (12 ms RT difference between 0ms SOA and 300ms SOA, 3ms between 150ms SOA and 300ms SOA).The main effect of SOA for negative SOAs can be discussed in terms of a foreperiod effect (Bertelson & Boons, 1960; Mattes & Ullrich, 1997): The flankers serve as a warning signal. This allows temporal preparation for the processing of the target, in particular with the longest SOA. However, this temporal preparation is very general and does not differentiate between the flanker types. One could argue at this point that the shorter RTs with negative SOAs might cover potential flanker type effects but the data show that there was not even a trend for a facilitation of responses in case of effect compatible flankers with negative SOAs.

Experiment 2

The first experiment provided evidence that the impact of the external presentation of response effects on the preparation of the responses depends on the time at which the effects were presented. Thus, it seems that the stage of response preparation is crucial for the processing of effect information. Experiment 2 was designed to investigate this in more detail.

The basic idea of the experiment was to relate the time of flanker presentation closer to the actual stage of response preparation. An indicator of the time necessary to select, program and execute a response is the response time. However, response times differ between participants and usually decrease with practice. Therefore, with the fixed SOAs in Experiment 1 the presentation of effect flankers occurred at different individual points in time for each participant, and this point in time varied with practice. A way to avoid this problem might consist in the adaptation of the SOAs to the individual response times and their changes with practice. Thus, instead of using fixed SOAs as in the first experiment, the flankers were presented at 0, 25, 50 and 75 % of the mean individual response time at the given stage of practice. Because the effect compatibility of the flankers affected response times only at positive SOAs, flankers were always presented either together with or after the target, i.e. there were no negative SOAs in Experiment 2.

Given the mean RT of about 800 ms in the conditions with positive SOAs in Experiment 1, 25% of mean RT should correspond to 200 ms, 50 % to 400 ms and 75 % to 600 ms on average. That means, SOAs used in Experiment 2 were much longer than those used in the first experiment.

Method

Participants

Thirty undergraduate students from the Department of Psychology at the University of Sunderland served as participants. They had normal or corrected-to-normal vision. None of them had participated in the first experiment. Participants received course credit.

Stimuli and apparatus

The apparatus and the target stimuli were identical to Experiment 1. A difference to the first experiment consisted in the effect stimuli. In the second experiment, the same stimuli that we used as targets were also used as effects. Figure 3 illustrates the stimulus-response-effect assignment.

Figure 3

Using the same stimuli as targets and flankers made the experiment not only more similar to one of our previous experiments (Ziessler & Nattkemper, 2002), it also lead to a more natural situation. Under natural conditions the effect of an action or a response is often the new stimulus for the following response. Thus, in Experiment 2 the effect stimuli were task relevant stimuli, but the participants did not have to react to them.

Design and procedure

The acquisition phase was identical to Experiment 1.

The test phase consisted of 320 trials, resulting from the combination of the 8 targets with the five flanker types and the 4 SOAs. All combinations were applied two times. Trials were presented in random order. Mean RTs were calculated after every 40 trials. These mean RTs were used as the base RT for the next 40 trials to adjust the time of flanker presentation to the individual RTs. For the first 40 trials the mean RT from the last block of the acquisition phase was taken as base RT. Flankers appeared at SOAs of 0, 25, 50, and 75 % of these individual mean RTs.

Flanker types were the same as in Experiment 1. The letter *D* was used as neutral flanker.

It should be noted that due to using the same stimuli as targets and as effects, the flankers could not only activate an effect code but also a response. However, the effect flankers were selected in a way that they never activated the same response than the target. In other words, all flankers (except the neutral) were always response-incompatible with the target. For example, *S* was never presented as flanker with *W* because *S* would activate the same response and this would override the effect-incompatibility of *S* with *W*.

The whole experiment lasted about 75 minutes.

Results

The first 40 trials of the test phase were not included in the data analysis. As described above, for these trials the mean RT from the last acquisition block was taken as basic RT for adaptation of the SOAs. However, as conditions in the test phase were more complex than in the acquisition phase, mean RTs in the first block of the test phase were actually 160 ms longer than mean RTs in the last of block of the acquisition phase. Therefore, SOAs in the first half block were too short and not comparable to the SOAs in the following part of the experiment. Except from that, data were analyzed as in the previous experiments. RTs above 2000 ms were counted as errors (3.9 % of all data). Three of the thirty participants were discarded from the analysis due to their high amount of erroneous responses (> 25 %). The remaining 27 participants had an average error rate of 9.28 %. Individual means were computed for each flanker type and relative SOA. The statistical analysis is based on these individual means. The mean RTs averaged over the 27 participants and the error percentages related to each flanker type are shown in Table 2. A repeated-measures 5 (flanker type) x 4 (SOA) ANOVA was performed. The

ANOVA yielded a significant main effect of SOA, $F(3, 78) = 7.26$, $p < .001$. The SOA effect consisted in increased mean RTs at the 0 % SOA compared to the 25 % and 50 % SOAs. At the 75 % SOA RTs increased again. The main effect of flanker type was not significant, $F(4, 104) = 1.18$, $p = .324$. Most importantly, there was a significant interaction between flanker type and SOA, $F(7.1, 184.2) = 2.23$, $p = .033$. Figure 4 illustrates the flanker-type effect depending on SOA in form of the RT difference between effect-compatible trials and effect-incompatible trials.

Figure 4 about here

Separate analyses of the flanker-type effect for the four SOAs did not reveal any significant effect. The $F(4, 104)$-values amounted to 2.42 ($p = .053$), 1.75 ($p = .145$), 1.94 ($p = .110$), and 1.68 ($p = .160$) for the 0 %, 25 %, 50 %, and 75 % SOA, respectively. Post-hoc tests showed for the 0% and 25 % SOA a significant difference between trials with regular effect-compatible flankers and incompatible flankers (same hand), $t(26) = 2.42$, $p = .023$ for 0% SOA and $t(26) = 2.14$, $p = .04$ for 25% SOA. At the 50% SOA, trials with the alternate effect-compatible flankers resulted in shorter RTs than trials with neutral flankers, $t(26)= 2.55$, $p = .017$, and trials with effect incompatible flankers (same hand), $t(26) = 2.19$, $p = .038$. Finally, at the 75% SOA, in trials with regular effect compatible flankers participants responded significantly slower than trials with neutral flankers, $t(26) = 2.30$, $p = .029$. All other differences were not significant. Thus, the single t-tests indicate that at short SOAs there was first facilitation for trials with regular effect flankers compared to neutral or effect incompatible flankers. With longer SOAs, trials with the alternate effect flankers were facilitated, but not the trials with the regular effect flankers. Finally, at the longest SOA, the facilitation effect was reversed; effect compatible trials were related to longer RTs than neural trials.

The error analysis showed that the amount of errors was not related to flanker types. There were 8.7 % of erroneous responses with the alternate effect-compatible flankers and 9.52 % with the regular effect-compatible flankers (including outliers). Error rates for neutral and the two types of effect-incompatible flankers were between these extreme. The differences were not significant, $F(4, 104) = .24$, $p = .915$.

Discussion

Experiment 2 supports the data of the first experiment. Effect information presented by flanking letters after target presentation affected the response times. The effect on response times depended on the SOA. Both types of effect-compatible flankers facilitated the RTs when presented shortly after the target compared to neutral or effect-incompatible flankers. Those facilitation effects were observed for SOAs between about 0 and 400 ms. Interestingly, Experiment 2 showed a differentiation between the two effect-compatible flanker types confirming a similar trend in Experiment 1. Regular effect flankers led to a maximal facilitation of responses when presented at about 0 - 200 ms (25 % of mean RT) after the targets, alternate effect flankers had their strongest impact when presented at about 400 ms (50 % of mean RT) after the target. The earlier facilitation effect of the regular effect flankers as compared to the alternate flankers is probably due to an additional stimulus-stimulus effect. The regular effects were presented following the correct responses to the target all through the experiment. Therefore, the codes of the response effect are not only activated by anticipating the effect from the selected response. In addition, the presentation of the target might directly activate the representation of the regular effect. This could have facilitated the processing of the regular effect flankers. Compared to that, the activation of representations of the alternate effect can only result from response selection and develop with response preparation. As a consequence, representations of alternate effects might be activated later than representations of regular effects.

Another interesting result is the fact that flanker effects did not only disappear, as in Experiment 1, but reversed at the longest SOA. Again we can only speculate why effect compatible flankers after long SOAs could have led to longer response times than neutral or incompatible flankers. We assume that for these long SOAs the preparation of the responses is almost complete. The response effects are already anticipated and the activation of the response-effect codes cannot be supported anymore by external stimulation. Instead the appearance of the effect in the environment might indicate the successful execution of the response. This could probably cause response inhibition. Further experiments are necessary to test this assumption.

Experiment 3

The experiments so far suggest that the onset of the effect stimuli relative to the targets seems to be important. However, in both experiments the flankers once presented remained on the screen up to the response. Therefore we still do not know at which point in time the assumed interference between stimulus-induced and response-induced activation of effect codes might occur. To investigate this further, in Experiment 3 we limited the time over which the effect stimuli were available for visual processing by masking the flankers after 140 ms. We expected stronger flanker effects if the visual processing of the flanker stimuli would take place at the same time than the anticipation of the response effects in course of response preparation.

Method

Participants

Thirty students of different departments of Humboldt University Berlin and of different secondary schools in Berlin (Germany) took part in the experiment. They received either course credits or were paid for their participation. Two of the participants were excluded because they reported in the post-experimental interview to have noticed during the experiment that they had participated in an earlier pilot version of the experiment.

Stimuli and Apparatus

Target and effect letters and their presentation conditions corresponded to Experiment 1 (see Fig. 1). Stimulus presentation and response recording were controlled by a Rhotron VME system with an Atari high-resolution monochrome monitor (Atari SM 124) with a refresh rate of 71 Hz. Responses were key presses with the index and middle fingers of each hand. The two keys for each hand were mounted on a special response panel and were separated by 17 cm.

Design and Procedure

The acquisition phase was basically identical with the previous experiments. There were only some minor differences. The warning signal in each trial was not the "+" sign but an exclamation mark. The warning signal was presented for 500 ms. The target stimulus followed after a random time interval of 800 to 1200 ms. Immediately after the correct response the effect letter was presented. The effect letter remained on the screen for 500 ms. Participants performed 8 blocks of trials in the acquisition phase. Each block consisted of 64 trials presenting each of the 8 stimuli 8 times. Thus, the acquisition phase included 64 more trials than the first two experiments.

The test phase corresponded to Experiment 1, i.e. flanking letters were either presented before or after the target in a within-participants design. Flanker types were the same as in the first two experiments. Neutral letters were *D* and *Z*. The time delay (SOA) between targets and flankers was varied with SOAs of -280 ms, -140 ms, 0 ms, 140 ms and 280 ms. Negative SOAs indicate that the flankers were presented before the target and positive SOAs that the flankers were presented after the target. Each single trial corresponded to the trial procedure described for the first experiment. Presentation times for the warning signal and the effects followed the same timing used in the acquisition phase.

The presentation time of the flankers was limited to 140 ms. After 140 ms the flankers were masked by overwriting them with a pattern mask. The mask was generated by superimposing randomly selected items from the set of the five special characters §, $, &, %, and /. The pattern mask remained on the screen until participants´ response.

The test phase consisted of 9 blocks with 64 trials each. All combinations of targets, flanker types, and SOAs were presented in random order. The five types of flankers appeared with equal probability. The whole experiment lasted about 75 minutes.

Results

Erroneous responses and responses with RTs longer than 2000 ms were excluded from the analysis. In total, 2.7% of the data were discarded. No participant had to be excluded related to the error criterion. The data from the first block of the test phase did not enter the analysis because they were presumably confounded by factors that were related to becoming familiar with and adjusting to the changed task situation after flanker stimuli were introduced. The mean RTs for the five flanker types and the five SOAs are shown in Table 2. An ANOVA with the within-subject factors flanker type and SOA only revealed a significant effect of SOA, $F(2.5, 68.6) = 50.14$, $p < .001$. The main effect of flanker type was not significant, $F(3.0, 82.0) = 1.16$, $p = .33$. Also the interaction between flanker type and SOA did not reach significance, $F(8.6, 232.4) = 1.39$, $p = .143$. However, planned comparisons using pairwise t-tests indicated that at the -280 ms SOA in trials with neutral flankers RTs were significantly longer than in trials with regular effect flankers, $t(27) = 3.10$, $p < .005$, trials with effect compatible/ same hand flankers, $t(27) = 4.07$, $p < .001$ and trials with effect incompatible/ different hand flankers, $t(27) = 3.47$, $p = .002$. The difference between trials with neutral and alternate effect compatible flankers was marginally significant, $t(27) = 1.90$, $p = .068$. At the -140 ms SOA, the 0 ms SOA and the 140 ms SOA there was not any significant difference between flanker types. But at the 280 ms SOA trials with both types of effect flankers yielded shorter RTs than trials with neural flankers, $t(27) = 2.15$, $p = .04$ for the regular effect flankers and $t(27) = 3.16$, $p = .004$ for the alternate effect flankers. Moreover, RTs in trials with alternate effect flankers RTs were significantly shorter than in trials with effect incompatible flankers/ same hand, $t(27) = 2.14$, $p = .042$. All other differences between flanker types were not significant. Thus, whereas at the longest negative

SOA responses in trials with effect compatible and effect incompatible flankers were faster than in neural trials, at the longest SOA a differentiation between compatible and incompatible trials was observed. Numerically both types of effect compatible flankers were associated with shorter RTs compared to both types of effect incompatible flankers. Figure 5 illustrates the differences between trials with effect compatible and incompatible flankers depending on SOA.

Figure 5

The error analysis did not reveal any significant differences between flanker types, $F(4, 108) = .384$, $p = .82$.

Discussion

In general the results of the present experiment confirm the main results of Experiment 1. The effect compatibility of the flankers did not affect the responses to the targets if the flankers were presented before target onset. It seems that participants cannot make use of the information about the particular effect as long as the response has not been determined by the stimulus. If information about the effects was provided after target onset, it facilitated the responses to the targets compared to wrong or neutral information. Moreover, as in the first experiments, there was only a benefit of effect-compatible flankers but no cost of incompatible flankers compared to neutral flankers. RTs under the effect-incompatible condition were almost identical to RTs under the neutral condition.

However, the limitation of the flanker presentation to 140 ms also caused some changes of the results compared to the very similar first experiment. The first change emerged at negative SOAs. Whereas flanker types did not affect RTs in Experiment 1 if flankers were presented before the target, both effect-incompatible and effect-compatible flankers resulted in shorter RTs than neutral flankers in Experiment 3. This is difficult to explain. It might be that the shortly presented neutral flankers as new stimuli interfered more with the identification of the targets than the more familiar effect-related flankers. Probably this was not found in Experiment 1 because the simultaneous presence of target and flankers over the full period between target onset and response caused always a higher interference between flanker and target processing, also if flankers were presented before targets. Nevertheless, and most importantly, effect-compatible and effect-incompatible flankers did not affect the responses to the targets differently at this stage. The second change between the results of both experiments emerged with positive SOAs. In Experiment 1 we found that effect-compatible flankers presented simultaneously with the target led to the shortest RTs and that this facilitation effect decreased with longer SOAs. Experiment 3 shows another pattern; numerically effect-compatible flankers led to the longest RTs at the 0 ms SOA. Only at the longest SOA of 280 ms a facilitation of responses to targets with effect-compatible flankers was observed. Thus, compared to the previous experiments it seems that the limited availability of the flanker stimuli led to weaker flanker effects that occurred later in the course of response preparation. We assume that facilitation of responses by effect compatible flankers takes place if the internal activation of effect codes by effect anticipation coincides with the activation of the same effect codes by external stimulation. If this assumption is correct, then the data suggest that effect codes are only activated after response selection. In case of our experiment it might take about 200 ms before the effect codes become active. We will discuss this later in more detail. But before doing that we want to show with a last experiment that the flanker effects described in the above three experiments are specific effects of their compatibility or incompatibility with the response effects rather than unspecific effects of the paradigm.

Experiment 4

Basically Experiment 4 was a replication of Experiment 3 with only one exception: In the test phase the flankers were taken from the set of targets and selected corresponding to their relationship to the responses rather than the effects. As in the original paradigm introduced by Eriksen and Eriksen (1974), flankers were neutral, response compatible, or response incompatible, but unrelated to the response effects. In contrast to effect-related flankers, the response-compatible or incompatible flankers should always activate their corresponding responses independently of their presentation time. Participants are always waiting for one of these stimuli throughout the experiment and are prepared respond as fast as possible. In case of response-compatible flankers, flankers and target would activate the same response, in case of response-incompatible flankers, different responses. Thus, we should expect that independently on the presentation of the flankers before or after the target response-compatible flankers facilitate the response whereas response-incompatible flankers inhibit the response.

Method

Participants

Thirty students of different departments of Humboldt-University Berlin and of different secondary schools in Berlin took part in the experiment. They received either course credits or were paid for their participation. None of them had participated in the preceding experiments.

Stimuli and Apparatus

Stimuli and apparatus were in all details identical to Experiment 3.

Design and Procedure

The acquisition phase was conducted as described for Experiment 3, i.e. participants responded to the 8 target letters with the 4 four key-pressing responses and were presented with the effect letters after each correct response. This was followed by a test phase in which the effects were still present but not used as flankers. Instead, flankers were selected from the set of target letters. Additionally, *D* and *Z* were used as neutral flankers. Both characters were not presented in the acquisition phase and thus were not related to one of the targets, responses, or effects. Thus, except the flankers, Experiment 3 and 4 were absolutely identical.

Three flanker types were distinguished (Tab. 3, see also Figure 1).

Insert Table 3 about here

In neutral trials, the target was flanked by new characters (*D* or *Z)*. In response-compatible trials, the flankers required the same response as the target. For example, if the target was *W*, response-compatible flankers could be *W* or *S*. For response-incompatible trials a letter requiring another response was used as flankers (e.g. *FWF*). Response-incompatible flankers could require a response with the same or with the other hand with the same frequency. Numbers of trials and blocks corresponded to Experiment 3.

Results

The data were analyzed as in Experiment 3. Again, the data from the first block of the test phase did not enter the analysis. RTs longer than 2000 ms were considered as outliers and counted as errors. Participants had an overall error rate of 2.9 % including wrong responses and responses that extended the 2000 ms threshold. Individual means were computed for each condition defined by flanker type, and SOA. Table 2 presents the average RTs and error numbers for responses to targets flanked by neutral, response-compatible, and response-incompatible flankers dependent upon SOA.

The ANOVA with the within-subjects factors flanker type (neutral, effect-compatible, effect-incompatible) and SOA (-280 ms, -140 ms, 0 ms, 140 ms, 280 ms) yielded two reliable effects: a main effect of flanker condition, $F(2, 58) = 20.57$, $p < .001$, indicating that on average response-compatible flankers facilitated responding (751 ms) compared to neutral (777 ms) and response-incompatible flankers (777 ms). The second reliable effect was a main effect of SOA, $F(4, 116) = 62.26$, $p < .001$. Responses were performed faster if the flankers were presented in advance of target onset than with or after target onset. Most importantly, both factors did not interact, $F(8, 232) = 1.85$, $p = .068$. Separate ANOVAs for negative and positive SOAs confirmed that response-compatible flankers facilitated responding relative to response-incompatible flankers independently of SOA. When the flankers were presented before the target, there was a significant effect of flanker type, $F(2, 58) = 3.681$, $p = .031$, but no interaction between flanker type and SOA, $F(2, 58) = 2.38$, $p < .102$ [1]. When the flankers were presented simultaneously with or after the target, again a significant flanker-type effect, $F(2, 58) = 18.99$, $p < .001$, and no interaction between flanker type and SOA was found, $F < 1$. Thus, response-compatible flankers facilitated responding compared to response-incompatible flankers under all presentation conditions (Figure 6) and not only if flankers were presented after the target as it was found in Experiment 3 for effect-compatible flankers.

Figure 6 about here

An ANOVA over the relative error frequencies for the three flanker types did not find any significant effect, $F(2, 58) = .974$, $p = .384$.

Finally, we compared Experiment 3 and Experiment 4 in order to test more directly whether or not the effects of response-related flankers were different from the effects of effect-related flankers (compare Figures 5 and 6). To this end, RTs were analysed with a mixed-factors ANOVA including Flanker Relatedness (effect related vs. response related) as a between-subjects factor and SOA (-280, -140, 0, 140, 280 ms) and compatibility (compatible, neutral, incompatible) as within-subjects factors. For Experiment 3, data for the two effect-compatible and the two effect-incompatible flanker types were pooled so that the experiments became comparable. The analysis indicated that the main effect of compatibility was significant over both experiments, $F(1.78, 99.53) = 15.84$, $p < .001$. Averaged over both experiments, for trials with compatible flankers the mean RT was 748 ms whereas for trials with neutral flankers 766 ms and for trials with incompatible flankers 762 ms were found. However, the general compatibility effect was modulated by Flanker Relatedness, $F(1.78, 99.53) = 6.87$, $p = .002$, and by flanker relatedness and SOA, $F(6.79, 380.49) = 2.71$, $p = .001$. The two- and three-way interactions confirm the statistical significance of the difference between both experiments: If the flankers were response related, a facilitation of responses in compatible trials was found over the full range of the SOAs, but if the flankers were effect related only for the long positive SOA this facilitation was observed. Apart from that, also the main effect of SOA was significant, $F(2.84, 159.25) = 104.20$, $p < .001$. For the negative SOAs, RTs decreased the earlier the flankers were presented in advance of the target. The SOA effect did not depend on Flanker Relatedness, $F < 1$ for the interaction between SOA and Flanker Relatedness. The two-way interaction between SOA and compatibility was significant, $F(6.79, 380.49) = 1.972$, $p = .048$, but as the tree-way interaction already indicated, this interaction depended on Flanker Relatedness. The main effect of Flanker Relatedness was not significant, $F < 1$, indicating that average RTs did not differ between both experiments.

Discussion

The main reason for conducting Experiment 4 was to explore whether the functional signature of effect-related compatibility effects is actually different from that of response-related compatibility effects of irrelevant flanker stimuli. This investigation was necessary to exclude that the flanker effects observed in the first three experiments would just be an artifact of the method.

The comparison of Experiments 3 and 4 clearly shows that there is a difference between effect-related flankers and response-related flankers. In Experiment 3 it has been shown that effect-compatible flankers had an impact on response preparation only when the effect-related information was provided after presenting the action-demanding target. Effect-related flankers presented before the target or in close temporal vicinity to the target did not affect response preparation. This means that the information available from the effect-compatible flankers became effective only after information concerning the to-be-executed response was available. By contrast, facilitation effects of response-compatible flankers were obtained if the flankers were presented before, together with or after the target. In this case flankers and targets activate their respective responses independently on the presentation of the flankers before or after the responses. Altogether, the observations emerging from the present and the preceding experiment lead us to conclude that the information available from response-related and effect-related flanker stimuli affects the responses to the targets in a different way, i.e. effects of effect-related flankers are functionally different from effects of response-related flankers.

General Discussion

With the present series of experiments we wanted to investigate how effect codes are integrated in the planning and execution of motor responses. In Experiments 1 and 3, information about the response effects was presented before, simultaneously with, or after the onset of the target. The results of both experiments clearly indicated that advance information about the to-be-produced effects had little or no effect on response times. It seems that in none of the two experiments effect-related information presented before the target could be used to activate or prime the response. This outcome is clearly not compatible with a “strong” version of the ideo-motor theory that states that the effect anticipation is mandatory for response selection and the one and only way of how actions can be voluntarily selected (Hommel et al., 2001, Kunde, 2003, Kunde et al., 2004). Instead, Experiments 1, 2 and 3 suggest that effect-related information plays a role in later phases of response planning: Activated representations of the effects used in our experiments are not the prerequisite for response selection, but effect representations are activated in course of response planning depending on the selected response. This assumption is in line with the idea that response effects are anticipated related to the prepared motor program to enable an internal test of the program in advance of its execution and to monitor the execution of the program. Consequently, anticipation of the effects does not precede but follows the selection of a motor program. It seems that information about effects as provided by the flankers can only be build in the process of response planning if at least a preliminary stage of the program is available. It should be a stage at which the cognitive system starts to anticipate the effects that can be achieved with the motor program that is under preparation. Activation of the same effect codes by external stimulation can facilitate this process resulting in faster responses.

In particular, Experiment 3 with a limited presentation time of the effect-related flankers indicated that the point in time at which the effects are involved in response planning is rather late. Only for the longest SOA of 280 ms a facilitation of the responses by effect compatible flankers was found. This seems to be in conflict with the very similar Experiment 1 where strongest flanker effects were observed for the 0 ms SOA. Flankers remained on the screen until response onset in Experiment 1 but were only presented for 140 ms in Experiment 3. We assume that the facilitation of responses takes place if effect codes are activated not only by internal processes through the anticipation of effects depending on the selected motor response, but also by external stimulation. It seems that the facilitation effect is strongest if both processes occur at the same time. In Experiment 1 visual processing of the flankers starts with their presentation and can go on until the response is executed. Thus, flankers presented together with the target can have their impact at any time during the RT period. In Experiment 3 visual processing can only take place during the limited presentation time. If this is correct, Experiment 3 provides the most reliable estimation at which point in time the anticipation of effect codes is involved in response planning under the given experimental conditions. This seems to occur at about 200 to 300 ms after target onset.

Interestingly, in Experiments 1 to 3 no difference between neutral and effect-incompatible flankers was found. Only the effect-compatible flankers facilitated the responses when presented with or shortly after the targets. In the framework of the ideomotor principle we should expect benefits for effect-compatible and costs for effect-incompatible flankers. Both flanker types should activate the responses producing these effects. In case of effect-compatible flankers that would be the correct response. In case of effect-incompatible flankers that would be an incorrect response. Thus, the missing costs for effect-incompatible flankers are evidence against the idea that the activation of effect codes would select the response. However, it should be noted that the results for the neutral flankers have to be considered with caution. Neutral flankers were new stimuli in all experiments. That could result in a relative increase of response times compared to the effect-compatible and effect-incompatible conditions. Also in Experiment 4, no RT differences between trials with response-incompatible and neutral flankers were found. Usually, incompatible flankers inhibit the response compared to neutral flankers (e.g. Eriksen & Eriksen, 1974). Consequently, we cannot be sure if there is really only facilitation with effect-compatible flankers and no effect with effect-incompatible flankers. Therefore, our argumentation is mainly build on the differences between compatible and incompatible flankers as illustrated by Figures 2, 3, 4 and 6.

Taken together, the results of the present experiments support the assumptions of a model that we proposed earlier (Ziessler et al., 2004). In this model we suggest to make a distinction between the desired effects and the anticipated effects. Depending on the environmental situation and the internal state, goals are set for the behavior.

The goals are the desired effects of the to-be-planned behavior. Then the motor program is selected that is likely to achieve these goals. Based on the selected program, the cognitive system anticipates the effects that the program execution should cause in the environment. The first process has been described in terms of inverse models the second in terms of forward models (e.g., Frith, Blackmore, & Wolpert, 2000; Jordan, 1996; Wolpert, Miall, & Kawato, 1998). If the effects are anticipated, they can be compared with the desired effects. This allows for an internal test of the selected program. Differences between desired and anticipated effects cause modifications of the motor program. However, if the anticipated effects are in correspondence with the desired effects, the selected motor program receives additional activation that facilitates its execution. Thus, the interaction between the inverse and the forward model provides a circuit that is important for internal testing of the planned behavior and to initiate the execution. Critical for the system is the learning of action effects. We assume that the system learns to anticipate the effects that will be produced by a prepared motor program. The learning is driven by the comparison between anticipated effects and the actual effects. Differences result in an adjustment of effect anticipation. As the model describes it, response-effect learning is embedded in response planning. Earlier experiments (Ziessler & Nattkemper, 2002, Ziessler et al., 2004) provided evidence supporting this assumption. With a very different paradigm, Kühn, Elsner, Prinz and Brass (2009) confirmed our assumption of response-effect learning as occurring in response planning by demonstrating action-effect binding between the anticipated effect of no response and the response plan to do nothing.

The present experiments prove another aspect of the proposed model: Effect anticipation is a component of response planning which is based on the already selected motor program. These anticipated effects are not used to select the motor program.

The discussion leaves us with the question of the validity of the ideomotor principle. At least for our experimental conditions the ideomotor principle does not seem to apply. In our experiments the actions were reactions to external stimuli and not actions to achieve internally generated goals. Under these conditions we could not find any evidence for response selection by activation of effect codes. Related to that, Herwig, Prinz and Waszak (2007) distinguished between stimulus-based and intention-based actions. They assumed that depending on the type of action the participants would be in a different mode of sensorimotor integration. If participants were in the reaction mode they would integrate the external stimuli with the required actions, but they would not learn action effects. In contrast, the intention mode would lead to a binding between the actions and their effects. Only then participants would actually learn effects and would be able to use them in turn for response selection. Indeed, the experiments performed by Herwig et al. (2007) supported these assumptions. Keller, Wascher, Prinz, Waszak, Koch and Rosenbaum (2006) provided electrophysiological evidence for a similar distinction between stimulus-based and intention-based actions. Stimulus-locked ERPs provided evidence for stimulus-response binding if participants were in the reaction mode and response-locked ERPs provided evidence for response-effect binding if participants were in the intention mode.

Thus, it might be related to this distinction that in our experiments no evidence for response selection by activation of effect codes was found. Participants reacted to the targets and did not intend to produce the effects. Nevertheless, in our experiments participants obviously learned which effects will be produced by their responses. Only then effect-compatible and effect-incompatible flankers could cause different effects on response times. Therefore, we do not agree that the intention mode is necessary for effect learning. What seems necessary is that participants expect something to happen after their response. What they learn and how fast they learn depends on how specific this expectation is (Ziessler & Nattkemper, 2004). If and how response effects are used after learning seems to be another question.

Paelecke and Kunde (2007) investigated the use of effect codes in response control with a PRP-paradigm (Pashler, 1984, 1994; Logan & Gordon, 2001). PRP paradigms are often used to locate a particular stage of information processing relative to the stage of response selection. The PRP paradigm is based on the assumption that response selection can only be carried out for one response at a given moment time, whereas processes before or after response selection could run in parallel, i.e. response selection constitutes a bottleneck in information processing (Pashler, 1984). In Paelecke and Kunde's (2007) experiments participants had to do two choice reaction tasks in sequence. Stimuli for both tasks were presented with SOAs of 50 to 1500 ms. Following the logic of the paradigm, at short SOAs response selection for the first task would withhold response selection for the second task. However, processes of the second task that occur before response selection can be completed. Consequently, differences between two conditions in the second task should disappear at short SOAs if the differences were due to processes before response selection. At long SOAs differences between the two conditions should not be affected by the first task. In contrast, if the differences were due to processes included in or after response selection the differences should not be affected by the length of the SOA. The critical variation in Paelecke and Kunde's experiments consisted in the response-effect compatibility in the second task. In their Experiments 1 and 2, there was a dimensional overlap between features of the responses and features of the effects. In the compatible case responses and effects shared the same features; in the incompatible case features had the opposite value. Effect-compatible responses could be performed more quickly than effect-incompatible responses. This compatibility effect did not depend on SOA. Another version of effect compatibility was created by introducing a dimensional feature overlap between a feature of the imperative stimulus and a feature of the response effect (Experiment 4). This time there was no compatibility effect at short SOAs, but only at long SOAs. Based on these results, Paelecke and Kunde made a difference between effect codes activated through effect anticipation (endogenously activated) and effect codes activated by external stimuli (exogenously activated). Their results suggest that endogenously activated effect codes affect the responses within or after the response bottleneck whereas exogenously activated effect codes had their impact before the stage of response selection. Thus, for endogenously activated effect codes (or if the cognitive system is in intention-based mode) it seems likely that effect codes affect response selection. However, if the effect codes are exogenously activated, as by the flankers in our experiments, their impact on response times is not due to response selection. Paelecke and Kunde assume that exogenous effect code activation would lead to response activation before response selection. This is contradictory to our interpretation of the present results which allocates the effect of exogenously activated response effects in later stages of response preparation after response selection. From our point of view, the results of the present experiments question Paelecke and Kunde's interpretation. There are at least two other explanations for their results. First, as the authors discuss themselves in the paper (p. 642), the presentation of the response effect together with the imperative stimulus (exogenous effect activation) could facilitate the processing of the imperative stimulus using the fixed stimulus-effect relationship. That means, activation of the effect codes would affect stimulus processing that occurs prior to response selection. Second, with the short intervals the stimuli for Task 1 and 2 were presented before the first response, whereas with the long interval the response to Task 1 was already executed before the second stimulus was presented. Because at long SOAs the first response was already executed when the second stimulus was presented, the processing of the second stimulus led directly to response selection for the second task. Thus, the stimulus-induced activation of effect codes could directly support the preparation of the response resulting in shorter RTs for effect compatible and longer RTs for effect incompatible conditions. This was not possible at short SOAs. Following the logic of the PRP paradigm, participants had to withhold the selection of the second response until the selection of the first response was completed. Possible activation of effect codes by the external stimulus might have decayed over time until response selection could start. Consequently, at short SOAs, RTs were not affected by effect compatibility.

In conclusion, in our view it is very important to make the distinction between desired effects and anticipated effects. Without this distinction the term “effect anticipation” is misleading because it might refer to two different things, the anticipation of effects in terms of desired effects (i.e. the endogenous activation of effect codes) and the anticipation of effects depending on a selected motor program. Under intention-based conditions both is necessary. Probably the ideomotor principle has its justification under those conditions. It is then the activation of effect codes for desired effects that leads to the selection of appropriate actions and the activation of codes for anticipated effects that allow the internal testing and monitoring of the execution of the selected response. However, if we just react to external stimuli we anticipate the learned effects depending on the motor program determined by the external stimulus and use them for internal testing of the selected program and monitoring of response execution.

References

Adams, J.A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3,* 111-149.

Bertelson, P. & Boons, J.P. (1960). Time uncertainty and choice reaction time. *Nature, 187,* 531-532.

Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of Experimental-Psychology: Human Perception and Performance, 27*, 229-240.

Eriksen, B.A., & Eriksen, C.W. (1974). Effects of noise letters on the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16 (1),* 143-149.

Frith, C.-D., Blakemore, S.J., & Wolpert, D. M. (2000). Explaining the symptoms of schizophrenia: Abnormalities in the awareness of action. *Brain Research Reviews, 31*, 357-363.

Harleß, E. (1861). Der Apparat des Willens [The apparatus of will]. *Zeitschrift für Philosophie und philosophische Kritik, 38*, 50 – 73.

Herbart, J.F. (1824). *Psychologie als Wissenschaft neugegründet auf Erfahrung, Metaphysik und Mathematik.* Erster, synthetischer Teil [Psychology as a science newly based on experience, metaphysics, and mathematics]. Königsberg, Germany: August Wilhelm Unzer.

Herwig, A., Prinz, W., & Waszak, F. (2007). 'Two modes of sensorimotor integration in intention-based and stimulus-based actions', *The Quarterly Journal of Experimental Psychology, 60,11*, 1540 – 1554.

Hommel, B. (1993). Inverting the Simon effect by intention. *Psychological Research, 55*, 270 – 279.

Hommel, B. (1996). The cognitive representation of action: Automatic integration of perceived action effects. *Psychological Research, 59*, 176 – 186.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849-937.

James, W. (1890). *The principles of psychology*. New York: Holt.

Jordan, M.I. (1996). Computational aspects of motor control and motor learning. In H. Heuer & S.W. Keele (Eds.). *Handbook of perception and action, Vol. 2: Motor skills*. (pp. 71-120). San Diego, CA, US: Academic Press.

Keller, P., Wascher, E., Prinz, W., Waszak, F., Koch, I., & Rosenbaum, D. (2006). Differences between intention-based and stimulus-based actions. *Journal of Psychophysiology, 20*, 9–20.Koch, I. & Kunde, W. (2002). Verbal response-effect compatibility. *Memory & Cognition,* 30, 1297-1303

Kühn, S., Elsner, B., Prinz, W. & Brass, M. (2009). Busy doing nothing: Evidence for nonaction-effect binding. *Psychonomic Bulletin and Review, 16*, 542-549.

Kunde, W. (2001). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 387-394.

Kunde, W. (2003). Temporal response-effect compatibility. *Psychological Research,* 67, 153-159

Kunde, W., Hoffmann, J., & Zellmann, P. (2002). The impact of anticipated action effects on action planning. *Acta Psychologica, 109*, 137-155.

Kunde, W., Koch, I. & Hoffmann, J. (2004). Anticipated action effects affect the selection, initiation and execution of actions. *Quarterly Journal of Experimental Psychology, 57A*, 87-106.

Logan, G. D., & Gordon, R. D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review, 108,* 393–434.

Lotze, R.H. (1852*). Medicinische Psychologie oder die Physiologie der Seele* [Medical psychology or the physiology of the soul]. Leipzig: Weidmann´sche Buchhandlung.

Mattes, S. & Ulrich, R. (1997). Response force is sensitive to the temporal uncertainty of response stimuli. *Perception and Psychophysics, 59,* 1089-1097.

Münsterberg, H. (1888). *Die Willenshandlung. Ein Beitrag zur physiologischen Psychologie* [The intended act. A contribution to physiological psychology]. Freiburg: Mohr.

Paelecke, M. & Kunde, W. (2007). Action-effect codes in and before the central bottleneck: Evidence from the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 33, 3,* 627–644

Pashler, H. (1984). Processing stages in overlapping tasks: Evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 358–377.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116,* 220–244.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, *9,* 129 – 154.

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82,* 225 – 260.

Schmidt, R.A. (1988). *Motor control and learning: A behavioral emphasis* (2nd edition). Champaign, IL: Human Kinetics.

Wolpert, D.M., Miall, R.Ch., & Kawato, M. (1998). Internal models in the cerebellum. *Trends in Cognitive Science, 2,* 338-347.

Ziessler, M., & Nattkemper, D. (2002). Effect anticipation in action planning. In W. Prinz & B. Hommel (Eds.), *Common Mechanisms in Perception and Action. Attention and Performance XIX*. Oxford: University Press.

Ziessler, M., Nattkemper, D. & Frensch, P.A. (2004). The role of anticipation and intention for the learning of effects of self-performed actions. *Psychological Research, 68,* 163-175.

Table 1: Overview of the flanker types applied in Experiment 1. The examples are related to target *W*.

Flanker type	**Example**
Neutral	DWD ZWZ
Effect compatible (regular) Effect compatible (alternate)	YWY CWC
Effect incompatible (same hand) Effect incompatible (other hand)	RWR MWM

Table 2: Reaction times and error rates in Experiments 1-4. Reaction times are reported in ms, error rates are reported in percentages. Error rates were summarized over the 5 SOAs.

	Flanker type				
SOA	neutral	effect compatible (regular)	effect compatible (alternate)	effect incompatible (same hand)	effect incompatible (different hand)
Experiment 1					
-300 ms	728	713	736	706	719
-150 ms	745	769	746	728	755
0 ms	828	784	780	828	808
150 ms	823	814	775	831	827
300 ms	797	809	832	814	836
Error	6.1%	6.7%	6.1%	6.7%	5.8%
Experiment 2					
0%	889	856	889	915	872
25%	849	810	863	858	854
50%	857	841	809	845	840
75%	854	891	865	860	850
Error	9.3%	9.5%	8.8%	9.5%	9.5%
Experiment 3					
-280 ms	714	686	686	682	681
-140 ms	725	712	711	707	707
0 ms	766	786	785	776	771
140 ms	775	773	776	776	786
280 ms	799	774	759	797	779
Error	2.7%	2.9%	2.9%	2.6%	2.5%
Experiment 4					
	neutral	response compatible		response incompatible	
-280 ms	724	699		714	
-140 ms	729	730		752	
0 ms	795	757		802	
140 ms	823	788		808	
280 ms	815	788		808	
Error	2.6 %	3.1%		2.8%	

Table 3. Overview of the flanker types applied in Experiment 4. The examples are related to target *W*. Response compatibility was estimated by comparing the response-compatible and response-incompatible conditions with the neutral condition. These conditions were all neutral with respect to effect compatibility.

Flanker type	**Example**
Neutral	DWD ZWZ
Response compatible	WWW SWS
Response incompatible	FWF HWH

Figure Captions

Figure 1. The mapping of targets, responses, and response effects in Experiments 1 and 3. *LM* – left middle finger, *LI* – left index finger, *RI* – right index finger, *RM* – right middle finger.

Figure 2. Mean RT differences between trials with effect-compatible and effect-incompatible flankers depending on SOA in Experiment 1. RTs in trials with regular and alternate effect-compatible flankers are compared to the mean RT in trials with the two effect-incompatible flankers (averaged over same- and different-hand incompatible effects). Negative differences indicate a facilitation of the responses in effect compatible trials.

Figure 3. The mapping of targets, responses, and response effects in Experiments 2 and 4. *LM* – left middle finger, *LI* – left index finger, *RI* – right index finger, *RM* – right middle finger.

Figure 4. Mean RT differences between trials with effect-compatible and effect-incompatible flankers depending on SOA in Experiment 2. The differences are shown for trials with regular and alternate effect flankers in relation to the mean RT in trials in with both types of incompatible effect flankers (averaged over same- and different-hand incompatible effects). SOA is scaled in percentage of the mean RT. Negative differences indicate a facilitation of responses in effect compatible trials.

Figure 5. Mean RT differences between trials with effect-compatible and effect-incompatible flankers depending on SOA in Experiment 3. RTs in trials with regular

and alternate effect-compatible flankers are compared to the mean RT in trials with the two effect-incompatible flankers (averaged over same- and different-hand incompatible effects). Negative differences indicate a facilitation of the responses in effect compatible trials.

Figure 6. Mean RT differences between trials with response compatible and response incompatible flankers. Negative differences indicate a facilitation of the responses in response compatible trials.

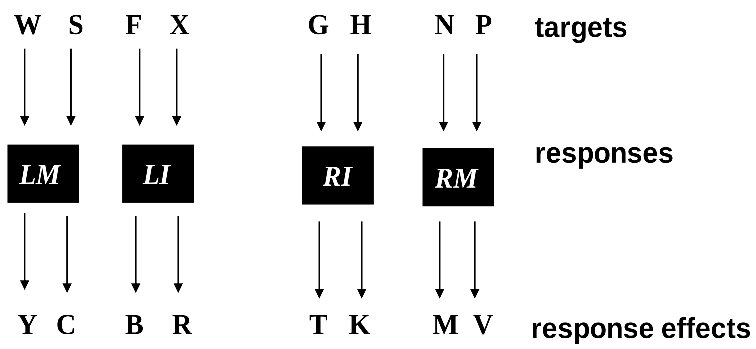
W S F X G H N P
targets
LM
LI
RI
RM
responses
Y C B R T K M V
response effects

Figure 1

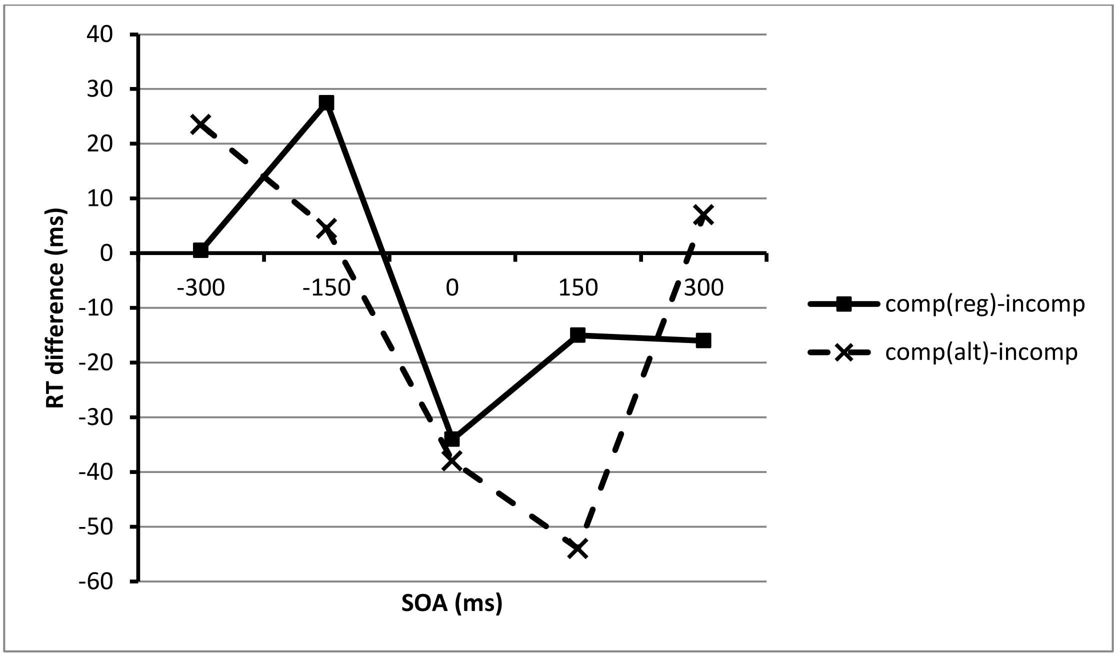
40
30
20
10
0
-10
-20
-30
-40
-50
-60
RT difference (ms)
-300
-150
0
150
300
SOA (ms)
comp(reg)-incomp
comp(alt)-incomp

Figure 2

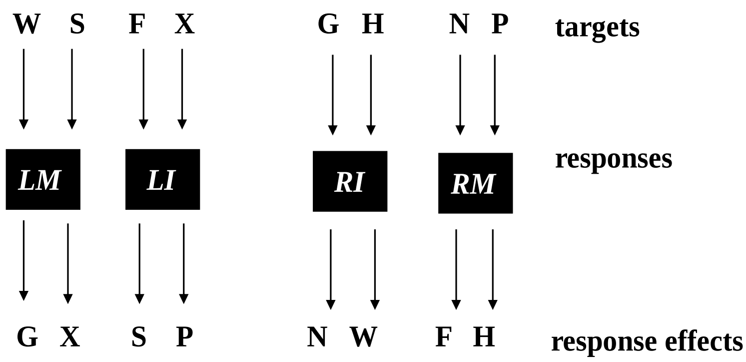
W S F X G H N P
targets
LM
LI
RI
RM
responses
G X S P N W F H
response effects

Figure 3

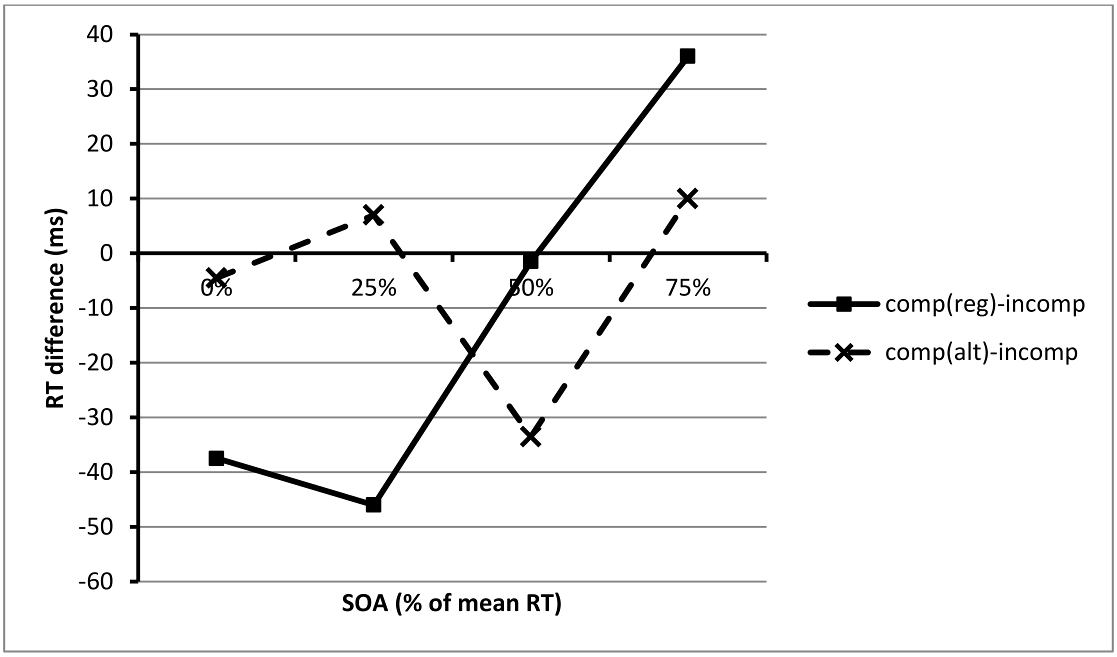
40
30
20
10
0
-10
-20
-30
-40
-50
-60
RT difference (ms)
0%
25%
50%
75%
SOA (% of mean RT)
comp(reg)-incomp
comp(alt)-incomp

Figure 4

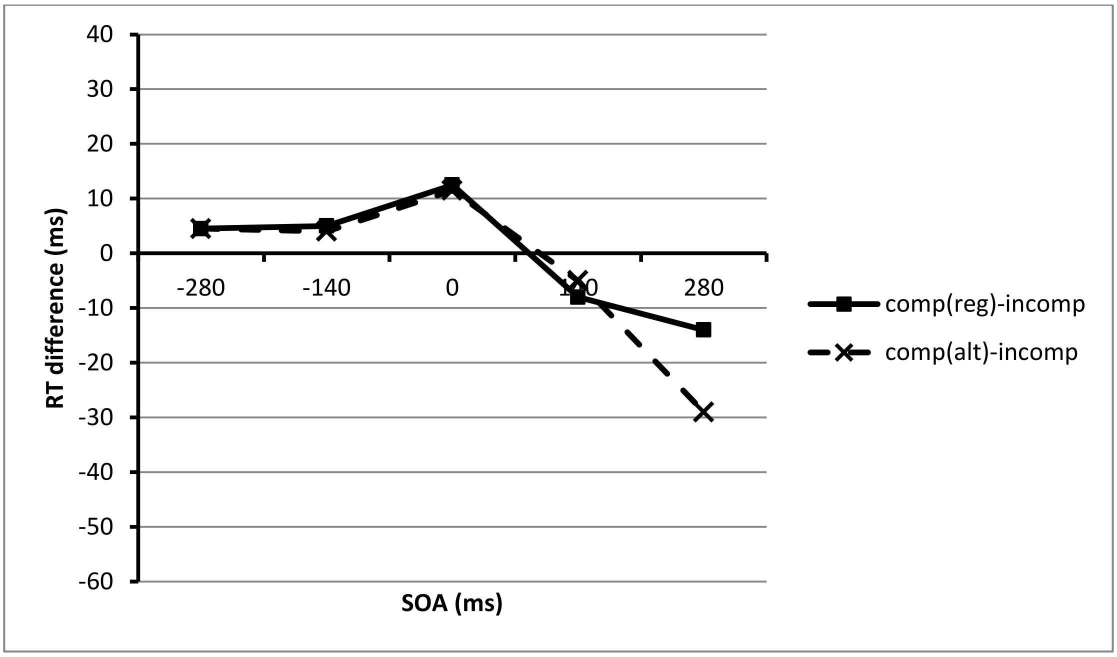
40
30
20
10
0
-10
-20
-30
-40
-50
-60
RT difference (ms)
-280
-140
0
140
280
SOA (ms)
comp(reg)-incomp
comp(alt)-incomp

Figure 5

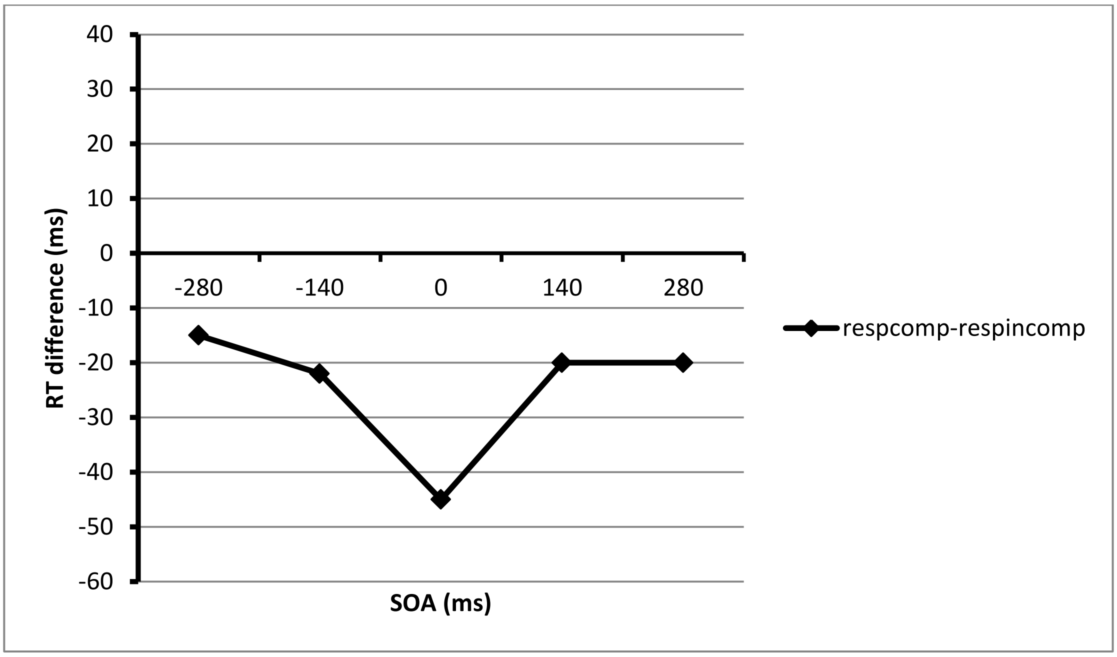
40
30
20
10
0
-10
-20
-30
-40
-50
-60
RT difference (ms)
-280
-140
0
140
280
SOA (ms)
respcomp-respincomp

Figure 6