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ORIGINAL ARTICLE

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Variable action effects: response control by context-specific effect anticipations

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Abstract The ideomotor principle (IMP) claims that bidirectional associations between actions and their contingent effects are acquired so that voluntary actions are accessed by the anticipation of intended effects. Until now, evidence for the IMP exists only for stable action-effect relations. The present paper explores whether the IMP also holds true for the initiation of actions for which no unconditional contingent action-effect relations exist. Participants responded with left and right key presses in two different contexts. They selected the responses according to the vertical (context A) or horizontal (context B) position of a target. Responses were followed by short/fast movements of the target in context A and comparatively long/slow movements in context B. Consequently, each response produced short and long effects equally often in both contexts. Nevertheless, RTs decreased in contexts with short effects and increased in contexts with long effects. Data confirm that action-effect associations were acquired context-specifically and that the same actions were accessed by different effect anticipations.

Introduction

One fundamental question within psychology is how the mind manages to select and initiate the appropriate behavioral acts to reach the various goals people are constantly striving for. More than 150 years ago a straightforward and plausible answer to this question was given by the ideomotor principle (IMP, cf. Herbart, 1825). The IMP states that actions inevitably become connected to their contingent sensorial effects. These associations between actions and their subsequent effects are assumed to be bidirectional. Consequently, performing an action not only leads to expectations of its sensorial effects, but vice versa, anticipating an effect also accesses the action that usually brings about this effect. If a person desires to reach a certain goal, this desire evokes the anticipation of the sensorial effects to be produced and the effect anticipation accesses the appropriate action. Thus, the IMP states that whenever a person performs a voluntary action, this action has been triggered by the anticipation of the intended effects.

The IMP was widely acknowledged at the end of the 19th century (Harleß, 1861; Herbart, 1825; James, 1890; Lotze, 1852; Münsterberg, 1889; Wundt, 1893), but soon fell into disrepute and oblivion with the upcoming theory of behaviorism (cf. Thorndike, 1913; for an historical overview see Stock and Stock (in press). Only recently, the IMP has once more attracted substantial theoretical and empirical interest (Greenwald, 1970; Hoffmann, 1993; Hoffmann, Sebald, & Stöcker, 2001; Hommel, 1996; Kunde, 2001; Prinz, 1997; Ziessler & Nattkemper, 2002).

Numerous recent studies provided experimental support for the IMP. Firstly, it has been shown that experiencing contingent action-effect relations does indeed lead to the acquisition of action-effect associations, irrespective of whether the effects are intended or not (Elsner & Hommel, 2001; Hoffmann et al., 2001; Hommel, 1996; Stock & Hoffmann, 2002; Stöcker, Sebald, & Hoffmann, 2003; Ziessler, 1998; Ziessler & Nattkemper, 2001, 2002). Secondly, there are studies indicating that the selection and initiation of responses is indeed preceded by an anticipation of their sensorial effects. It seems that anticipations of effects serve to select and initiate responses even if the responses are determined by an imperative stimulus (Kunde, 2001, 2003).

To illustrate the acquisition of action-effect associations, let us consider a recent study by Elsner and Hommel (2001). In the first part of the study, the

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acquisition phase, participants experienced contingent response-effect relations between left and right key presses and irrelevant low- and high-pitched tone-effects. In a subsequent test phase, participants were required to perform the same key presses, but in this phase the effect-tones were presented either as imperative stimuli or as free choice signals. Participants performed and selected more often the responses that had produced the presented effect-tone in the acquisition phase. Thus, data confirm the first statement of the IMP that bidirectional associations between actions and their contingent effects are established in the acquisition phase.

The second statement of the IMP, i.e., that effect anticipations do indeed precede and influence action initiation, was convincingly confirmed in a recent study by Kunde (2001). He investigated compatibility phenomena between responses and their subsequent effects in manual choice reaction tasks. Usually, compatibility phenomena are investigated in situations in which stimuli and responses overlap in at least one dimension, like location (Simon, 1969) or duration (Kunde & Stöcker, 2002). Typically, reaction times and error rates decrease when the stimuli and the responses are compatibly assigned sharing common features in the overlapping dimension (for theoretical accounts see Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990). Kunde (2001) brought forward the argument that comparable compatibility effects are to be expected between responses and their subsequent effects if these effects are indeed anticipated before response initiation. In agreement with this consideration he was able to show that compatibility between responses and their subsequent effects leads to faster and less erroneous responses. For example, in one experiment, participants were asked to respond to two color stimuli with a forceful or a soft key press. After response execution, auditory effects that were either loud or quiet were presented. In some blocks, forceful key presses led to loud effects and soft key presses led to quiet effects (compatible condition), whereas this mapping was reversed in other blocks (incompatible condition). Responses were carried out faster when response force and the intensity of auditory effects were compatibly assigned despite participants being instructed to respond only according to the color stimuli. Thus, effects that were in principle irrelevant for task performance have been shown to influence response initiation. As the effects were presented *after* response execution, the results indicate that effects had indeed been anticipated before the responses were executed.

There is already a remarkable amount of evidence for the IMP. The present paper goes beyond the scope of the current evidence, as we start to explore a neglected issue in the acquisition of action-effect associations. Until now, the acquisition of action-effect associations and the anticipation of effects have been investigated exclusively for stable action-effect relations. However, in reality, actions often produce different effects depending on the situational context. For example, think of the different effects that may result from pressing the enter key on a computer keyboard. If the computer operator is working within a word processing program, pressing the enter key results in inserting a new line, whereas the same action starts a new program when the mouse pointer is directed at the menu bar. Consequently, the specific action-effect relations only hold true in certain conditions and there are no general action-effect contingencies to adapt to.

Thus, in order to validate the general usefulness of the IMP, it has to be shown that action-effect associations are established context-specifically if necessary (Hoffmann, 1993; Hoffmann & Sebald, 2000; Hommel, Pösse, & Waszak, 2000). In other words, it has to be shown that the same actions are addressed by different effect anticipations in different contexts.

To this end, we conducted an experiment in which participants were required to perform the same responses in two different contextual conditions. In context A, responses produced certain α effects. In context B, the very same responses produced different β effects. If response-effect relations were indeed acquired context-specifically, the effects "α" and "β" should specifically influence the response initiations in the corresponding contexts. In order to control for the influence of the contextual stimuli on response initiation times, the context-effect assignments were counterbalanced, i.e., the mapping of contexts and effects was reversed in the second half of the experiment.

The situational context was varied in a way that is typically used in task-switching experiments (Allport, Styles, & Hsieh, 1994; Kleinsorge & Heuer, 1999; Koch, 2001; Meiran, 1996; Rogers & Monsell, 1995). In a characteristic task-switching experiment, participants are instructed to switch between two tasks. Both tasks typically require the same responses, i.e., participants perform the very same responses to carry out either task. In the present experiments we simply added different action effects that were irrelevant to the task but depended on which task was performed in a given trial. If action-effect relations are acquired task-specifically and if these effects are indeed anticipated before response initiation, the same responses should be triggered by different effect anticipations in the context of the two tasks.

Instructing participants to switch between tasks allowed us to investigate the role of context-specific action effects in response control. Certainly, the mechanisms that occur while switching between tasks are very interesting and challenging, but they are beyond the scope of this paper as task switching was just used here as a method to be able to present context-specific action effects. Therefore, we will restrict further discussion to the purpose of this paper, the investigation of context-specific action effects.

Experiment 1

We adopted the experimental setting used in several task-switching experiments by Meiran (1996, 2000a, 2000b; Meiran, Chorev, & Sapir, 2000; Meiran &

Gotler, 2001). Each individual trial started with the presentation of a cross and two brackets. The brackets were denoted as goals and determined the current task context. They were presented either above and below (context A) or to the left and right of the cross (context B) and served as a cue to which dimension of the spatial position of the target was relevant in a given trial. After 1,500 ms the target, a small circle referred to as a ball, appeared in one of the four quadrants formed by the cross. Participants were instructed to shoot the ball into the nearest goal (Fig. 1) by pressing one of two response buttons as fast as possible without making errors. One response button was located in a lower left position and was to be pressed if the ball was presented in one of the lower quadrants in context A or if the ball was presented in a quadrant on the left in context B. The other response button was located in an upper right position and was to be pressed if the ball was presented in one of the upper quadrants in context A or if the ball was presented in a quadrant on the right in context B.

In principle, our setting afforded the same responses according to the same targets as in the task-switching experiments of Meiran. If the brackets were presented above and below the cross (context A) participants pressed the upper right button if the target was presented in one of the upper quadrants, and the lower left button if the target was presented in one of the lower quadrants. If the brackets appeared to the left and to the right of the cross (context B) participants pressed the upper right button if the target was presented on the right, and the lower left button if the target was presented on the left.

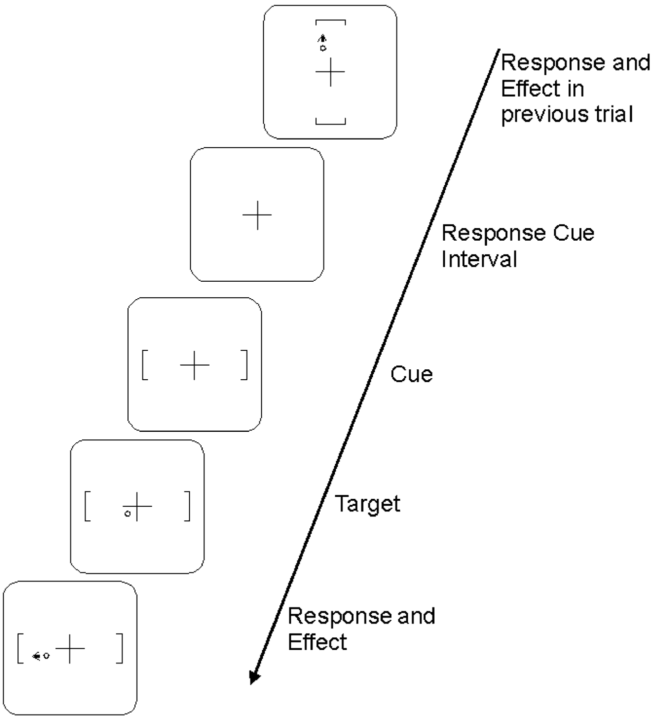

Fig. 1 Schematic description of a trial sequence proceeding from the top to the bottom. The top display corresponds to the last event in the previous trial. The response was executed and, as the response effect, the ball moved to the goal. The current trial started with an empty cross (second display). The response cue interval was fixed and after 1,500 ms the cue for the current context was presented (third display). After another 1,500 ms the target, referred to as a ball, appeared (fourth display). When the participant pressed the correct response key, the effect was presented, i.e., the ball moved to the goal after the context-specific duration

Within this typical task-switching setting we simply added effects to the performed actions. In contrast to Meiran's paradigm, participants initiated a movement of the ball to the appropriate goal by pressing the correct response button. For example, if the goals were presented above and below the cross (context A) and the ball was presented in one of the lower quadrants pressing the lower left button initiated a movement of the ball into the lower goal. Note that the movement of the ball was an arbitrary, irrelevant effect that was not necessarily to be taken into account when selecting the correct response.

We chose effect duration as the critical context-specific effect feature as Kunde (2003) had shown that effect duration had a substantial impact on response latencies. While investigating temporal response effect compatibility, Kunde (2003) asked participants to respond to two color stimuli with short or long key presses. After response execution, either short or long tones were presented. Short/long key presses could either lead to short/long (compatible) or to long/short (incompatible) effects. Responses were carried out faster when response duration and effect duration were compatibly assigned. In addition to this compatibility effect, Kunde found a general influence of effect duration on RTs. Response latencies increased with increasing effect duration, suggesting that it takes longer to anticipate a long effect tone than a short effect tone, and that response initiation has to wait until effect anticipation has been completed.

Considering these results, we varied the duration of the movements of the ball to the goals as either short or long depending on the given contexts. In one context (e.g., the up/down context) the ball moved fast to the nearest goal, i.e., the movement duration was short, whereas in the other context (e.g., the left/right context) the ball moved slowly to the goal, i.e., the movement duration was long. In line with Kunde's findings (2003), we expected faster responses for the context with the short effects, as these effects can be anticipated faster. In contrast, responses should be slower in the context with the long effects, as it should take longer to anticipate an effect that takes longer.

To ensure that differences in response latencies were due to the variation of effect duration and not just due to context differences, we counterbalanced the context-effect duration assignment within the experiment. For example, if participants experienced long effects in context A and short effects in context B in the first part of the experiment, this assignment was reversed in the second part of the experiment so that participants then experienced short effects in context A and long effects in context B.

As the same two response buttons were used in both contexts, one to shoot the target up (context A) and right (context B), the other to shoot the target left (context A) and down (context B), the effect durations for both responses in both contexts, were long for half of the trials (e.g., when the response keys were pressed to shoot the target up or down in context A) and short for the other half of the trials (e.g., when the same response keys were pressed to shoot the target left or right in context B). Therefore, if the variation of the effect duration showed an influence on response latencies a general response-effect association alone cannot account for the influence, but the context specificity of action-effects has to be taken into account.

Method

Participants

Sixteen students of the University of Würzburg (aged 19–38) participated in an individual session of approximately 30 min in fulfillment of a course requirement. They reported having normal or corrected-to-normal vision.

Apparatus and stimuli

An IBM-compatible computer with a 17-inch VGA display was used for stimulus presentation and response sampling. Responses were given with the index fingers of both hands on two external response keys (1.8 cm in width), which were fixed in a lower left and an upper right position on the table separated by 13 cm in vertical and horizontal orientation.

Stimuli were drawn in black on white. On the center of the screen a cross was presented extending 4.6 × 4.6 cm. The instructional cues were schematic "goals" that subtended 1 × 4.6 cm and were positioned at a distance of 7.9 cm from the center of the cross. Targets were circles (0.8 cm in diameter) presented in the middle of the four quadrants formed by the cross. With the onset of the response, the circle moved towards the nearest goal with a velocity of either 28.9 cm/s (fast) or 5.78 cm/s (slow), so that the duration of the movement was either 232 ms or 1,160 ms.

Design and procedure

A trial started with the presentation of a cue, i.e., goals appearing left and right or above and below the cross according to the current context. After a fixed cue target interval (CTI) of 1,500 ms the target was presented in one of the four quadrants formed by the cross. RTs were measured from the onset of the target to the onset of the key press. If the correct key was pressed, the target moved after the onset of the response to the goal, either fast or slowly. When the target reached the goal, both disappeared. If the incorrect key was pressed, an acoustic signal indicated the error and no target movement was presented. The next trial started in each case after a response cue interval (RCI) of 1,500 ms with the presentation of the next two goals. This means that the RCIs were always the same and the interval between effect offset and cue varied between 340 ms and 1,368 ms.

The contexts and the presented targets were chosen randomly with the constraint that each combination of current context (2), current target (4), previous context (2), and previous target (4) were presented four times per context-effect assignment. Additionally, the action-effect assignments for the two contexts were varied. Participants performed 256 trials with short effects for context A and long effects for context B and 256 trials with the reversed assignment with a short break after 128 trials. The order of the context-effect assignment was counterbalanced over participants. The investigator started a new program for the new context-effect-assignment so that participants might have expected that something would change in the second half of the experiment. At the beginning of the experiment, participants performed a short test of 20 trials with the action-effect assignment of the first part of the experiment.

Table 1 Mean RTs for short and long effect durations in Experiment 1 depending on experimental half for context repetitions and context switches

		Effect duration	
		Short (232 ms)	Long (1,160 ms)
First half	Context repetition	383	405
	Context switch	422	423
Second half	Context repetition	366	372
	Context switch	375	374

Results

The first two trials after each break and trials with RTs longer than 1,000 ms (1.0%) were discarded from further analysis. For the RT analysis, erroneous trials (4.5%) were also discarded.

The remaining RTs were subjected to an analysis of variance (ANOVA) with the within-subject variables experimental half,[1] context switch vs. context repetition, and effect duration (short vs. long). The corresponding mean RTs are listed in Table 1.

The analysis yielded a significant effect of experimental half, $F(1, 15) = 12.44$, $p < .01$, $MSE = 42{,}644.2$; participants responded slower in the first half of the experiment (408 ms) than in the second half (372 ms). Furthermore, there was a significant switching effect, $F(1, 15) = 20.02$, $p < .001$, $MSE = 9{,}064.8$; context switches were performed slower (398 ms) than context repetitions (381 ms). And most importantly, the influence of the effect duration was also significant, $F(1, 15) = 6.42$, $p < .05$, $MSE = 1{,}742.4$. RTs were slower when the effect was long (394 ms) than when it was short (386 ms). The interaction between experimental half and context switch vs. repetition was significant, $F(1, 15) = 18.95$, $p < .001$, $MSE = 4{,}456.5$; the difference between context switches and context repetitions was larger in the first experimental half (422 ms vs. 394 ms) and declined in the second experimental half (374 ms vs. 369 ms). The interaction between context switches vs. repetitions and effect duration approached significance, $F(1, 15) = 3.70$, $p = .074$, $MSE = 1{,}603.8$. The influence of the effect duration seemed to be present only in repetition trials (389 ms for long effects vs. 374 ms for short effects) and not in switch trials (398 ms for long effects vs. 398 ms

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[1] The variable experimental half was included in the analysis to check whether participants stuck to an acquired context-effect assignment or whether they also flexibly relearned context-effect assignments.

for short effects). None of the other effects were significant ($p > .13$).

We did not expect any influence of effect duration on the error rates. But to rule out speed-accuracy tradeoffs, the same analysis was performed on the error rates. This analysis yielded a significant switching effect, $F(1, 15) = 15.14$, $p < .001$, $MSE = 150.6$, context switches were performed with more errors (5.6%) than context repetitions (3.5%). No other effects approached significance ($p > .27$)

Discussion

Firstly, it is noteworthy that Experiment 1 replicates the typical results that are usually found within task-switching studies. Despite long intervals between the trials (RCI = 1,500 ms) and a long cue target interval (CTI = 1,500 ms) for context/task preparation, trials in which the context was switched were performed more slowly and with more errors than trials in which the context was repeated. These switch costs indicate that participants really switched between attending to the up/down or the left/right dimension of the target location. Furthermore, RTs as well as switch costs declined in the second half of the experiment as practice reduced RTs and the amount of switch costs (e.g., Gopher, Armony, & Greenshpan, 2000; Rogers & Monsell, 1995).

Of importance for the purpose of the present paper is the significant influence of the context-specific effect duration. Responses to the same targets were faster when they were followed by short effects whereas the same responses were slower when they were followed by long effects. Furthermore, as the very same response was followed equally often by short and long effects within each block, depending on the context, the results indicate that participants really acquired context-specific action-effect associations. Thus, this result is consistent with the basic hypothesis of the present study, namely that anticipations of effects to be produced are part of the context-specific intentions participants form. The influence of effect duration was the same in the both experimental halves ($F(1, 15) < 1$), despite the response-effect duration assignment being reversed in the experimental halves. It seems that participants also took the experimental half as a "context" and that they relearned this assignment quite quickly as it made no difference whether all trials of an experimental half (except for the first two trials) or only the last 128 trials of an experimental half were considered in the data analysis. How fast participants are able to relearn a response-effect assignment would be a very interesting question worth further investigation.

The influence of effect duration interacted marginally significantly with the variable context switch vs. context repetition, as it seemed to be present only in context-repetition trials and not in context-switch trials. There would be two obvious possible accounts if this non-significant result proves to be valid and replicable. Firstly, not only the duration of the subsequent effect might influence RT, but also the duration of the effect of the previous trial. In context repetition trials the effect duration of the previous trial corresponds to the effect duration of the current trial. In contrast, in context-switch trials the two effect durations do not correspond. Consequently, the impact of effect duration would be more pronounced in repetition trials.

The second explanation takes recent findings of the task-switching paradigm into consideration. If different tasks instead of different contexts are considered, it will be expected that in switch trials, tasks are not prepared to the same degree as in repetition trials as a new task cannot be fully prepared in advance without having the target presented (e.g., Meiran, 2000a, 2000b; Rogers & Monsell, 1995). It might be assumed that the extent to which effect anticipations influence response preparation depends on the degree of task preparation. Consequently, in repetition trials in which the task is well prepared before the target is presented, the anticipation of effects plays a decisive role in response initiation. In contrast, in switch trials in which the task preparation can be completed only after the target has appeared, response initiation might be controlled mainly by the representation of the target, so that effect anticipations would play a minor role. This account assumes two different modes of action control. If the current task context is well prepared before the target appears, participants have formed corresponding intentions, and effect anticipations trigger response selection and initiation. If the current task context is not sufficiently prepared when the target appears, the target takes control over response selection and initiation. Note that these considerations would be a severe restriction of the IMP as they claim that effect anticipations play a minor role in action control when the action-effect-assignments change within different contexts.

Experiment 2

We replicated Experiment 1 with the only modification that the preparation time for the current task context was varied. By introducing short (100 ms) and long (1,500 ms) CTIs we elaborated on whether the influence of the effect duration really depends on the activation strength of the context-specific intentions, as the marginally significant interaction with the variable context switch vs. context repetition possibly suggests. When the CTI is short, participants have only a little time to activate the current context-specific intention. Especially in switch trials with short CTI, the current intention might be only slightly activated so that the influence of the effect duration on RTs should vanish if it really depends on the activation of an intention appropriate to the context.

Table 2 Mean RTs for short and long effect durations in Experiment 2 depending on experimental half, cue target interval (*CTI*), and context repetition vs. switch

			Effect duration	
			Short (232 ms)	Long (1,160 ms)
First half	CTI short	Context repetition	475	490
		Context switch	547	547
	CTI long	Context repetition	435	436
		Context switch	449	473
Second half	CTI short	Context repetition	446	453
		Context switch	493	508
	CTI long	Context repetition	419	427
		Context switch	432	446

Method

Participants

Sixteen students of the University of Würzburg (aged 19–38) participated in an individual session of approximately 30 min in fulfillment of a course requirement. They reported having normal or corrected-to-normal vision.

Apparatus and stimuli

Apparatus and stimuli were the same as in Experiment 1.

Design and procedure

Design and procedure were identical to Experiment 1 with the exception that the CTI was either short (100 ms) or long (1,500 ms). Context and target sequence was random with the constraint that each combination of current context (2), current target (4), current CTI (2), previous context (2), previous target (4), and previous CTI (2) was presented once for each effect duration assignment. Again, participants performed 256 ($= 2 \times 4 \times 2 \times 2 \times 4 \times 2$) trials with short effects for context A and with long effects for context B and 256 trials with the reversed assignment. The effect, i.e., the movement of the ball, started with the offset of the response.[2]

Results

The first two trials after each break and at the beginning of the experiment and trials with RTs longer than 1,000 ms (2.1%) were discarded from further analysis. For the analysis of RTs, erroneous trials (2.8%) were also discarded.

RTs of the remaining trials were subjected to an ANOVA with the within-subject variables experimental half, context switch vs. context repetition, CTI (100 ms vs. 1,500 ms), and effect duration (short vs. long). The corresponding RTs are presented in Table 2.

The analysis yielded a significant effect of the experimental half, $F(1, 15) = 15.69$, $p < .001$, $MSE = 52{,}990.9$; participants responded slower in the first half of the experiment (482 ms) than in the second half (453 ms). Furthermore, there was a significant switching effect, $F(1, 15) = 34.76$, $p < .001$, $MSE = 100{,}404.2$, as context switches were performed slower (487 ms) than context repetitions (447 ms), and a significant CTI effect, $F(1, 15) = 59.87$, $p < .001$, $MSE = 197{,}300.4$, as RTs were slower for short CTI (495 ms) than for long CTI (439 ms). The influence of effect duration was significant, $F(1, 15) = 9.73$, $p < .01$, $MSE = 7{,}481.6$. RTs were slower when the effect was long (473 ms) than when it was short (462 ms). Furthermore, the interaction between experimental half and context switch vs. repetition was significant, $F(1, 15) = 5.00$, $p < .05$, $MSE = 1{,}910.1$, showing that the RT difference between context repetition trials and context switch trials was larger in the first half of the experiment (459 ms vs. 504 ms) and declined in the second half (436 ms vs. 470 ms). The interaction between experimental half and CTI was also significant, $F(1, 15) = 16.86$, $p < .001$, $MSE = 7{,}866.3$, as RTs increased more for short than for long CTI in the first half of the experiment (515 ms for short vs. 448 ms for long CTI) than in the second (475 ms vs. 431 ms). And the interaction between context switch vs. repetition and CTI was significant, $F(1, 15) = 16.92$, $p < .001$, $MSE = 21{,}649.9$, showing that the RT difference between context repetition trials and context switch trials was larger when the CTI was short (466 ms vs. 524 ms) than when it was long (429 ms vs. 450 ms). The four-way-interaction between experimental half, context switch vs. repetition, CTI, and effect duration was also significant, $F(1, 15) = 8.91$, $p < .01$, $MSE = 2{,}144.9$. The corresponding RTs are depicted in Table 2, but we can offer no conclusive interpretation of this four-way-interaction. No other effects approached significance ($p > .13$).

To rule out speed-accuracy tradeoffs, the same analysis was performed on error rates. This analysis yielded a significant effect of experimental half, $F(1, 15) = 5.65$, $p < .05$, $MSE = 35.9$, as there were more errors in the first half of the experiment (3.2%) than in the second half (2.4%). Furthermore, there was a significant switching effect, $F(1, 15) = 22.03$, $p < .001$, $MSE = 366.4$, as context switches were performed with more errors (4.0%) than context repetitions (1.6%). The interaction between experimental half and context switch vs. repetition was significant, $F(1, 15) = 5.26$, $p < .05$, $MSE = 31.2$, as error rates for context switches compared with

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[2] The action-effect started with the offset of the response as we also measured response duration in this experiment. However, the results concerning response duration were unsystematic and will not be reported here.

context repetitions increased more in the first half of the experiment (1.6% for context repetitions vs. 4.7% for context switches) than in the second half (1.6% vs. 3.3%). The interaction between context repetition vs. context switch and CTI was significant, $F(1, 15) = 7.74$, $p < .05$, $MSE = 56.5$, as error rates for switches compared with repetitions increased more for short CTI (1.4% vs. 4.7%) than for long CTI (1.8% vs. 3.2%). The interaction between CTI and effect duration approached significance, $F(1, 15) = 3.80$, $p = .07$, $MSE = 22.9$, as well as the three-way interaction between experimental half, CTI, and effect duration, $F(1, 15) = 4.14$, $p = .06$, $MSE = 42.68$, reflecting especially high error rates for short compared with long CTIs (4.5% vs. 1.9%) when the effect duration was long in the first experimental half. No other effects were significant ($p > .10$)

Discussion

The results show a general training effect in that RTs and error rates were reduced in the second half of the experiment. Additionally, participants responded slower and more prone to error when they had less time to prepare for an upcoming trial due to short CTIs. This effect decreased with practice, so that the CTI impact on general task performance was somewhat smaller in the second half of the experiment. Furthermore, the results again show the pattern typically found in task-switching experiments. Switch trials were prolonged and more prone to error than repetition trials and these switch costs were larger for short CTI than for long CTI. This again implies that participants really switched between different intentions when responding in two task contexts. As in Experiment 1, switch costs were decreased in the second half of the experiment showing a practice effect for switching ability.

Most important to this study is the influence of the context specific effect duration. A response was carried out faster when it was performed in a context with short effects whereas the same response was slowed down in another context with long effects. The influence of effect duration was the same in both experimental halves ($F(1, 15) < 1$), despite the response-effect duration assignment being reversed in the experimental halves. Again, it made no difference to the impact of effect duration whether all trials or only the last 128 trials were considered for data analysis, supporting the former assumption that participants relearned the response-effect assignment very fast.

Contrary to Experiment 1, the main effect of effect duration was *not* modulated by the variable context switch vs. context repetition. The marginally significant interaction between effect duration and context switch vs. repetition in Experiment 1 does not seem to be a reliable effect as it was not replicated in Experiment 2. Thus, we can rule out the suspicion that the duration of the effect of the former trial has a strong impact on RTs in the current trial. If this were the case, RTs should always increase when the effects of the former trials are long whereas RTs should decrease when the effects of the former trials were short. This was clearly not the case.

Furthermore, we found neither a modulation of the influence of effect duration on RTs by the CTI variation nor a triple interaction between effect duration, CTI variation, and context switch vs. repetition. Hence, effect anticipations to initiate responses were not restricted to cases where the task context was already well prepared, either because of context repetitions or because of long preparation times before target presentation. Rather, effect anticipations were always necessary to initiate a response.

Thus, Experiment 2 rules out both alternative explanations discussed for Experiment 1. Instead, the results suggest that context-specific action-effect assignments were acquired and that effects were anticipated before response initiation.

General discussion

First of all, it is to be noted that we replicated the results of Kunde (2003). It takes longer to initiate a response if it produces a long effect than if it produces a short effect, indicating that it takes longer to anticipate a long effect and that response initiation has to wait for the anticipation of the effects that trigger the response.

This basic finding is extended by our study in two ways. Firstly, effect durations influence response initiation even if there is no dimensional overlap between the instructed response set and the presented effect set. In Kunde's study, (2003) participants were instructed to perform either short or long responses, which produced either short or long effects. Thus, duration was a dimension that was relevant for the response set and the effect set. In our experiments, duration was not a relevant dimension of the response set. Participants were simply instructed to press one of two response keys as fast as possible. Nevertheless, effect duration influenced RTs.

Secondly, and most importantly, our results indicate that if action-effect relations vary with the context, action-effect associations are acquired context-specifically and that the same actions are accessed by different effect anticipations. By implementing effects in differing contexts, we were able to show that context-specific effect durations influence response performance in that the initiation of one and the same response was delayed when the present context signaled long lasting effects whereas that very same response was initiated faster when the present context signaled short effects. This result was significant in both Experiments 1 and 2 and implies that before responses are initiated their subsequent effects are anticipated in order to access the responses even when the response-effect assignments are valid only for specific contexts. Thus, the reported results are an important extension of empirical findings that support the general validity of the IMP.

Note that the duration of the effects was totally irrelevant to the performance of the key presses, as the context cue and the presented target determined the appropriate response. Nevertheless, effect duration affected response performance. To our knowledge, this is the first time it has been shown that even irrelevant effects that vary in different contexts are anticipated in order to trigger the appropriate actions.

In conclusion, the experiments in this paper further support the IMP by showing that action-effect associations are acquired even if they are only valid in specific contexts. Effects are anticipated before response execution and influence response initiation according to the specific context in which they are valid.

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