Psychological Research (2003) 67: 153–159
DOI 10.1007/s00426-002-0114-5

ORIGINAL ARTICLE

Wilfried Kunde

Temporal response-effect compatibility

Received: 21 December 2001 / Accepted: 23 July 2002 / Published online: 25 February 2003

Abstract This study investigated the impact of duration-varying response effects on the generation and execution of duration-varying responses. Participants performed short or long keypresses which produced auditory effects of corresponding duration (short response -> short tone, long response -> long tone) or of noncorresponding duration (short response -> long tone, long response -> short tone). Experiment 1 revealed faster responding with a corresponding than with a noncorresponding Response-Effect (R-E) mapping; that is, a temporal R-E compatibility effect. Additionally, increasing effect duration increased response latencies, whereas it decreased keypress duration. Experiment 2 showed that the influence of temporal R-E compatibility persists even when responses are cued in advance, suggesting that at least part of it originates from response generation processes occurring later than a traditional response selection stage. These findings corroborate and complement effect-based theories of action control which assume that the selection, initiation, and execution of movements is mediated by anticipation of their sensory effects.

Introduction

It is a well-known finding in experimental psychology that in choice reaction tasks (CRTs) performance is superior when stimuli afford compatible rather than incompatible responses. It is, for example, easier to respond to a left-sided stimulus with a left response and to a right-sided stimulus with a right response than with the reversed Stimulus-Response (S-R) mapping (Fitts & Seger, 1953). This is the case even when stimulus location is nominally task-irrelevant, e.g. when responding to the color of a laterally presented stimulus (Simon, 1969).

Most accounts of S-R compatibility effects agree that the presentation of a stimulus automatically primes its spatially corresponding response. This automatic response activation is helpful when the stimulus actually requires the primed response, but it produces response competition, and a deterioration of performance, when the primed response must not be carried out (cf. Hommel & Prinz, 1997 for a recent overview).

Influences of S-R compatibility are not confined to the S-R feature of spatial location. Recently, Grosjean & Mordkoff (2001) identified a temporal instance of S-R compatibility: Responses are initiated faster when briefly presented stimuli require short keypresses and longer lasting stimuli require long keypresses rather than with the opposite S-R mapping. As is the case in the spatial domain, these temporal compatibility effects occur even when stimulus duration is task-irrelevant, suggesting that stimuli of certain duration automatically evoke responses of corresponding duration, as stimuli in a certain location evoke responses of corresponding locations (Kunde & Stöcker, 2002).

Interestingly, compatibility influences manifest themselves not only between stimuli and responses (i.e. S-R compatibility) but also between responses and their contingent sensory effects (i.e. R-E compatibility). For example, responses in a certain location are initiated faster when they produce a spatially corresponding visual effect (e.g. lighting up a spatially corresponding lamp) than when they produce a spatially noncorresponding effect (Ansorge, 2002; Hommel, 1993; Kunde, 2001a; Riggio, Gawryszewski, & Umiltà, 1986). Likewise, responses of a certain force are initiated faster when they lead to auditory effects of corresponding intensity (loudness) rather than effects of noncorresponding intensity (Kunde, Koch, & Hoffmann, 2003).

The observation of such R-E compatibility effects has theoretically relevant implications. Most notably it implies that contingent but irrelevant response effects (i.e. post-response stimuli) become anticipated in advance of

W. Kunde
Institut für Psychologie, Universität Halle-Wittenberg,
06099 Halle (Saale), Germany
E-mail: w.kunde@psych.uni-halle.de

overt responding – otherwise they could not influence responses that precede them in time. This inference is of interest from the perspective of effect-based theories of motor control which hold that actions are represented in terms of – and thus necessarily accessed by – their anticipated sensory effects (e.g. Hoffmann, 1993; Hommel, 1996a; Hommel, Müsseler, Aschersleben, & Prinz, 2001; James, 1890; Prinz, 1997). The existence of R-E compatibility suggests a) that the proposed effect anticipation for the purpose of action production actually takes place, and b) that anticipatory effect codes have the same (or similar) power to evoke corresponding motor patterns as sensorially activated stimulus codes in traditional S-R compatibility experiments (cf. Tlauka & McKenna, 1998). If this conjecture is correct, R-E compatibility effects can serve as a useful indicator for the process of effect anticipation in movement production – a process scarcely investigated and poorly understood so far (Kunde, Hoffmann, & Zellmann, 2002; Kunde, 2001b).

However, to verify the validity of R-E compatibility effects as an inferential tool for the study of anticipatory effect codes in movement production, it is essential to know whether similar phenomena and explanatory principles as known from S-R compatibility research hold for R-E compatibility effects as well. Given the presumed functional parallelism between stimulus codes in S-R compatibility and anticipatory effect codes in R-E compatibility, and in view of recent evidence for temporal S-R compatibility effects, the prospect offers itself that similar temporal compatibility effects might manifest themselves also between responses and effects of varying duration. Testing this prediction was the main purpose of the present study.

Experiment 1

To explore the existence of a temporal R-E compatibility effect, participants performed keypresses of short or long duration (often denoted as ‘dit’ and ‘dah’ reactions according to their labels in the Morse alphabet) in reaction to a color stimulus. In different sessions the keypresses produced auditory effects of corresponding duration (short keypress-short tone, long keypress-long tone) or of noncorresponding duration (short keypress-long tone, long keypress-short tone). A temporal R-E compatibility should show up as faster (and more accurate) responding with a corresponding than with a noncorresponding R-E mapping.

Anticipated effects may not only affect the timepoint responses are started (i.e. response times, RTs) but also the way these responses are physically carried out. Recent evidence suggests that cognitive processes can affect the *when* and *how* of responses in an independent manner, and thus RTs and measures of response execution afford insight into mutually not exchangeable aspects of response production (Abrams & Balota, 1991; Ulrich et al., 1998). Therefore the subsequent data analyses also concerned the response durations the participants actually performed as a measure of response execution. To avoid misunderstandings, the actual performed response duration (i.e. the dependent variable) will be denoted by the acronym *RD*, whereas the spelled out term *response duration* is used when referring to the response that should have been made (i.e. a short or long keypress).

Method

Participants Twenty undergraduates from the University of Würzburg participated in fulfillment of a course requirement.

Apparatus and Stimuli Stimuli were presented on a VGA Monitor. Responses were recorded by a single microswitch connected to the parallel port of an IBM-compatible computer. The key (12×12 mm) was pressed with the index finger of the right hand, and was positioned centrally in front of the subjects. The imperative stimulus was a red or green (from the standard VGA-Palette) colored circle (45 mm diameter) presented in the middle of the screen on a black background. The required response was either a brief keypress (“dit” response: release of the response key in less than 121 ms after pressing the key) or a longer keypress (“dah” response: release of the key between 121 ms and 300 ms after pressing the key). Half the participants performed a dit response to a red stimulus and a dah response to a green stimulus, whereas this S-R mapping was reversed for the other participants. The release of the key produced a tone (800 Hz, 72dB) of either short duration (80 ms) or longer duration (240 ms). The tone was produced by the soundcard of the PC and presented by two loudspeakers positioned directly behind the response key.

Procedure After an inter-trial interval of 1000 ms, a fixation cross (1 cm × 1 cm) was presented in the middle of the screen and replaced after 1000 ms by the imperative color stimulus. Then RT (starting from stimulus onset) and RD were measured. When RD did not match the required duration or exceeded the upper limit of 300 ms, a visual error feedback was displayed for 1500 ms (the terms “Key pressed too long” vs. “Key pressed too short” in German). In case of an error, the effect of the actually performed response was presented. After having the correct response durations demonstrated by the experimenter about 10 times, participants performed 24 practice trials. Then they worked through a blocked condition with corresponding R-E mapping (dit reaction-short effect tone, dah reaction-long effect tone) and a condition with non-corresponding R-E mapping (dit reaction-long tone, dah reaction-short tone). Each mapping condition consisted of 8 miniblocks of 16 trials, respectively, in which each stimulus was presented eight times in random order. Half of the participants received the corresponding R-E mapping first, and then after a brief rest of about 5 min., the non-corresponding mapping, whereas for the other participants the order of mappings was reversed. The participants were informed that each response would produce a certain tone, which in separate blocks would either correspond or not correspond with the keypress duration. They were instructed to respond to the stimuli as quickly and as accurately as possible, irrespective of the auditory effects.

Results

Response times Responses with RTs below 100 ms and above 1000 ms (0.2% of the data) and responses with RDs above 300 ms (3.9%) were excluded. RTs were submitted to an analysis of variance (ANOVA) with response duration (short [dit] vs. long [dah]) and effect duration (short [80 ms] vs. long [240 ms]) as repeated measures. The mean RTs, percentages of error (PE) and RDs from the factorial combinations of these variables are listed in Table 1.

Table 1 Reaction times (RTs), percentages of error (PE), response duration (RD) as a function of response type (short [dit] vs. long [dah]) and response effect (short vs. long) in Experiment 1

Response	Effect duration					
	short			long		
	RT	PE	RD	RT	PE	RD
short (dit)	365	5.9	77	390	6.4	70
long (dah)	394	6.6	220	387	9.4	209

RT = Response time (ms), PE = Percentage of error (%), RD = Response duration (ms)

The ANOVA of RTs revealed significant all three possible sources of variance. First, in replicating earlier findings (Klapp, 1995; Kunde & Stöcker, 2002) dit responses were initiated more quickly than dah responses (377 ms vs. 391 ms, $F(1,19) = 5.71$; $p < .05$). Second, responses that produced a short effect were on average initiated more quickly than responses that produced a long effect (379 ms vs. 388 ms, $F(1,19) = 6.95$; $p < .02$). Third, there was an interaction between response duration and effect duration ($F(1,19) = 7.68$; $p < .02$). RTs were faster in the two conditions with a corresponding R-E mapping than in the two conditions with a noncorresponding mapping.[1]

Error rates Due to the use of a 2 CRT and the initial exclusion of all too long responses, all errors with dit responses were erroneous dah reactions whereas all errors with dah responses were erroneous dit reactions. An inspection of error trials with respect to RTs and RDs revealed no systematic effects. In the analysis of error rates, the main influence of effect duration reached significance and had the same direction as in RTs ($F(1,19) = 6.95$; $p < .02$). The main effect of response duration and its interaction with effect duration was not significant (*ps* > .12, respectively).

RDs To explore the relationship of response onset and response execution, we computed the correlation coefficients between RTs and RDs across trials for each participant and within each cell of the experimental design. The mean of these correlations was nearly zero (r (RT-RD) = .029). An ANOVA with the variables required response duration and effect duration revealed (somewhat trivially) shorter RDs for dit responses than for dah responses (dit: 74 ms, dah: 214 ms, $F(1,19) = 620.23$; $p < .01$). Additionally, RD was shorter with a long effect than with a short effect, thus response effects exerted a contrasting bias on response execution ($F(1,19) = 26.10$; $p < .01$). This was the case for dit responses as well as for dah responses ($F < 1$ for the interaction of response duration and effect duration).

[1]Whereas dit responses profited considerably from a compatible (short) tone in comparison to an incompatible (long) tone, dah responses profited only marginally from a compatible (long) tone in comparison to an incompatible (short) tone. It is thus tempting to speculate that the R-E compatibility effect is stronger for dit than for dah reactions. Yet, such an inference is not possible. Because of potential baseline differences between individual responses or response effects, the only valid measure for a compatibility effect is the *interaction* between them, which includes all responses and effects and thereby eliminates all baseline differences between them. It is therefore not meaningful to asses a compatibility influence for either a single stimulus, response, or response effect in isolation (cf. Kornblum & Lee, 1995, p.860 for a comprehensive discussion of this methodical issue).

Discussion

Experiment 1 establishes a new phenomenon, temporal R-E compatibility: Performance is superior with a corresponding than with a noncorresponding relationship between the duration of responses and the duration of their contingent auditory effects. This broadens the validity of the basic R-E compatibility phenomenon and corroborates the inference that anticipatory effect codes produce R-E compatibility effects for the same features – and presumably by similar mechanisms – as stimulus codes produce traditional S-R compatibility effects (Ansorge, 2002; Kunde, 2001a; Koch & Kunde, 2003).

The analysis of RDs revealed two mentionable results. First, RTs and RDs were uncorrelated trial-by-trial, which accords with other zero (or near zero) correlations in the literature and suggests that these behavioral indices reflect dissociable aspects of response production (cf. Grosjean & Mordkoff, 2001; Mordkoff, Miller, & Roch, 1996; Ulrich et al., 1998). Second, increasing effect duration on average decreased RDs. The plausible reasons for this contrast influence of effect duration on RD will be discussed in the General Discussion section.

Experiment 2

After having identified the basic temporal R-E compatibility effect, Experiment 2 intended to explore its functional locus within the movement production process. We have recently observed that R-E compatibility effects, at least in the domain of intensity, persist even when responses were fully prepared in advance, that is with response certainty (Kunde et al., 2003). This observation is of twofold theoretical significance. First, it contradicts stage-oriented compatibility models which assume that compatibility effects originate from a response selection stage and should thus not occur when response selection has already been completed beforehand (Kornblum et al., 1990; Sanders, 1980). Second, it suggests that anticipatory effect codes, which cause the R-E compatibility effects, mediate not only early aspects of movement specification (response 'selection' in stage theory terms) but also contribute to the ultimate release of already specified actions (response 'initiation') – in our view an important, but barely acknowledged, function of effect codes in movement production (cf. Greenwald, 1970; Hommel et al., 2001).

Experiment 2 explored whether these inferences hold for the R-E dimension of duration as well. Therefore participants were provided with either a valid or neutral response cue, in varying time-points ahead of the imperative stimulus. We expected first, to replicate the temporal R-E compatibility effect of Experiment 1 when no response preinformation is provided (i.e. with an uninformative neutral cue), and, second, to find this influence persisting even when responses are prepared in advance (i.e. with a 100% valid precue).

Method

Participants Sixteen undergraduates from the University of Würzburg participated in fulfillment of a course requirement.

Apparatus, stimuli and procedure The same apparatus, stimuli and procedure as in Experiment 1 were used with the exception that the fixation cross now served as a response cue. The cross was presented in white color (and served as a neutral response cue) in one-third of the trials, whereas it had the color of the next imperative stimulus (i.e. was a valid cue) in the other two-thirds of trials. Participants were informed that a colored fixation cross predicted the next required response with 100% certainty, and they were instructed to prepare the cued response as efficiently as possible. The onset of neutral and valid cues preceded the stimulus onset by a randomly varying cue-stimulus interval (CSI) of either 200 ms, 1500 ms, or 2000 ms, respectively. The fixation cross was replaced by the imperative color stimulus, which remained visible until execution of the response. The maximum CSI was set to 2000 ms because Klapp (1995) found dit-dah responses to be fully prepared then. Half the participants performed a dit response to a red stimulus and a dah response to a green stimulus, whereas this S-R mapping was reversed for the other participants.

The order of stimuli was random. After 24 practice trials the participants performed 8 miniblocks of 36 trials with the corresponding and noncorresponding R-E mapping, respectively. Half the participants received the corresponding R-E mapping first and then, separated by a brief break of 5 min., the noncorresponding R-E mapping, whereas this order was reversed for the other participants.

Results

Responses with RTs below 100 ms or above 1000 ms (0.5% of all responses) or RDs of more than 300 ms (3.6% of all responses) were discarded.

Response times RTs from correct responses were entered into an ANOVA with the repeated measures of cue type (neutral vs. valid), cue-stimulus interval (200 ms, 1500 ms, and 2000 ms), response duration (short [dit] vs. long [dah]) and effect duration (short [80 ms] vs. long [240 ms]). The mean RTs, error rates and RDs from the factorial combinations of these variables are listed in Table 2.

RTs were lower with valid than with neutral cues, $F(1,15)=369.09$; $p<.01$, and decreased with increasing CSI, $F(2,30)=76.72$; $p<.01$. This decrease was much stronger with valid cues than with neutral cues ($F(2,30)=129.91$; $p<.01$, for the interaction of CSI and cue type), suggesting that, as instructed, valid cues were indeed used for response preparation.

RTs were lower for dit responses than for dah responses, $F(1,15)=10.97$; $p<.01$. The dit-dah difference on average decreased with increasing CSI, resulting in a marginally significant interaction of response type and CSI, $F(2,30)=2.97$; $p<.07$. Response times were higher with an effect tone of long duration than of short duration, $F(1,15)=13.60$; $p<.01$. This influence was more pronounced with unprepared than with prepared responses which produced an interaction between tone duration and cue type, $F(1,15)=8.92$; $p<.01$ (cf. Table 2).

There was an influence of R-E compatibility, reflected in an interaction of response duration and effect duration, $F(1,15)=5.97$; $p<.03$. Dit responses were initiated more quickly when they produced a short tone (364 ms) than a long tone (388 ms) whereas dah responses were initiated more quickly when they produced a long tone (397 ms) than short tone (402 ms). The size of the R-E compatibility effect over CSI differed slightly between valid and neutral cues resulting in a significant four-fold interaction, $F(2,30)=3.33$; $p<.05$. Single comparisons showed, however, that the R-E compatibility effect was reliable even with highly prepared responses, $F(1,15)=12.61$; $p<.01$ with the 2000 ms CSI valid-cue condition. No other effect was reliable (all Fs <1).

Error rates Error rates were higher with neutral than with valid cues, $F(1,15)=6.10$; $p<.05$. Additionally,

Table 2 Reaction times (RTs), percentages of error (PE), response duration (RD) as a function of response cue (neutral vs. valid), response type (short [dit] vs. long [dah]), response effect (short vs. long), and CSI (200 ms...2000 ms) in Experiment 2

Response	Neutral cue						Valid cue					
	short response effect			long response effect			short response effect			long response effect		
	RT	PE	RD	RT	PE	RD	RT	PE	RD	RT	PE	RD
CSI: 200 ms												
short (dit)	440	5.3	84	464	8.0	79	377	5.4	86	399	5.8	80
long (dah)	473	8.2	224	487	8.2	217	419	4.3	222	410	6.0	215
CSI: 1500 ms												
short (dit)	413	6.1	84	446	5.6	78	281	4.9	84	289	4.4	76
long (dah)	465	7.0	223	453	7.9	213	322	1.9	215	308	4.1	210
CSI: 2000 ms												
short (dit)	412	7.2	85	449	5.3	76	258	4.9	85	282	3.1	76
long (dah)	446	7.4	218	450	5.0	208	289	5.0	215	277	3.3	212

CSI = Cue-Stimulus-Interval, RT = Response time (ms), PE = Percentage of error (%), RD = Response duration (ms) there was an interaction between CSI and effect duration, $F(2,30) = 5.16$; $p < .02$: Error rates were lower for short effects (than for long effects) with a short CSI but higher for short effects (than for long effects) with a long CSI. It seems reasonable that the CSI itself represents a duration model that interacts with the anticipation of duration-varying effects. A short CSI might promote the building up of the representation of a short effect (allowing for a lower PE with short than long effects), whereas a long CSI might promote the building up of the representation of a long effect (allowing for a lower PE with long than short effects). No other effect approached significance (all $ps > .14$).

RDs The mean within-condition correlation between RT and RD across trials was again virtually zero, r(RT-RD) = 0.005. Dah responses had longer RDs than dit responses, $F(1,15) = 625.01$; $p < .01$. As in Experiment 1 the response key was pressed longer when the response produced a short tone than when it produced a long tone, $F(1,15) = 7.51$; $p < .02$. Finally, RDs decreased by 4 ms with increasing CSI, $F(2, 30) = 6.40$; $p < .05$, which accords with previous reports of a decrease of RDs under conditions of response certainty (cf. Klapp, 1995; Experiment 2 and 3). No other effect reached significance ($ps > .10$).

Discussion

Experiment 2 replicates the temporal R-E compatibility effect observed in Experiment 1. Moreover, valid response preinformation reduced RTs by about 40%, and the RT-level with a CSI of 2000 ms was well within the range of a simple reaction task for this type of response (Klapp, 1995). Thus, responses were indeed selected as efficiently as possible. Nevertheless a sizeable influence of temporal R-E compatibility persisted. This suggests that anticipated response effects remain functionally relevant for the purpose of response initiation.[2] Finally, it was again found that on average long effects reduced RDs relative to short effects.

[2]This observation additionally provides evidence against a perceptual explanation of R-E compatibility effects: One might argue that the stimuli in the present experiments acquire the meaning of the responses they are assigned to (e.g. a red stimulus may become "short" because it required a short response). The present results may thus be construed as a kind of (acquired) S-R compatibility effect rather than an R-E compatibility effect (cf. Hasbroucq & Guiard, 1991). Previous research has already rejected this account by demonstrating R-E compatibility effects without response-specific stimuli, which makes the acquisition of response-specific stimulus meaning impossible (cf. Kunde, 2001a, Experiment 3). Moreover, the informative cues in the present study were 100% valid, turning the subsequent stimuli functionally into GO-Signals. Stimulus color was thus irrelevant and with all likelihood ignored. A perceptual explanation faces serious problems in explaining why R-E compatibility effects persist even 2000 ms after cue presentation, i.e. long after the perceptual analysis of the cue has finished.

General Discussion

The present study intended to merge two lines of recent research: 1) the study of temporal S-R compatibility on the one hand (Grosjean & Mordkoff, 2001; Kunde & Stöcker, 2002), and 2) the study of R-E compatibility on the other hand (Ansorge, 2002; Kunde, 2001a; Kunde et al., 2003). Adding up the evidence from these domains suggests the existence of temporal R-E compatibility effects, and we have indeed observed this phenomenon in two experiments. The observation that stimuli and anticipated effects exert compatibility effects for the same features corroborates the assumption of a functional resemblance of stimulus codes in S-R compatibility and effect codes in R-E compatibility. This inference is underlined by the persistence of R-E compatibility effects with response certainty, which mirrors similar observations in S-R compatibility research (Hommel, 1995; 1996b).

The existence of R-E compatibility effects in general, and their persistence with response certainty in particular, appears quite counterintuitive when viewed from the perspective of traditional stage theory. First, stage theory's tenet of a linear information transition from stimuli to responses in general leaves little room for an influence of effects that *follow* but do not precede responses. Second, stage-oriented models limit the origin of compatibility effects to a response selection stage that should not contribute to performance when response selection has finished (i.e. responses are prepared, Kornblum et al., 1990; Sanders, 1980). The persistence of R-E compatibility effects under such conditions, however, showed that effect codes maintain their power to affect the motor system far beyond the proposed selection stage, presumably up to the point the action is ultimately carried out. This "late" impact of anticipated action effects points to their functional role for triggering the actual response beginning.

In contrast, R-E compatibility phenomena accord well with theories assuming an effect-based action production (Greenwald, 1970; Hommel et al., 2001; James, 1890). Here, contingent response effects act as the only available mental cues for the recollection of required motor patterns. This provides a natural explanation for why an anticipation even of nominally task-irrelevant, and thus in principle ignorable, response effects occurred in the present study at all. Otherwise, one would have to make the theoretically uncomfortable assumption that effects become anticipated as a more or less useless by-product of an otherwise effect-unrelated response production process (for other impacts of irrelevant effects on performance cf. Hoffmann, Sebald, & Stöcker, 2001; Kunde et al., 2002; Stöcker, Hoffmann, & Sebald, in press). Moreover, effect-based theories make no sharp distinction between different stages of movement production. Rather, effect codes are assumed to become activated for response specification and to remain active until the action is ultimately carried out. The impact of response effects on processes that immediately precede overt responding (i.e. response initiation) fits well into this general picture.

In sum, the present findings can be parsimoniously explained by the assumption that stimulus codes and effect codes contribute to response production in a comparable manner. Once activated, both automatically prime corresponding responses, thereby producing S-R compatibility effects in the case of stimuli, and R-E compatibility in the case of effects. One may even go so far as to assume that stimuli and effects are represented by the same cognitive codes, as proposed by the recent theory of event coding (TEC; Hommel et al., 2001). However, even from perspective of such codes there remains one worthwhile difference between S-R and R-E compatibility which concerns the way these codes become activated, namely *exogenously* (by perception) in S-R compatibility but *endogenously* (by anticipation) in R-E compatibility. This difference in code activation is reason enough to keep the phenomena separated. After all it is the crucial characteristic of goal-oriented actions that they are specified by future and thus endogenously activated effect codes rather than by externally driven stimulus codes. We may unnecessarily limit our insights into this crucial endogenous code activation process if we exclusively studied situations with exogenous code activation as is the case in traditional S-R compatibility research (cf. Kunde, 2001b).

To avoid a mingling of exogenous and endogenous code activation is also warranted by the observation that post-response effects exerted a contrasting bias on response execution (i.e. a short effect increased RD relative to a long effect and vice versa), whereas pre-response stimuli normally exert an assimilating influence (short stimuli decrease RD relative to a long stimulus and vice versa, Grosjean & Mordkoff, 2001). Two not mutually exclusive explanations for this contrast bias are tenable. First, because the physical durations of the effect tones (80 ms and 240 ms, respectively) fitted the range on the accepted response durations (0–120 ms for dit reactions and 121–300 ms for dah reactions) the effect duration may have served as a kind of response model. With an incompatible R-E mapping, however, the effect models do not fit the requested response durations, and to prevent the erroneous execution of an inappropriate response, participants may intentionally shift response durations away from the forthcoming effect duration. I find this account unsatisfying for two reasons. First, contrast biases occur even when responses and effects do not share the same physical dimension (e.g. responses of varying *force* producing effects of varying *loudness*, Kunde et al., 2003) and thus the effects cannot serve as a simple physical model. Second, one would expect that pre-response stimuli are used as response models in the same manner. Yet, stimuli bias response duration execution, if anything, towards but not away from, their own duration (Grosjean & Mordkoff, 2001; Kunde & Stöcker, 2002).

A slightly different second account holds that the various sources of action feedback (tactile, auditory etc.) become integrated into a multisensory effect ensemble. An effect-based response production process may be concerned with attaining a certain duration of this entire effect ensemble. Prolonging the auditory component would therefore require a compensatory shortening of the tactile component (reflected in RD) to maintain a certain constant overall duration. This intermodal compensation account was quite successful in explaining effect-induced contrast biases on the timing of actions where actions, requested at a certain point in time, are emitted earlier the more their auditory feedback is delayed (cf. Aschersleben & Prinz, 1997). A favorable property of this explanation would thus be its broader explanatory validity, covering different experimental domains. Moreover, an effect-oriented control process should reasonably focus on alterable post-response events (i.e. effects) and should not care too much about unalterable pre-response events (i.e. stimuli), which might explain why post-response effects, but not pre-response stimuli, provoke a countermanding response execution (cf. Grosjean & Mordkoff, 2001).

Whichever interpretation is correct, it should be clarified when the adjustment of execution takes place, before or after response initiation. The trial-by-trial zero correlation of RT and RD at least allows for the possibility that the adjustment takes place later than, and independent of, the RT interval – an assumption shared by several recent models of motor control (Desmurget & Grafton, 2000; Glover & Dixon, 2001; Ivry, 1986; Spijkers, et al., 1981). However, a closer investigation of this question is clearly warranted.

A final worthwhile observation of the present study is that it took more time to initiate dah than dit responses – a well known finding traditionally attributed to the more effortful "programming" of dah responses (e.g. Klapp, 1995). More relevant in the present context, it also took on average more time to initiate responses with long than with short effects (which was particularly true for dit reactions where a long effect was incompatible at the same time). If the time needed to initiate a response is increased by merely increasing the duration of some artificial response effect, it is tempting to speculate that the well-known dah-dit difference might likewise originate from differences in the duration of anticipated (tactile) feedback. This would be a challenge of the traditional programming approach to motor control and thus calls for a more thorough investigation.

Acknowledgements I thank Peter Frensch, Michael Zießler, and an anonymous reviewer for their valuable comments on an earlier version of the paper. Funding for this research was provided by a grant of the German Research Foundation to Joachim Hoffmann at the University of Würzburg (Grant HO 1301/6–1).

References

Abrams, R.A. & Balota, D.A. (1991). Mental Chronometry: Beyond reaction time. *Psychological Science,* 2, 153–157.

Ansorge, U. (2002). Spatial intention-response compatibility. *Acta Psychologica,* 109. 285–299.

Aschersleben, G., & Prinz, W. (1997). Delayed auditory feedback in synchronization. *Journal of Motor Behavior, 29(1)* 35–46.

Aschersleben, G., Stenneken, P., Cole, J., & Prinz, W. (2002). Timing mechanisms in sensorimotor synchronization. In W. Prinz & B. Hommel (Eds.), Common mechanisms in perception and action. Attention and Performance XIX (pp. 227–244). Cambridge: MIT Press.

Desmurget, M. & Grafton, S. (2000). Forward modelling allows feedback control for fast reaching movements. *Trends in Cognitive Sciences,* 4, 423–431.

Fitts, P. M., & Seeger, C. M. (1953). S-R compatibility: spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology*, 46 199–210.

Glover, S. & Dixon, P. (2001). Dynamic illusion effects in a reaching task: Evidence for separate visual representations in the planning and control of reaching. *Journal of Experimental Psychology: Human Perception and Performance, 27(3*): 560–572.

Greenwald, A. G. (1970). Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. *Psychological Review*. 77(2) 73–99.

Grosjean, M. & Mordkoff, T. (2001). Temporal Stimulus-Response compatibility. *Journal of Experimental Psychology: Human Perception and Performance*. *27*. 870–878.

Hasbroucq, T., & Guiard, Y. (1991). Stimulus-response compatibility and the Simon effect: Toward a conceptual clarification. *Journal of Experimental Psychology: Human Perception and Performance*, *17*(1) 246–266.

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for complicated movements and a ''memory drum'' theory of neuromotor reaction. *Research Quarterly of the American Association for Health, Physical Education, and Recreation, 31,* 448–458.

Hoffmann, J. (1993). Vorhersage und Erkenntnis [Anticipation and Cognition]. Göttingen: Hogrefe.

Hoffmann, J., Sebald, A., & Stöcker, C. (2001). Irrelevant response effects improve serial learning in Serial Reaction Time tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27(2)* 470–482.

Hommel, B. (1993). Inverting the Simon effect by intention: Determinants of direction and extent of effects of irrelevant spatial information. *Psychological Research*, 55(4) 270–279.

Hommel, B. (1995). Stimulus-response compatibility and the Simon-Effect: Toward an empirical clarification. *Journal of Experimental Psychology: Human Perception and Performance*, *21(4)*, 764–775.

Hommel, B. (1996a). The cognitive representation of action: Automatic integration of perceived action effects. *Psychological Research 59*(3) 176–186.

Hommel, B. (1996b). S-R compatibility effects without response uncertainty. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *49A*(3) 546–571.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). A Theory of Event Coding (TEC): A Framework for Percpetion and Action Planning. *Behavioral and Brain Sciences*, *24*, 849–937.

Hommel, B. & W. Prinz (1997) Theoretical issues in stimulus-response compatibility. Amsterdam: North Holland: Elsevier.

Ivry, R. (1986). Force and timing components of the motor program. *Journal of Motor Behavior*. 18. 449–474.

James, W. (1981 (orig. 1890)). The principles of psychology. Cambridge, MA: Harvard University Press.

Klapp, S. T. (1995). Motor response programming during simple choice reaction time: The role of practice. *Journal of Experimental Psychology: Human Perception and Performance, 21(5)* 1015–1027.

Koch, I. & Kunde, W. (2003) Verbal response-effect compatibility. *Memory and Cognition* (in press).

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulusesponse compatibility: A model and taxonomy. *Psychological Review, 97(2)* 253–270.

Kornblum, S. & Lee, J.W. (1995). Stimulus-Response Compatibility with relevant and irrelevant stimulus dimensions that do and do not overlap with the response. *Journal of Experimental Psychology: Human Perception and Performance*. *21*. 855–875.

Kunde, W. (2001a). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception and Performance*. *27*, (2), 387–394.

Kunde, W. (2001b). Exploring the hyphen in ideo-motor action. Commentary in *Behavioral and Brain Sciences*. *24*, 891–892.

Kunde, W. & Stöcker, C. (2002). A Simon effect for Stimulus-Response Duration. *The Quarterly Journal of Experimental Psychology*. *Section A: Human Experimental Psychology*. 55 (A). 581–592.

Kunde, W., Hoffmann, J. & Zellmann, P. (2002). The impact of anticipated action effects on action planning. *Acta Psychologica*. *109 (2)*. 137–155.

Kunde, W., Koch, I., & Hoffmann, J. (2003). Anticipated action effects affect the selection, initiation and execution of actions. *The Quarterly Journal of Experimental Psychology*. *Section A*. *Human Experimental Psychology* (in press).

Mordkoff, T., Miller, J., & Roch, A-C. (1996). Absence of coactivation in the motor component: Evidence from psychophysiological measures of target detection. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 25–41.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9(2)* 129–154.

Riggio, L., Gawryszewski, L. G., & Umiltà, C. (1986). What is crossed in crossed-hand effects? *Acta Psychologica, 62(1)* 89–100.

Sanders, A. (1980). Stage analysis of reaction processes. In G. E. Stelmach & J. Requin (Eds.), Tutorials in motor behavior (pp. 331–354). Amsterdam: North Holland.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology, 81*, 174–176.

Spijkers, W. A., & Walter, A. (1985). Response processing stages in choice reactions. *Acta Psychologica, 58*, 191–204.

Stöcker, C., Hoffmann, J. & A. Sebald. (2003). The Influence of Response-Effect Compatibility in a Serial Reaction Time Task. *The Quarterly Journal of Experimental Psychology*. *Section A*. *Human Experimental Psychology* (in press).

Tlauka, M. & McKenna, F.P. (1998). Mental imagery yields stimulus-response compatibility. *Acta Psychologica*. 94. 227–252.

Ulrich, R., Rinkenauer, G., & Miller, J. (1998). Effects of stimulus duration and intensity on simple reaction time and response force. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 915–928