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The impact of anticipated action effects on action planning

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Abstract

Three experiments with a total of 72 participants investigated the assumption that motor actions are planned in terms of their sensorial effects. Participants had to prepare a certain action A that consistently led to a sensorial effect (a tone of certain pitch). Instead of (in Experiment 1) or before (in Experiments 2 and 3) the execution of the prepared action, another response B had to be carried out, which either resulted in the same or in a different auditory effect (a tone of same or different pitch). It was found that a to-be-executed response B was in general initiated more quickly when it resulted in the same effect as a concurrently prepared response A. The results are considered as evidence for the basic notion that the preparation and initiation even of very simple actions is mediated by an anticipation of their reafferences. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Except for reflexive and emotional behavior humans generally act in order to produce certain effects, may it be to open a bottle, to turn on a radio, to sign a contract or whatever else. In any individual instance a particular action (or sequence of actions) has to be determined that will produce the desired effect reliably, and

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apparently humans are capable of doing so with little effort and without any conscious reflection. How do actors accomplish this task? More than 100 years ago, introspective psychologists like Harleß (1861), Herbart (1824) or James (1981, 1890) argued that a certain voluntary action is directly initiated by a memory retrieval of those sensorial effects that were experienced to consistently follow when the action was carried out in the past. According to this idea, the human actor acquires bidirectional associations between actions and their reliable effects, which are activated in the opposite direction if a certain effect is desired, so that the anticipated (desired) effect evokes the action that consistently produced this effect. In an extreme, one can assume that actions become exhaustively represented by their sensorial effects and that thus actions can be accessed solely by recollecting their reafferences – an idea that following James (1981,1890) has been known as the ideo-motor (IM) hypothesis.

The general notion that action effects contribute to behavioral control is not an exclusive assumption of the IM hypothesis (cf. Hoffmann, 1993; Hommel, 1998 for a comparison of the IM hypothesis with other concepts of motor control). For example, the closed-loop theory by Adams (1971) as well as the Schema theory by Schmidt (1975) assume that the sensorial effects of a performed action are temporarily stored (in a so called "perceptual trace" [Adams, 1971] or "recognition Schema" [Schmidt, 1975]). However, in these theories action effects are primarily functional for control of movement execution rather than for movement selection as asserted by IM theory. The Schema theory assumes that movement selection is mediated by so called recall schemata which are functionally dissociated from the effect-representing recognition schemata. Likewise, in closed-loop theory perceptual traces are relevant solely for the online movement correction by means of a comparison with actual action feedback. Hence, the particular assumption of the IM hypothesis that representations of forthcoming effects are an inevitable component of the cognitive action antecedents (i.e. that action effects are functional in ***advance*** of movement execution for planning or initiating a movement) is barely acknowledged in traditional theories of motor control, and has thus rarely been examined experimentally so far.

Only recently the IM hypothesis experienced a revival (cf. Hoffmann, 1993; Hommel, 1998; Prinz, 1997). Basically, two lines of research can be distinguished. Some studies investigated the factors that influence the learning-dependent formation of associations between actions and their effects (e.g. Hoffmann, Sebald, & Stöcker, 2001; Stock & Hoffmann, in press; Ziessler, 1998). Other studies aimed to test the assumption that motor acts are indeed evoked by an activation of their (already associated) effect codes. These studies convincingly demonstrated that the perception of an action effect (or effect-resembling stimulus) increases the probability and speed of selecting the particular action that produces this effect (e.g. Elsner & Hommel, 2001; Greenwald, 1970a,b; Hommel, 1993, 1996; Ziessler & Nattkemper, in press).

Action induction by action-effect perception strongly suggests that actions and their effects are associated in a bi-directional manner, otherwise a stimulated effect code could hardly induce the motor pattern from which it typically originates. Still, this does not yet prove that effect codes do become activated in case they are not already perceptually available in advance of response selection. This, however, is the crucial assumption of the IM hypothesis which asserts that actions are selected by anticipated rather than by perceived effects (cf. Greenwald, 1970b; Kunde, 2001). Thus, in our view it is desirable to show that effect codes become endogenously activated (i.e. anticipated) during action planning even when not sensorially stimulated. Some clues for the relevance of such anticipatory effect representations can be drawn from induction studies. For example response induction is much stronger when subjects also intend to produce the effects which are presented to them, that is when a presented response effect meets an already pre-activated effect representation (Hommel, 1993, 1996, Experiment 1).

The purpose of the present study was to reinforce the relevance of anticipatory effect representations for action planning by showing that response effects have an impact on response preparation even when they are available exclusively after response execution. Observing such influences of forthcoming response effects necessarily implies that effect codes are actually activated in advance of overt responding. Otherwise it is logically impossible that a future effect could influence a response that precedes this effect in time.

2. General method and predictions

To pursue this purpose, we employed different variations of a response preparation paradigm. The subjects were instructed to prepare as well as possible one out of four possible responses (e.g. simple key-presses). The common (and crucial) feature of the reported experiments was that each response produced one out of two auditory effects, either a low-pitched or a high-pitched tone. These effects were assigned in a way that respectively two of the four responses led to the same tone (cf. Fig. 1), with the response-tone mapping remaining constant for each individual subject.

According to the IM hypothesis it was assumed that preparing one of these responses comprises an anticipation of its respective reafferences. Apart from sensations that accompany every choice reaction (e.g. a tactile sensation in the responding finger, maybe an auditory "click" from pressing the response key) this should also hold for the salient auditory effect of the planned action. We expected that the anticipation of this auditory effect in the course of response preparation would to a certain degree also enhance the readiness to perform other responses that share this effect. This is because the presumably time-consuming endogenous activation of the effect representation has already been undertaken for the planning of the initially prepared action. We will refer to this assumption as the collateral facilitation hy-

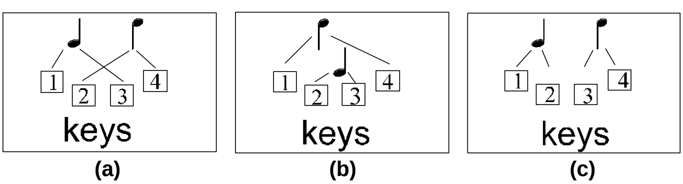

Fig. 1. Possible mappings of the four actions and the two action effects in Experiments 1 and 2.

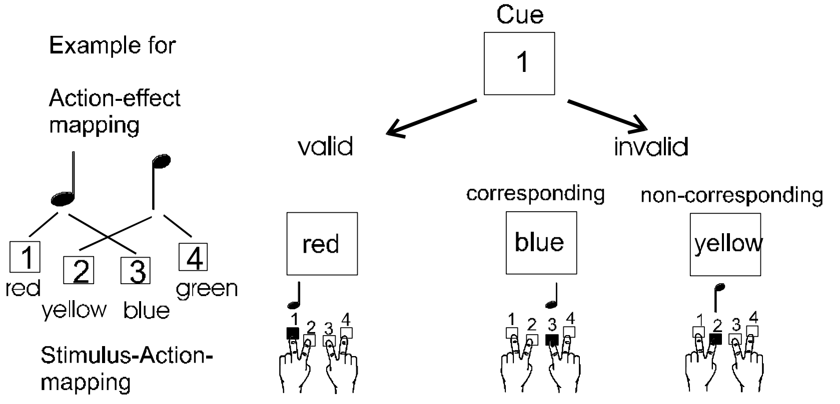

Fig. 2. Valid and invalid trials in Experiment 1. Following an invalid cue the prepared and to be emitted action either led to the same or different effects.

pothesis. If, for example, with the leftmost key-tone mapping depicted in Fig. 1, action 1 would be prepared, this should also facilitate the initiation of action 3 but not of action 2 or 4. Hence, action 3 should be initiated more quickly if it is requested instead of – or in close temporal proximity to – the preparation of action 1 (for a different approach that will be considered in detail in the introduction of Experiment 2 cf. Stoet & Hommel, 1999).

3. Experiment 1

Experiment 1 tested the collateral facilitation hypothesis by means of a response reprogramming paradigm (cf. Meyer & Gordon, 1985). Participants performed a choice-reaction task in which four colors were assigned to four response keys. Shortly before the stimulus was presented, a cue indicated the probable next response. In 25% of the cases the cue was invalid, that is, not the cued action but one of the remaining three actions had to be carried out. [1] Within invalid trials two cases can be distinguished: the actually to be performed and the formerly prepared action either resulted in the same or in different auditory effects (see Fig. 2). If it holds true that anticipated behavioral effects do substantially contribute to the preparation and initiation of motor acts, it can be assumed that besides the cued action, the other action with the same effect will also be (collaterally) facilitated to a certain degree. Consequently following an invalid cue, an action should be initiated more quickly if it leads to the same effect as the originally prepared action.

[1] The proportion of invalid trials cannot be infinitely increased, since the cue will be used less frequently the less reliably it predicts which action must be carried out subsequently. As the results will show, however, there were very pronounced cuing effects with 25% invalid trials, which verifies that the cues were indeed used for response preparation.

3.1. Method

3.1.1. Participants

Twenty four undergraduates (6 men, 18 women) at the University of Würzburg (aged 19–36 years) participated in fulfillment of a course requirement.

3.1.2. Apparatus and stimuli

The presentation of the stimuli and the recording of responses and reaction times (RTs) were provided by an IBM-compatible PC with a 15-in. VGA-Graphics-Display. The viewing distance was approximately 80 cm. Responses were made with the index and middle fingers of both hands on an external four-key pad connected to the parallel port of the computer. The key midpoints were separated by approximately 30 mm. The imperative stimulus was a circular color-dot (45 mm diameter) presented in the middle of the black screen. The colors red, yellow, blue and green (from the standard VGA color-palette) were mapped onto the response keys in a left to right order for all participants. The presentation of the stimulus was preceded by the presentation of a digit (15 mm high) that indicated the next response. The digits 1–4 were assigned to the four responses in a left to right order, and the digit 0 served as a neutral cue. We used digits (i.e. a different set of stimuli as the imperative color dots) to make entirely clear to the subjects the distinction between cues and imperative signals. In 280 of the 480 experimental trials the cue was valid, in 80 trials it was neutral and in 120 trials it was invalid. In the case of an invalid cue one of the remaining three responses had to be executed with equal probability. The order of trials was random.

Two of the four responses triggered a high tone (650 Hz) and two triggered a low tone (250 Hz) each lasting about 600 ms. The auditory effects were generated by the sound-card of the computer and emitted by two loudspeakers that were mounted on the left and right side of the monitor. The assignment of the two auditory effects to the four responses yielded six different response–effect (R–E) mappings (the three mappings from Fig. 1 and an additional three that resulted from exchanging the high and low tone), which were counterbalanced across subjects.

3.1.3. Procedure

After an inter-trial interval of 1000 ms the response cue was presented in the middle of the screen. Participants were instructed to prepare the cued action as well as possible. After 1500 ms the cue was replaced by the color stimulus that was visible until response. Immediately after recording a response, its auditory effect was emitted. Even in the case of an error the tone of the erroneous response was presented but additionally accompanied by a visual error-feedback (the word "Fehler!", the German term for error) of 600 ms. After 24 practice trials the participants worked through 480 experimental trials.

3.2. Results

Responses below 100 ms and above 1000 ms were considered as outliers and discarded (0.6% of all responses).

3.2.1. Cue effects

The first analysis was confined to the cueing-effects. The RTs and error rates for trials with valid, neutral and invalid cues amounted to 382 ms (0.78%), 529 ms (3.90%) and 545 ms (10.36%). One-way analyses of variance (ANOVA) for repeated measures revealed the cuing conditions significantly different for RTs ($F(2,42) = 124.79$; $p < 0.01$), as well as for error rates ($F(2,42) = 36.27$; $p < 0.01$). Single comparisons revealed that for RTs the difference between valid and neutral trials ($F(1,23) = 133.79$; $p < 0.01$) as well as the difference between neutral and invalid trials were significant ($F(1,23) = 17.35$; $p < 0.01$). The same pattern was evident in the error data ($F(1,23) = 15.26$; $p < 0.01$ for the difference between valid and neutral trials, and $F(1,23) = 44.43$; $p < 0.01$ for the difference between neutral and invalid trials).

3.2.2. Influence of action effects

In order to test the impact of action effects, responses with a corresponding vs. noncorresponding effect with the cued action within invalid trials were compared. An explorative analysis suggested a substantial variation of the data pattern with practice. Therefore the data were entered into a two-way ANOVA with the variables effect-correspondence (corresponding vs. noncorresponding effects between prepared and executed action) and practice [first half of the experiment (trials 1–240) vs. second half (trials 241–480)] as repeated measures. The analysis showed a significant decrease of RTs from the first to the second half (first half: 560 ms, second half: 528 ms; $F(1,23) = 22.03$; $p < 0.01$) and, more importantly, a significant interaction between effect-correspondence and practice ($F(1,23) = 11.73$; $p < 0.01$): whereas no influence of effect-correspondence was observed in the first half of the experiment (corresponding effects: 563 ms, noncorresponding effects: 557 ms; $F < 1$), responses were initiated significantly faster in the second half, when the effect of prepared and executed response corresponded than when they did not correspond (corresponding effects: 518 ms, noncorresponding effects: 537 ms; $F(1,23) = 6.68$; $p < 0.02$).

The error rates for actions with a corresponding vs. noncorresponding effect were 11.85% and 10.82% in the first half, and 9.58% and 9.23% in the second half. In the analysis of error data no effect approached significance (all ps > 0.23). Since the lower RTs for actions with corresponding effects were accompanied by slightly higher error rates one might suspect some kind of speed–accuracy trade-off. However, a closer look on the error data shows that the rather high error rate for actions with a corresponding effect is caused by a specific type of error that fits in nicely with the collateral facilitation hypothesis: participants quite often erroneously launched the invalidly cued action. This was called a *perseveration error*. In the remaining errors participants neither executed the cued nor the required action. When the effects of cued and required action did not correspond, both types of errors occurred about equally frequent (perseverations: 5.3%, other errors: 4.8%, $F < 1$ for this difference). However, in the case that the effects of cued and to be performed action corresponded, perseverations were considerably more frequent than other errors (perseverations: 7.0%, other errors: 3.7%, $F(1,23) = 4.57$; $p < 0.05$). Thus, the error data can be summarized as follows: there was no general tendency for a higher error rate with corresponding effects, but participants tended to erroneously launch the prepared action when it led to the same effect as the actually requested action.

3.3. Discussion

Experiment 1 was motivated by the idea that response preparation inevitably comprises an anticipation of response effects. This effect anticipation should allow to switch more quickly from a prepared to an unprepared response when both responses share a common sensorial effect, which – following a sufficient amount of practice – was indeed confirmed. Additionally, participants were less likely to successfully withhold an invalidly cued action when it led to the same effect as an actually requested action. Presumably, these perseveration errors arise from the fact that the representation of the already anticipated auditory effect of the invalidly cued action becomes additionally activated by initiating a response that shares this effect. This might occasionally push the cued action over its execution threshold and thus lead to a perseveration error. Altogether Experiment 1 provides first evidence for the collateral facilitation hypothesis.

4. Experiment 2

There are two reasons for why the results of Experiment 1 are not fully conclusive and require further confirmation. First, the influence of effect-correspondence was evident only after a sufficient amount of practice. Apparently the tones must have been experienced as consistent outcomes of the actions frequently enough in order to become associated with them. This possibility was taken into account in Experiment 2 by introducing a training phase in which participants were given ample opportunity to experience the R–E mapping (see Section 4.1).

Second, and theoretically more important, the collateral facilitation observed in Experiment 1 appears inconsistent with a recent related approach by Stoet and Hommel (1999). The authors argued that action planning leads to the activation and temporal binding of so called action features (e.g. spatial features of the planned action like whether it is to be performed with a "left" or "right" limb). [2] Binding a particular feature is assumed to make it temporarily less available for planning other actions, which should hamper the initiation of actions with overlapping features. To test this prediction the authors used an elegant, so called ABBA paradigm (see Fig. 3): participants were presented with a stimulus A and prepared a corresponding action A. But before carrying out this action, another stimulus B was presented which had immediately to be responded to by a second action B, followed by the already prepared action A. In accordance with the binding hypothesis (and inconsistent with our collateral facilitation hypothesis) the initiation of action B was in-

[2] For the sake of simplicity, we provisionally assume that spatial "action features" and auditory "action effects" are functionally equivalent. However, as the results of Experiments 2 and 3 will show, they actually can not be equated. This point is considered in more detail in Section 6.

deed impaired (rather than facilitated) when another action A was concurrently prepared that shared the same feature.

There is one possibly crucial difference between the ABBA paradigm and the reprogramming paradigm of the present Experiment 1. Whereas in the ABBA paradigm the plan for action A had to be maintained beyond the initiation of action B (because execution of action A was required in each individual trial), the plan for the invalidly cued action in the present Experiment 1 was probably abandoned because this action did not have to be executed anymore. Interestingly, Stoet and Hommel (1999) found that briefly after an action plan had been dismantled (i.e. after an action had been carried out), other actions that shared a feature with the released action could in fact be executed more easily. This aftereffect of dismantling a plan was assumed to reflect some persisting activation of the unbound features of the performed action. It therefore seems possible that the collateral facilitation found in Experiment 1 simply reflects some kind of aftereffect following the dismantling of an action plan, rather than being a relevant property of ongoing action planning, as we claim. A straightforward way to test if this procedural difference is responsible for the conflicting outcomes is to test the collateral facilitation hypothesis within the ABBA paradigm. This was done in Experiment 2.

In our adaptation of the ABBA paradigm the participants were presented with a digit and prepared a corresponding keypress A (see Fig. 3). Before carrying out the prepared action, a second digit was presented which had to be responded to immediately with a second keypress B, followed by the already prepared keypress A. The two actions were associated with either the same or with different auditory effects.

The main hypothesis in Experiment 2 concerned the first executed action (B). As in Experiment 1 it was expected that, by preparing action A, the other action that results in the same auditory effect will also be facilitated to some degree. Therefore the leading keypress B should be executed more quickly if it results in the same effect as the already prepared keypress A, than if it leads to a different effect.

Beyond broadening the validity of the collateral facilitation hypothesis to the somewhat different experimental situation of the ABBA design, we intended to asses the time course of anticipated action effects in action planning and thus varied the

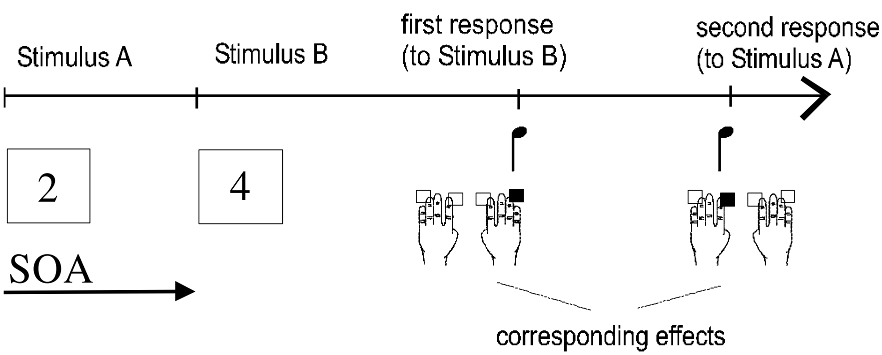

Fig. 3. A sample trial with corresponding action effects in Experiment 2.

stimulus onset asynchrony (SOA) between the two stimuli A and B. By varying the SOA, the initiation of action B was required in varying time points of the preparation of action A. This allowed us to asses during which phases of planning action A the proposed collateral facilitation of effect-corresponding actions is most pronounced. Finally, in order to reduce possible effects of learning the crucial R–E associations that may have caused the practice-dependent variation of the data pattern in Experiment 1, a training phase preceded Experiment 2. In the training phase participants were instructed to simply press the four response keys at leisure and to observe which tones resulted.

Note that in the present conditions the first to-be-initiated action (B) and the already prepared action (A) produced different tones in 66% of the cases, and the same tone in 33% of the cases. Thus, the additional preparation of an action with an effect that corresponds with the cued action was neither instructed nor would it be an advantageous strategy in the present conditions. Thus, Experiment 2 tested a strong version of the collateral facilitation hypothesis, namely, that anticipating a certain effect *inevitably* facilitates all actions from which this effect results.

4.1. Method

4.1.1. Participants

A fresh sample of 24 undergraduates (4 men, 20 women) at the University of Würzburg (aged 18–30 years) participated.

4.2. Apparatus, stimuli and procedure

4.2.1. Effect-learning trials

The responses were made with the index and ring finger of both hands on four separate external response keys. The keys for the index and ring finger within each hand were separated by 50 mm and the two index fingers were separated by approximately 30 cm, so that the arms could be placed comfortably on the table.

The participants were instructed to press the four response keys at leisure and to observe which tones resulted from pressing the keys. The only restriction was that each key should be pressed about equally frequent. Two of the four keys triggered a low tone (1650 Hz) and the other two triggered a high tone (4000 Hz) of 100 ms duration. The tone duration was reduced compared to Experiment 1 because we expected (and as the results will show indeed found) relatively low interresponse times, and thus the tone of the first executed action B would otherwise have been interrupted abruptly by presentation of the tone of the second response. The fast succession of the tones also motivated the use of different pitches which phenomenally made the tones more distinguishable. The R–E mapping was balanced across participants as in Experiment 1. The participants performed 200 keypresses which took them about 5 min.

4.2.2. Experimental trials

Each trial started with a fixation cross presented for 200 ms. Following an 800 ms blank interval Stimulus A (a digit ranging from 1 to 4) was presented for 300 ms.

Participants were instructed to prepare the cued action (A) as well as possible. Either 500, 1000, 1500 or 2000 ms after the onset of Stimulus A, Stimulus B was presented and remained visible until response B was made. Response B should be executed as quickly as possible, immediately followed by the already prepared action A. We used digits both as cues for action A and as stimuli for action B because it turned out that the color-response mapping in Experiment 1 was relatively hard to acquire. To ensure a clear distinction between the stimuli for the two responses, action A stimuli were red-colored and action B stimuli were green-colored. In case of an error in either of the two actions a brief visual error feedback (the word "Fehler") was presented.

Each combination of first and second response was equiprobable within each level of SOA with the restriction that first and second response were always different. The order of trials was random. After 24 practice trials participants performed 576 experimental trials.

4.3. Results

Responses below 150 ms or above 1500 ms (action B) and below 20 ms or above 500 ms (interresponse times between actions B and A) were considered as outliers and discarded (1.2 % of the B-responses and 1.4% of the A-responses). For the RT analysis only trials with a correct response in actions A and B were considered, whereas the error rates for actions B and A were assessed independently. Explorative data analysis yielded no variation of the data pattern with practice. RTs and error rates for actions B and A were entered into an ANOVA with effect-correspondence (corresponding vs. noncorresponding effect between the two actions) and SOA (500, 1000, 1500, 2000 ms) as repeated measures. Table 1 shows the mean RTs and error rates of each factorial combination of these two variables.

4.3.1. Action B

The RTs decreased with increasing SOA ($F(3,69) = 80.47$; $p < 0.01$). Additionally, action B was overall initiated more quickly when it led to the same effect as action A ($F(1,23) = 4.92$; $p < 0.05$). Whereas the influence of effect-correspondence was quite pronounced with an SOA of 500 ms (30 ms, $F(1,23) = 8.15$; $p < 0.01$) it was not significant with an SOA of 2000 ms (10 ms, $F(1,23) = 1.25$; $p > 0.25$), which led to a marginally significant interaction between effect-correspondence and SOA ($F(3,69) = 2.36$; $p < 0.08$). The analysis of the error rates also yielded a significant decrease with increasing SOA ($F(3,69) = 12.19$; $p < 0.01$). No other effect approached significance (all Fs < 1).

4.3.2. Action A

The only effect in the analysis of interresponse times (IRTs) was a numerically small (6 ms, rounded) but significant increase of RTs with increasing SOA ($F(3,69) = 6.46$; $p < 0.01$). In contrast to IRTs the error rates showed a significant decrease with SOA ($F(3,69) = 15.29$; $p < 0.01$). It is therefore likely that the increase of IRTs is the result of a speed-accuracy trade off. We therefore hesitate to draw any conclusion from this effect.

Table 1
Experiment 2: response times (in ms) and error rates (in %) for action B (first action) and interresponse time for action A (second action) as a function of SOA and effect-correspondence between actions A and B

Effect-correspondence	SOA															
	Action B								Action A							
	500 ms		1000 ms		1500 ms		2000 ms		500 ms		1000 ms		1500 ms		2000 ms	
	RT	PE	RT	PE	RT	PE	RT	PE	IRT	PE	IRT	PE	IRT	PE	IRT	PE
Noncorresponding effects	671	3.5	602	2.2	582	2.4	568	1.5	137	4.1	141	2.3	143	2.3	144	1.3
Corresponding effects	641	4.1	588	2.6	563	2.0	558	1.4	139	3.8	142	2.1	140	2.6	142	1.4

Note. RT = response times, PE = percentage of errors, SOA = stimulus onset asynchrony, IRT = interresponse times.

4.4. Discussion

Experiment 2 yielded four main results. First, and most important, a motor action (B) was initiated more quickly when a concurrently prepared action (A) resulted in the same instead of a different auditory effect. Thus, collateral facilitation of effect-corresponding responses was found even though, unlike in Experiment 1, the initially prepared action (A) remained relevant whilst action B was initiated. This clearly suggests that collateral facilitation is a functional consequence of ongoing response selection rather than simply an aftereffect of having refrained from a selected response.

Second, preparing action A generally influences the initiation of action B more strongly the smaller the SOA between the two response stimuli. This reflects the standard result from dual-task research that two tasks in general interfere with each other more, the more they temporally overlap (e.g. Welford, 1952). Thus, the increasing RTs/error rates for action B with decreasing SOA presumably result from interference between the preparation of action A and the initiation of action B, which is stronger the more the two processes overlap in time.

Third, the impact of the correspondence of the sensorial effects on the initiation of action B tended to be stronger with a short SOA, that is the earlier during the preparation of action A the initiation of action B was requested. This indicates that the auditory action effects have a stronger influence on earlier rather than on later phases of action preparation.

Fourth, the influence of effect-correspondence was not observed in the interresponse times (action A), which probably reflects that the planning of action A has been completed in advance of the initiation of action B.

Altogether, Experiment 2 provided further evidence for the collateral facilitation hypothesis. Note that whereas Stoet and Hommel (1999) using the ABBA paradigm observed that a response was *inhibited* when it shared a feature with a concurrently prepared response, we found that it was facilitated. We tentatively conclude that the reason for this contradictory outcome is that, whereas the responses in our experiments overlapped with respect to their *distal sensorial effects*, the responses in the study by Stoet and Hommel (1999) overlapped with respect to their *spatial location*. Apparently the distal (auditory) effect of a response is not a response feature functionally equivalent to a response's spatial location. However, before taking this contention seriously we sought to replicate and extend our finding in a third experiment.

5. Experiment 3

So far, we used rather simple keypress responses. In contrast, Stoet and Hommel (1999) had participants perform considerably more complex actions. Actually action A could be considered as a motor sequence subjects had to release a homekey to touch another response key and to return to the start position again. The difference in response complexity may have somehow caused the contradictory patterns of results of the two studies. One may for example argue that with the simple actions in the present experiments subjects used a different strategy [3]: rather than planning a distinct action A, and inserting a second, distinct action B, subjects may construct a unitary plan of a two-element sequence consisting of the two consecutively to-be-performed actions (i.e. an action sequence B–A). Although observing faster construction of a plan with response elements that result in the same effect would not be a trivial finding in itself, we felt that adding an experiment with a more complex action A, thereby making a ''sequence strategy'' less likely, would make our case more convincing.

The initially planned action (A) was a pen-transport task: participants were to lift a pen from a touch sensitive graphic tableau, to move it a certain distance to the left or right and to put it down again on the tableau surface. This action is reasonably more complex than simply pressing a key down. The first to-be-performed response (B) was a force-varying action. Participants were to press the pen onto the tableau either softly or forcefully (cf. Carlton, Carlton, & Newell, 1987; Kunde, 2001 for the use of this type of response). The two actions again resulted in tones of the same or of different pitch. We again predicted that action B would be initiated more quickly if it leads to the same auditory effect as the concurrently planned action A.

5.1. Method

5.1.1. Participants

A fresh sample of 24 undergraduates (4 men, 20 women) at the University of Würzburg (aged 19–25 years) participated.

[3] We are grateful to Bernhard Hommel for calling our attention to this argument.

5.1.2. Apparatus, stimuli and procedure

The responses were made with a Wacom ArtPad graphic tableau (KT-0405-R) with a pressure-sensitive pen. The position of the pen and the pressure it exerted on the tableau was sampled with a rate of 200 Hz. The pen was held with the right hand. At the beginning of a trial the pen should be comfortably positioned in the middle of the pad, with a force of more than 0 cN but less than 50 cN. After an intertrial interval of 1500 ms, each trial started with an auditory warning click (100 Hz, 20 ms), followed by an 800 ms blank interval. Stimulus A was a left-pointing or right-pointing red arrow (15 mm wide, 10 mm high) presented for 300 ms. Participants were instructed to prepare a lateral shift of the pen according to the direction of the arrow. This action (A) should be prepared as well as possible. Either 500, 1000, 1500 or 2000 ms after the onset of stimulus A, stimulus B (a green-colored plus or minus sign) was presented and remained visible until response B was initiated. Response B was to briefly press the pen onto the tableau either softly (i.e. with a peak force of more than 50 cN but less than 200 cN) when a minus sign was presented, or forcefully (i.e. with more than 200 cN) when a plus sign appeared. Response time was the interval between stimulus presentation and the point in time when a pen pressure of more than 50 cN was measured. The participants were instructed to start Response B as quickly as possible, immediately followed by the already prepared action A. The interresponse time was the interval between the point in time the peak force of action B was reached and the point in time the pen hit the tableau after it had been moved laterally.

Both actions resulted in a tone of certain pitch. Immediately after the maximum pen pressure of action B was identified, either a low (250 Hz) or high tone (650 Hz) (65 dB) was presented by two loudspeakers positioned on the left and right side of the monitor. The tones were produced by the soundcard of the computer, which was programmed to produce a tone of maximal rise of loudness and a decay over a period of about 300 ms duration. When a forceful response was detected a low-pitched tone was presented and with a soft response a high-pitched tone was presented. This R–E mapping was constant for all participants because we felt that it resembled a high R–E compatibility (cf. Kunde, 2001). Action B also resulted in a low-pitched or high-pitched tone. For half the participants a high-pitched tone was emitted when the pen hit the tableau again after having traversed to the left side and a low-pitched tone was emitted after having traversed to the right side. For the other half this mapping was reversed. Thus, for each participant, the actions A and B resulted in the same tones in half of the trials and they resulted in different tones in the other half of trials.

In the case of an error, that is, when action B was exerted with an inappropriate force or action A was incorrectly performed (i.e. the pen was moved to the wrong side, the pen was not lifted or movement width was too short) a brief visual error feedback informing about the detected error(s) was presented at the end of the trial.

In the training phase subjects performed 64 trials of practice to familiarize them with the type of responses and to allow for the acquisition of the respective R–E mappings. Then they performed 192 experimental trials with each combination of first and second response equiprobable within each level of SOA. The order of trials was random. After every 64 trials there was an opportunity for a brief break.

5.2. Results

Responses with RTs below 150 ms or above 1500 ms (action B) and below 50 ms or above 1000 ms (interresponse times between actions B and A) were considered as outliers and discarded (2.7% of the A-responses and 2.1% of the B-responses). For the RT analysis only trials with a correct response in actions A and B were considered, whereas the error rates for actions B and A were assessed independently. RTs and error rates for actions B and A were entered into an ANOVA for repeated measures with the variables of effect-correspondence (corresponding vs. noncorresponding effect between the two actions) and SOA (500, 1000, 1500, 2000 ms). Table 2 shows the mean RTs and error rates of each factorial combination of these two variables.

5.2.1. Action B

RTs decreased with increasing SOA ($F(3,69) = 6.84$; $p < 0.01$). Additionally, action B was overall initiated more quickly when it led to same effect as action A ($F(1,23) = 7.19$; $p < 0.02$). The interaction of these two factors did not reach significance ($F(3,69) = 1.35$; $p > 0.10$). However, single contrasts revealed that the influence of effect-correspondence was clearly present with an SOA of 500 ms (24 ms, $F(1,23) = 6.91$; $p < 0.02$) but clearly absent with the longest SOA of 2000 ms (2 ms, $F < 1$). No effect approached significance in the analysis of error rates (all *Fs* < 1).

5.2.2. Action A

There were no significant effects, neither in the analysis of interresponse times nor in the analysis of error rates of action A (all *ps* > 0.25).

Table 2
Experiment 3: response times (in ms) and error rates (in %) for action B (first action) and interresponse time for action A (second action) as a function of SOA and effect-correspondence between actions A and B

Effect correspondence	SOA															
	Action B								Action A							
	500 ms		1000 ms		1500 ms		2000 ms		500 ms		1000 ms		1500 ms		2000 ms	
	RT	PE	RT	PE	RT	PE	RT	PE	IRT	PE	IRT	PE	IRT	PE	IRT	PE
Noncorresponding effects	576	7.2	548	7.5	539	6.7	537	6.5	301	0.6	305	0.3	302	0.2	303	0.8
Corresponding effects	552	7.8	543	6.9	528	6.2	535	7.1	295	0.4	293	0.6	301	0.2	305	0.4

Note. RT = response times, PE = percentage of errors, SOA = stimulus onset asynchrony, IRT = interresponse times.

5.3. Discussion

Experiment 3 replicated all major results of Experiment 2 and therefore extended the validity of the collateral facilitation hypothesis to a situation with a different set of more complex responses. First, action B was initiated more quickly when it resulted into the same effect as the concurrently prepared action A. It is therefore unlikely that response complexity is a relevant factor for collateral facilitation to occur. Second, the planning of action A interfered with the initiation of action B, and more so the closer the temporal proximity between planning of action A and the request to initiate action B, hence the SOA effect. Third, whereas the influence of the tone effects was, as in Experiment 2, clearly present with the shortest SOA, it was absent with the longest SOA and intermediate with intermediate SOAs, although the interaction of SOA and effect-correspondence missed significance. Yet, to explore if the SOA-related variation of the correspondence effect we consistently found in Experiments 2 and 3 reflects a reliable aspect of the data, we collapsed together the data of these two experiments. In the analysis of the combined data the interaction of SOA and effect-correspondence was reliable ($F(3, 141) = 3.30$; $p < 0.03$), suggesting that the failure of reaching significance is simply a matter of sample size. [4] Fourth, as in Experiment 2, effect-correspondence had virtually no influence on action A.

6. General discussion

The present experiments were prompted by the idea that motor acts are cognitively represented and thus accessed by their sensorial effects. In order to support this assumption, motor actions were coupled with auditory effects and participants were required to prepare for a certain action. The participants in Experiment 1 sometimes had to execute another action instead of the prepared one, and in Experiments 2 and 3

[4] This interaction is of some interest from the perspective of dual task research. The observation that the preparation of a certain action A interferes more strongly with the request to initiate another action B the closer the temporal proximity of the two actions is by no means is a new finding but well known as the psychological refractory period (PRP) effect. It is typically assumed that the PRP-effect results from a bottleneck or central resource that allows the preparation of only one response at a time (e.g. Welford, 1952). The theoretically relevant observation of the present study is that producing two responses that share a common sensorial effect markedly reduces the PRP effect (i.e. the increase of RTs with decreasing SOA). Greenwald and Shulman (1973) reasoned that from an ideo-motor point of view the costs of selecting a response are determined by the effort of activating and maintaining the images of the response's sensorial effects. They argued that when the stimuli in a PRP paradigm show high similarity with the responses they require, the effortful internal activation of response images is bypassed (by means of external stimulation of effect images), and PRP effects should decrease or even disappear. Indeed Greenwald and Shulman (1973) found virtually no PRP effects in such conditions (see also Klapp, Porter-Graham, & Hoifjeld, 1991). We assume that the decrease of the PRP effect in the present study resulted for a very similar reason. Whereas Greenwald and Shulman (1973) reduced the effort of internally anticipating response effects by presenting these effects as stimuli, we reduced the effort of internally anticipating response effects by reducing the number of to-be-activated effect representations from two to one in the case of overlapping auditory effects.

they always had to execute another action before executing the prepared one. Under the assumptions that (i) the preparation of an action indeed comprises an anticipation of its sensorial effects and (ii) this anticipation is time- consuming, it was predicted that the initiation of an unprepared action is accomplished faster, if it produces the same effect as concurrently prepared action.

Experiment 1 showed that (after a sufficient amount of practice) it was indeed slightly easier to switch from a prepared to an actually to be performed action when both resulted in identical rather than in different auditory effects. Experiment 2 revealed the same result in a situation where the initially prepared action had to be carried out in each individual trial, and in contrast to Experiment 1 had thus to remain in a preparatory state while a second response was initiated. These results were replicated in Experiment 3 with a set of more complex actions. The variation of the temporal proximity between planning of action A and initiation of action B showed that collateral facilitation of effect-corresponding actions was especially pronounced in early phases of action preparation. Altogether these results support the view that action effects play a substantial role in action preparation.

The fact that sensorial effects influenced the initiation of responses under the present task conditions seems noteworthy to us for two reasons. First, the action effects in the present experiments seemingly influenced the initiation of the preceding actions "backwards in time". This at first glance paradoxical influence of an effect on its cause can be resolved by the basic assumption that underlies the present experiments that representations of action effects become activated in advance of overt responding for the purpose of response preparation. Thus, the present experiments provide some evidence for the claim that (i) effect codes actually become endogenously activated in response preparation and that (ii) their anticipatory activation has the power to prime associated motor patterns (cf. Kunde, 2001 for additional evidence). Second, the co-activation of an action B with an effect that corresponded to the effect of an already prepared action A, was neither instructed nor would it have been a reasonable strategy, since the transition probabilities between any pair of two responses were constant. This observation suggests that anticipated effects evoke associated actions in an automatic fashion. [5]

An intriguing outcome of the present study that calls for some discussion is that it revealed benefits for the initiation of effect-overlapping actions, rather than costs as has been found in previous studies (Stoet & Hommel, 1999, in press). We want to discuss two not mutually exclusive reasons for this apparent discrepancy. First, one could argue that the tones in the present experiment were irrelevant action

[5] It is likely, however, that subjects have some degree of freedom in terms of which sensorial effects they represent their responses (cf. Wulf, Hoess, & Prinz, 1998). This may account for the fact that the influences of the tone effects were reliable but small in size. After all it is tenable that not all subjects (and not all the time) code their responses in terms of the auditory effects. It should also be noted that we conducted some pilot experiments using visual instead of auditory response effects that yielded even smaller and mostly unreliable results. We inferred from this outcome that the acquisition of an R–E association with a visual effect may be less probable because visual effects are more likely to be ignored (e.g. by simply looking away, closing ones eyes and so forth).

features and that action plans may include only relevant response features. Because the relevance of action effects was not varied in the present study, this objection remains to be tested. But if one follows this argument it needs to spelled out what distinguishes a relevant from an irrelevant response feature and why an anticipation of seemingly "irrelevant" action effects should take place at all when not functional, and thus not "relevant" for action planning. Second, it is conceivable that initiating an action that has an overlapping feature with an already prepared action implies both benefits as well as costs compared with initiating an action with no feature overlap. We focused our analysis on the benefits that arise when only a single effect-feature, shared by two actions, has to be recollected, whereas Stoet and Hommel (1999) focused on the costs that arise when a feature has to be "unbound" from an already existing action plan. Presumably, it will depend on the specific time exposures of recollecting a feature versus unbinding it whether overall RT benefits or overall RT costs of feature overlap emerge: if recollecting a feature is very time-consuming, and unbinding it is not, then one will observe feature-overlap benefits in RTs, as we found. If however, recollecting a feature is not very time-consuming, but unbinding is, one will find costs of feature overlap in RTs as in previous studies. The crucial point here is that the spatial features of a response and its auditory effects may indeed differ in the time their recollection requires. Because every movement of the body can be described in terms of its spatial features, it appears plausible that these features can be accessed very quickly. As a consequence the benefit of recollecting one instead of two spatial features may be negligible compared to the costs of unbinding them from an already constructed action plan, resulting in RT costs of spatial feature overlap. In contrast, the auditory effects introduced in the present study are very unfamiliar response consequences (probably never experienced by the participants before) and their recollection may require considerably more time than unbinding these effects from an already existing action plan, resulting in RT benefits of effect overlap. Future experiments, using different response features and response effects should clarify if this consideration is correct.

To conclude, we think the present study convincingly shows that planning a motor action incorporates a recollection of the action's sensorial effects, which provides support for the core assumption of the ideo-motor principle. We think the results are important since it appears that no other traditional theory of motor control could account for such an impact of forthcoming action effects. Thus, although a number of questions need to be resolved, the present research, even in this preliminary stage, highlights the role of effect anticipation on action planning. We think it is worthwhile to further investigate this impact in more detail.

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