Research Article

Auditory Warning Signals Affect Mechanisms of Response Selection

Evidence from a Simon Task

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Abstract. Irrelevant tone (accessory) stimuli facilitate performance in simple and choice reaction time tasks. In the present study, we combined accessory stimulation with a selective attention paradigm in order to investigate its influence on mechanisms of response selection. In the framework of a spatial stimulus-response compatibility task (Simon task), we tested whether accessory stimuli selectively affect bottom up triggered response activation processes (e.g., direct route processing), processing of task-relevant stimulus features (indirect route processing), or both/none. Results suggest a two-component effect of accessory stimuli within this selective attention task. First, accessory stimuli increased the Simon effect due to beneficial direct route processing. Second, accessory stimuli generally decreased reaction times indicating facilitation of indirect route processing.

Keywords: accessory stimuli, warning signal, response selection, Simon task

In reaction time tasks, responses are usually faster when an irrelevant tone stimulus (often called accessory stimulus) is presented prior or simultaneously to the target. Researchers have been especially interested in determining which processes are affected by the accessory stimulus (see Hackley & Valle-Inclán, 2003). Depending on the task context, the available evidence so far suggests that accessory stimuli increase the general readiness to respond nonspecifically (Niemi & Näätänen, 1981; Sanders, 1980), that they increase perceptual detection (Correa, Lupianez, Madrid, & Tudela, 2006; Rolke & Hofmann, 2007), or that they affect late motor components such as response force (Kiesel & Miller, 2007; Miller, Franz, & Ulrich, 1999; Stahl & Rammsayer, 2005; Ulrich & Mattes, 1996). More relevant for the current study, there is also evidence suggesting that response selection or decision processes are affected by accessory stimuli (Fischer, Schubert, & Liepelt, 2007; Stoffels, van der Molen, & Keuss, 1985). Hackley and Valle-Inclán (1998, 1999), for example, found that the stimulus-to-LRP (lateralized readiness potential) onset time interval was shortened by accessory stimuli but not the LRP-to-response interval, and they argued that the accessory tone accelerates premotor stages (e.g., early response selection) but not late response execution processes.

The present study extends this research by investigating the impact of accessory stimuli on mechanisms of response selection in more detail. In particular, we focused on automatic response activation and intentionally mediated stimulus-response (S-R) translation processes that are involved in response selection processes due to task-irrelevant as well as task-relevant stimulus attributes. To address this question, we applied a spatial S-R correspondence task (Simon, 1990) in which participants responded with left and right key presses to the *identity* of stimuli that were presented to the left or right of fixation. A typical Simon effect is expressed in faster responses when the response to the stimulus corresponds with the irrelevant stimulus location (Simon compatible) compared to slower responses when they do not correspond (Simon incompatible). The Simon effect in general is often explained in the framework of dual-route models (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990) that assume a direct and an indirect route of response activation. The direct route is associated with automatic (bottom up) response activation, because stimulus and response features overlap regarding their spatial locations. Therefore, the presentation of a stimulus at a particular location (e.g., left) automatically activates the corresponding response (i.e., left) in terms of an automatic visuo-motor response activation process irrespective of the required S-R mapping for that task (De Jong et al., 1994). The indirect (rule based) S-R translation route, in contrast, reflects the intentional identification and activation of the required response that is related to the identity of the stimulus (see Proctor & Vu, 2006, for an overview).

There are several possibilities of how an accessory stimulus might affect processing within a dual-route framework: First, an accessory stimulus might facilitate direct route processing. Consequently, the automatic response activation process is enhanced leading to facilitated activation of the response (correct or incorrect) that corresponds to the irrelevant stimulus location. This increased level of task-irrelevant response activation certainly benefits the execution of

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the correct response when stimulus location corresponds with the assigned response location but, analogously, it increases interference when the stimulus location does not correspond with the response location. At the same time, overall RT-levels are expected to be relatively unaffected by accessory stimuli, because increased costs for incompatible trials would presumably be compensated by increased benefits for compatible trials in accessory compared to no-accessory conditions. Therefore, we assume that if accessory stimuli affect direct route processing the Simon effect increases (Hypothesis #1).

Second, accessory stimuli might affect processing along the indirect route, that is, processing of task-relevant stimulus features (hypothesis #2). Facilitated processing of task-relevant features could occur at several levels. For instance, accessory stimuli might speed up the extraction of relevant stimulus attributes (e.g., facilitation of perceptual analysis) or benefit the identification or the implementation of the assigned response. In any case, the facilitation of processing task-relevant features would enable faster execution of the correct response (irrespective of Simon compatibility levels). As a result, we expect generally reduced RTs in accessory rather than in no-accessory conditions. Note, however, that reduced overall RT-levels in the accessory condition would technically still be associated with larger Simon effects compared to no-accessory conditions. That is, because Simon effects usually decrease for longer RTs due to an assumed rapid decay of the location information (e.g., Hommel, 1994). However, the consideration of RT distributions in addition to mean RTs can solve this problem and it predicts a Simon effect of equal size for comparable RT-levels.

As a third alternative, accessory stimuli might affect both direct and indirect route processing, which would probably reflect a combination of the two previous assumptions. That is, accessory stimuli affect direct response activation processes and increase the Simon effect irrespective of RT-levels (Hypothesis #1). In addition, however, general RT-levels are reduced due to speeding up the processing of task-relevant stimulus features (Hypothesis #2). As a result, in accessory conditions faster responses *and* increased Simon effects should be observed compared to no-accessory conditions even when considering the Simon effect at comparable RT-levels (Hypotheses #1 + 2).

In the present study, we presented trials in pairs of two (prime- and probe-trials, respectively). In both prime- and probe-trials, participants performed a spatial S-R correspondence (i.e., Simon) task. Yet, accessory stimuli were presented in prime-trials only but never in probe-trials (see below for a detailed description). This ensured that the Simon task in all prime-trials had an accessory-free $N-1$ history. Furthermore, the beginning of each prime-probe pair was self-initiated by participants by pressing a separate "continue" button. This separation served the purpose to further minimize potential $N-1$ transfer effects of the previous Simon task onto prime-trial processing (e.g., Fischer & Hagendorf, 2006). Consequently, in order to explore the impact of accessory stimulation as pure as possible we just considered performance in prime-trials. At the same time, we used this design to capture potential sequential trial-to-trial modulations of the Simon effect.[1] For this purpose, we considered performance in probe-trials. In other words, the effects of $N-1$ history (e.g., Simon compatibility and accessory stimulation in the prime-trial) on processing in N were exclusively studied in the accessory-free probe-trial.

Method

Participants

Twenty-six students (19 females, M age = 24.0 years) of the Technische Universität Dresden participated in the experiment. All had normal or corrected-to-normal vision. All participants claimed right-handedness, attended a single experimental session lasting about 45 min and received course credits.

Apparatus and Stimuli

Right or left pointing white arrows (1.43° × 2.77°) with an inner black cut-out were presented 2.67° left or right from the center of a black screen at a viewing distance of ~ 60 cm. A centralized plus sign (extending 0.57°) was shown as fixation sign. Stimuli were displayed on a 17 in. monitor that was connected to a Pentium I PC. Responses were made by pressing the "Z" (QWERTY keyboard) or the "·" key of the standard computer keyboard with the left and right index finger. The accessory tone stimulus was presented at 700 Hz (~ 50 dB) via loudspeakers at the left and right of the computer monitor.

Procedure

Participants were told to respond to stimulus identity, that is, responding left to left pointing arrows and right to right pointing arrows, respectively. They were also told that the location of stimulus presentation (left vs. right) was completely task irrelevant. We used this Stroop-like version of the Simon task (e.g., Kornblum, Stevens, Whipple, & Requin, 1999) in order to increase the Simon effect and to reduce the impact of decay. Trials were presented in pairs (i.e., prime- and probe-trials). Participants self-initiated the presentation of each prime-probe pair by pressing the space bar with the left or right thumb. Following this button press, the prime-trial started with the presentation of a central fixation sign (which stayed until the end of the prime-probe pair). After a variable interval of 250, 850, 1,450, 2,050, 2,650, and 3,250 ms, the prime-target was presented for

[1] Typically, Simon effects in a current trial N are decreased following incompatible compared to compatible trials in $N-1$ (see Hommel, Proctor, & Vu, 2004; Notebaert, Soetens, & Melis, 2001; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr & Ansorge, 2005 for theoretical accounts).

150 ms in addition to the fixation sign. In the accessory stimulus condition, the tone stimulus (150 ms) was always presented 250 ms *prior* to the onset of the prime-target constituting a constant foreperiod interval from tone onset to prime-target onset of 250 ms. Following a response or a maximum of 1,800 ms after target onset, feedback was presented for 300 ms. If the response was correct, the fixation sign continued whereas in case of a missing or erroneous response, error feedback was displayed instead of the fixation sign. After a constant inter-trial-interval of 1,700 ms, the probe-target was presented in addition to the fixation sign. Hereby, the probe-trial structure was the same as the prime-trial structure. Again, the fixation sign was present throughout the entire prime- and probe-trial and, therefore, could not be used as an additional accessory stimulus. Crucially, 50 ms after the response feedback in the probe-trial, the German word for "next" (weiter) *replaced* the fixation sign and required participants to self-initiate the subsequent prime-probe pair.

Prime-probe pairs, in which half of the prime-trials contained an accessory stimulus, were presented randomly throughout the experiment. The experiment consisted of two blocks each containing 96 prime- and probe-trials. Due to the self-initiation of prime-probe pairs, participants were encouraged to have a break after the first 96 trials. Prior to the experiment, eight prime-probe pairs (four with tone and four without tone) were presented as practice.

Results

Reaction times and error rates of prime- and probe-trials were analyzed separately.

Prime-Trial

Errors (3.3%) and prime-RTs below 150 ms or above 1,000 ms (1.1%) were excluded. Repeated measures ANOVAs included the factors $Simon_{PRIME}$ (compatible vs. incompatible) and accessory stimulus (accessory vs. no-accessory) (Table 1).

A main effect of accessory stimulus revealed that responses were considerably faster in trials in which an accessory stimulus preceded the prime-target (447 ms) compared to trials without an accessory stimulus (498 ms), $F(1, 25) = 178.24$, $MSE = 377.68$, $p < .001$. Overall responses were also faster in Simon compatible (450 ms) than in incompatible conditions (495 ms), $F(1, 25) = 111.66$, $MSE = 466.49$, $p < .001$. In addition, the factor Simon compatibility interacted significantly with the factor accessory stimulus, $F(1, 25) = 26.08$, $MSE = 131.53$, $p < .001$. That is, without an accessory stimulus a Simon effect of 33 ms, $t(25) = -7.98$, $p < .001$, was observed. However, a much larger Simon effect of 56 ms, $t(25) = -10.51$, $p < .001$, was obtained when an accessory stimulus preceded the prime-trial.

Table 1. Prime-trial reaction times (RT in ms), percent error (PE), Simon effect (in ms/%), and standard error of the mean (in parentheses) for conditions with accessory stimulus (AS) and without an accessory stimulus (no AS). C, Simon compatible; I, Simon incompatible

Prime		C	I	Simon effect
RT	No AS	481 (13.8)	514 (14.9)	**33**
	AS	419 (13.6)	475 (16.1)	**56**
PE	No AS	2.4 (0.4)	4.0 (0.6)	**2**
	AS	0.8 (0.3)	5.7 (0.7)	**5**

Yet, Simon effects decrease with time because of passive decay of automatic direct route activation (e.g., Hommel, 1994). Therefore, the finding of larger Simon effects in accessory stimulus conditions compared to no-accessory stimulus conditions is not conclusive because the overall RT-level is decreased with accessory stimuli. To elaborate whether larger Simon effects in accessory stimulus conditions are a result of generally faster RTs (less decay), we additionally analyzed cumulative distribution functions (De Jong et al., 1994). Therefore, we computed percentiles (10, 20, 30, 40, 50, 60, 70, 80, and 90%) for each participant and factorial combination. The interaction between Simon compatibility and percentile was not significant ($F < 1$), and the three-way interaction among $Simon_{PRIME}$, accessory stimulus and percentile fell just above the level of statistical significance, $F(8, 200) = 2.42$, $MSE = 411.37$, $p = .092$. Yet, further testing did not confirm a reliable decay for conditions with ($F < 1$) or conditions without an accessory stimulus, $F(8, 200) = 1.76$, $MSE = 470.38$, $p = .179$ (Figure 1).

Most importantly, however, with the present analysis we aimed at evaluating the size of the Simon effect for RT percentiles containing *comparable RT-levels* between the no-accessory and the accessory stimulus condition. The results were straightforward: For each comparable RT-level, we found larger Simon effects in the accessory stimulus condition than in the no-accessory stimulus condition (see Table 2).

Error rates were increased for Simon incompatible (4.9%) versus compatible trials (1.6%), $F(1, 25) = 37.74$, $MSE = 7.26$, $p < .001$. The factor accessory stimulus did not affect the error rates, $F < 1$. The interaction between Simon compatibility and accessory stimulus on error rates mirrored the RT data, $F(1, 25) = 24.18$, $MSE = 2.90$, $p < .001$. The Simon effect in error rates was much larger in trials with an accessory stimulus (Simon effect of 4.9%) than without an accessory stimulus (1.6%).

Probe-Trial

Both prime- and probe-trial errors (6.1%) and both prime-RTs and probe-RTs that were not within the range of 150–1,000 ms were excluded (1.7%). Repeated measures ANOVAs included the factors $Simon_{PRIME}$ (compatible vs. incompatible), accessory stimulus in the prime-trial (accessory vs. no-accessory), and $Simon_{PROBE}$ (compatible vs. incompatible).

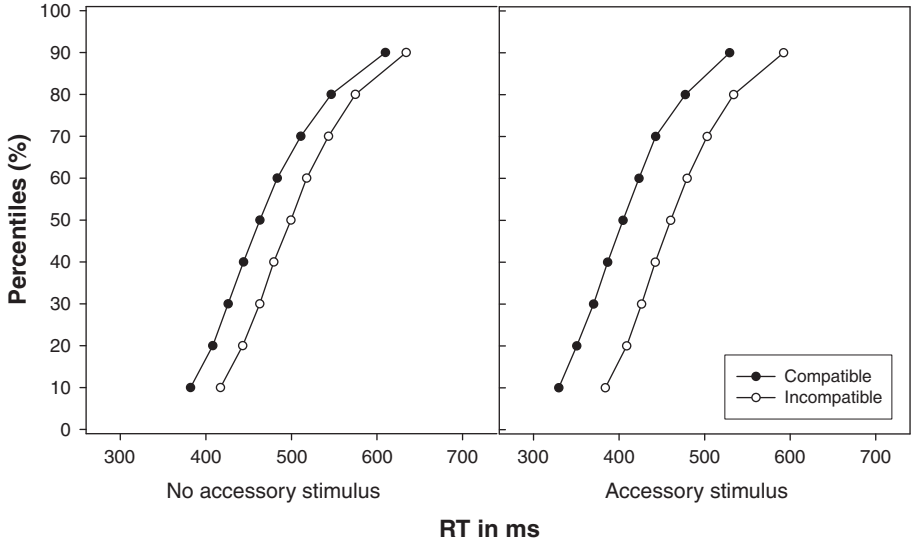

Figure 1. Percentiles (10–90%) of Simon compatible and incompatible reaction times (RTs) separately for conditions with and without an accessory stimulus.

Table 2. Comparison of Simon effects (in ms) across the RT distribution. Comparisons are made for percentiles with similar RT-level (i.e., RT values differing maximally ±11 ms) between the accessory and no-accessory conditions, respectively. The respective RT-level for each percentile is given in parenthesis (in ms)

Comparable RT percentile		Simon effect		
No-accessory	Accessory	No-accessory	Accessory	ANOVA
10% (400)	30% (398)	35	56	$F(1, 25) = 29.75$, $p < .001$
20% (426)	50% (432)	35	56	$F(1, 25) = 26.66$, $p < .001$
30% (444)	60% (451)	37	56	$F(1, 25) = 16.40$, $p < .001$
40% (462)	70% (473)	35	60	$F(1, 25) = 23.10$, $p < .001$
60% (501)	80% (506)	34	57	$F(1, 25) = 8.41$, $p < .01$
80% (561)	90% (561)	28	63	$F(1, 25) = 14.52$, $p < .01$

RTs were shorter in Simon compatible (455 ms) than in incompatible trials (489 ms), $F(1, 25) = 92.14$, $MSE = 647.78$, $p < .001$. This Simon effect depended strongly on Simon conflict in the previous prime-trial as shown in the interaction between $Simon_{PRIME}$ and $Simon_{PROBE}$, $F(1, 25) = 123.89$, $MSE = 666.60$, $p < .001$. That is, we observed a large Simon effect of 74 ms following compatible conditions, $t(25) = 13.79$, $p < .001$, while the Simon effect was eliminated (−6 ms), $t(25) = -1.32$, $p = .200$, when following incompatible prime-trial conditions. Furthermore, we found a three-way interaction among accessory stimulus, $Simon_{PRIME}$ and $Simon_{PROBE}$ on probe-trial RTs, $F(1, 25) = 4.45$, $MSE = 211.56$, $p < .05$.

Compared to the no-accessory condition, an accessory stimulus in the prime-trial increased probe RTs when prime- and probe-trial were compatible (CC), $t(25) = -3.48$, $p < .01$, or when prime- and probe-trial were incompatible (II), $t(25) = -3.24$, $p < .01$. In contrast, probe-trial RTs were not or only little affected when a compatible trial was followed by an incompatible trial (CI), $t(25) = .85$, $p = .404$ or vice versa, an incompatible trial was followed by a compatible trial (IC), $t(25) = -1.86$, $p = .075$ (see also Table 3 and General Discussion). This selective slowing after accessory stimulation might account for the generally slowed responses in the probe-trial (7 ms) following accessory stimulation compared to no-accessory stimulation in the prime-trial, $F(1, 25) = 15.28$, $MSE = 179.43$, $p < .01$, and might also account for the overall slight reduction of the Simon effect by 6 ms for accessory compared to no-accessory stimulation in the prime-trial, $F(1, 25) = 11.65$, $MSE = 37.70$, $p < .01$. Finally, Simon compatibility in the prime-trial also affected overall probe RTs. That is, probe responses were faster (10 ms) following compatible than incompatible prime-trials, $F(1, 25) = 19.70$, $MSE = 236.20$, $p < .001$.

A total of 3.0% of errors were committed in the probe-trials. Participants committed more errors in Simon incompatible (4.6%) than in compatible trials (1.4%), $F(1, 25) = 37.72$, $MSE = 13.91$, $p < .001$. As in the RT data, this Simon effect is modulated by previous Simon conflict, $F(1, 25) = 29.53$, $MSE = 18.07$, $p < .001$. After Simon compatible prime-trials, we observed a Simon effect of 6.4% which was eliminated (0%) after Simon incompatible prime-trials. The effect of the accessory stimulus on the sequential modulation of the Simon effect closely mirrored the pattern of the RT data (see Table 3). However, this

Table 3. Probe-trial reaction times (RT in ms), percent error (PE), Simon effect (in ms/%), and standard error of the mean (in parentheses) for conditions with accessory stimulus (AS) and without an accessory stimulus (no AS). Probe RT are presented depending on previous Simon compatibility in prime-trials. C, Simon compatible; I, Simon incompatible

		C			I		
Prime probe		C	I	Simon effect	C	I	Simon effect
RT	No AS	424 (13.6)	505 (14.5)	**81**	476 (14.4)	468 (15.1)	**−8**
	AS	437 (13.5)	503 (13.9)	**66**	484 (13.8)	479 (14.8)	**−5**
PE	No AS	0.5 (0.3)	7.9 (1.2)	**7**	2.8 (0.7)	2.4 (0.5)	**0**
	AS	0.8 (0.2)	6.1 (1.1)	**5**	1.5 (0.4)	1.7 (0.4)	**0**

influence was only numerically present and did not reach the level of statistical significance, $F(1, 25) = 3.14$, $MSE = 7.60$, $p = .088$. Accessory stimuli in the prime-trial led also to fewer errors in the probe-trial (2.5% vs. 3.4%), $F(1, 25) = 5.03$, $MSE = 7.91$, $p < .05$. Furthermore, probe error rates were generally higher when the prime-trial was Simon compatible (3.8%) compared to incompatible (2.1%), $F(1, 25) = 17.02$, $MSE = 9.32$, $p < .001$.

Discussion

The present study investigated the impact of an irrelevant tone stimulus on concurrent processing of relevant and irrelevant stimulus information within a selective attention task. In particular, we asked how task-irrelevant, auditory accessory stimuli modulate automatic response activation and S-R translation processes in a spatial S-R correspondence task (i.e., Simon task). The results are straightforward and suggest that accessory stimuli reveal two differential effects:

First and in accordance with our Hypothesis #1, the presentation of a task-irrelevant accessory stimulus clearly influenced the size of the Simon effect. That is, the Simon effect was consistently larger in trials containing an accessory stimulus than in trials without one. Consequently, this finding suggests that accessory stimuli in the Simon task particularly facilitate automatic response activation that is associated with direct route processing. Important for this interpretation, increased Simon effects in the accessory compared to the no-accessory condition cannot be attributed to faster responses (and therefore less decay), because larger Simon effects were also found when differences in RT distributions were controlled for (e.g., for each comparable RT-level, see Table 2).

There are at least two alternatives to account for this result: First, the finding of an increased Simon effect due to an accessory stimulus (irrespective of RT-level) is consistent with evidence accumulation models (Coles Gratton, Bashore, Eriksen, & Donchin, 1985; Ratcliff & McKoon, 1988). These models propose that accessory stimuli increase the accumulation of automatic response activation. Faster accumulation rates result in an increase of stimulus location-based response activation irrespective of whether this response is correct or incorrect. Consequently, with accessory stimulation a higher amount of accumulated response activation is reached at the point in time when the assigned response has eventually been identified by means of indirect route. Therefore, increased or facilitated evidence accumulation by accessory stimuli lowers the distance to the threshold of correct response execution (compatible trials) and thus, benefits performance. At the same time, accessory stimuli also lower the distance to the threshold of the incorrect response when the stimulus appears at a location that does not correspond to the required response (incompatible trials). This in particular slows the execution of the correct response and increases the chances of an erroneous response.

Second, increased Simon effects under accessory stimulation may emerge because accessory stimuli directly affect the decay rate of the stimulus location-based response activation. If decay is reduced, response activation associated with the irrelevant stimulus feature would be prolonged, would stay longer in the system and thus, would provide the source of increased interference (e.g., increased temporal code overlap, Hommel, 1994). Consequently, reduced decay of irrelevant response activation also increases Simon effects. Yet, our findings did not show clear decay functions in either of the two accessory stimulus conditions. Therefore, a decay explanation cannot provide a complete account of the accessory effect.

Before we can safely conclude that our results support the assumption that accessory stimuli facilitate the impact (e.g., faster accumulation) of automatic response activation in direct route processing, an alternative reasoning needs to be addressed. That is, the use of arrowheads in the context of a Simon task (e.g., Stroop-like Simon) gives rise to two forms of compatibility that could contribute to the observed performance: S-R and S-S compatibility, respectively. One could argue, for example, that it is not perfectly clear whether the finding of an increased Simon effect under accessory stimulation can be solely attributed to increased automatic response activation on the basis of S-R compatibility (i.e., overlap of irrelevant stimulus location with response location) or whether this finding might (at least partially) result from accessory stimuli affecting perceptually based S-S compatibility as well (i.e., overlap between relevant stimulus identity and irrelevant stimulus location).[2]

[2] In this respect, S-S compatibility might also be responsible for the lack of decay in the present version of the Simon task. We thank Ulrich Ansorge for mentioning this possibility.

To secure that accessory stimuli truly affect automatic response activation processes on the basis of S-R compatibility, we conducted a second experiment which did not contain S-S compatibility, that is, there was no dimensional overlap between relevant (i.e., identity) and irrelevant (i.e., location) stimulus attributes (a detailed description of the experiment is provided in the Appendix). Importantly, the finding of an increased Simon effect in conditions of accessory stimulation was also replicated in a setting in which any contribution of S-S compatibility can be ruled out.

The second main result of the present study is that accessory stimuli not only affected the size of the Simon effect but, additionally, led to considerably faster overall responses in conditions with an accessory stimulus than in conditions without one. Given the present experimental context, this finding is not trivial because it not only replicates previous findings of accessory-driven RT benefits in simple or choice RT tasks (Hackley & Valle-Inclán, 2003; Stahl & Rammsayer, 2005; Ulrich & Mattes, 1996), but importantly, extends them to a task in which different attributes of a single stimulus compete for the control of action. We attribute this general reduction of RTs to an effect of accessory stimuli on the processing of task-relevant stimulus features which is, at least for incompatible trials, associated with processing along the indirect route (Hypothesis #2). Although processing along the indirect route has often been associated with top-down control processes, such as monitoring of whether the accumulated response activation is in accordance with the assigned response, the effect of an accessory stimulus on processing task-relevant stimulus features could practically occur at various levels (e.g., perceptual, response selection and/or motor stages; see for example, Fischer et al., 2007; Hackley & Valle-Inclán, 1999; Kiesel & Miller, 2007; Rolke & Hofmann, 2007). Yet, the question at which level the accessory stimulus impacts processing according to the indirect route cannot be solved with the present data.

Finally, although accessory stimuli increased the Simon effect in the prime-trial, the subsequent trial-to-trial modulation of the Simon effect in the probe-trial was not increased. Instead, the sequential modulation was less pronounced under accessory conditions. Reduced Simon effects following incompatible trials compared to larger Simon effects following compatible trials have often been taken as evidence for conflict triggered control adjustments (e.g., Botvinick, Carter, Braver, Barch, & Cohen, 2001; Stürmer, et al., 2002). Our data show that the elimination of the Simon effect after response conflict is not affected at all by the presence/absence of an accessory stimulus in the prime-trial. This does not support the idea that the effect of the accessory stimulus on the sequential modulation of the Simon effect is related to cognitive control processes (note, however, the possibility of floor effects). Alternatively, the sequential modulation of the Simon effect has also been explained in terms of feature repetitions (e.g., Hommel et al., 2004). That is, in binary choice tasks responses are especially fast in CC and II trial transitions (which contain 50% complete feature repetition and 50% complete feature alternation) compared to usually slower responses in CI and IC trial transitions in which only partial feature repetitions/alternations occur (see Hommel, 1998; Hommel et al., 2004). A close examination of our data shows that accessory stimuli in the prime-trial slowed usually fast compatible-compatible (CC) and incompatible-incompatible (II) prime-probe trial transitions (complete feature repetition/alternations). At the same time, no reliable accessory-based effects on probe-trial responses were found for partial feature repetition/alternation trials (i.e., IC and CI), which, together, might explain the reduced sequential modulation of the Simon effect. Therefore, we speculate that the response slowing in those particular CC and II trials might reflect some sort of counter-compensation following fast (accessory modulated) prime-RTs in order to prevent potential perseveration in the probe-trial. Of course, subsequent research is needed for further clarification.

Taken together, presenting task-irrelevant accessory tones in a spatial S-R correspondence task revealed two differential effects. First, accessory stimuli increased response speed, most likely due to facilitation of task-relevant processing (e.g., extracting the stimulus identity). Second, and in addition, accessory stimuli modulated automatic response activation processes that are associated with direct route processing.

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References

Botvinick, M. M., Carter, C. S., Braver, T. S., Barch, D. M., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624–652.

Coles, M. G. H., Gratton, G., Bashore, T. R., Eriksen, C. W., & Donchin, E. (1985). A psychophysiological investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 529–553.

Correa, A., Lupianez, J., Madrid, E., & Tudela, P. (2006). Temporal attention enhances early visual processing: A review and new evidence from event-related potentials. *Brain Research, 1076*, 116–128.

De Jong, R., Liang, C. C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 731–750.

Fischer, R., & Hagendorf, H. (2006). The control of visual attention and its influence on prioritized processing in a location negative priming paradigm. *Psychological Research, 70*, 317–335.

Fischer, R., Schubert, T., & Liepelt, R. (2007). Accessory stimuli modulate effects of non-conscious priming. *Perception & Psychophysics, 69*, 9–22.

Hackley, S. A., & Valle-Inclán, F. (1998). Automatic alerting does not speed late motoric processes in a reaction-time task. *Nature, 391*, 786–788.

Hackley, S. A., & Valle-Inclán, F. (1999). Accessory stimulus effects on response selection: Does arousal speed decision making? *Journal of Cognitive Neuroscience, 11*, 321–329.
Hackley, S. A., & Valle-Inclán, F. (2003). Which stages of processing are speeded by a warning signal? *Biological Psychology, 64*, 27–45.
Hommel, B. (1994). Spontaneous decay of response-code activation. *Psychological Research, 56*, 261–268.
Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition, 5*, 183–216.
Hommel, B., Proctor, R. W., & Vu, K.-P. L. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research, 68*, 1–17.
Kiesel, A., & Miller, J. (2007). Impact of contingency manipulations on accessory stimulus effects. *Perception & Psychophysics, 69*, 1117–1125.
Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility – A model and taxonomy. *Psychologcial Review, 97*, 253–270.
Kornblum, S., Stevens, G. T., Whipple, A., & Requin, A. (1999). The effects of irrelevant stimuli. I. The time course of stimulus-stimulus and stimulus-response consistency effects with Stroop-like stimuli, Simon-like tasks, and their factorial combinations. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 688–714.
Miller, J. O., Franz, V., & Ulrich, R. (1999). Effects of auditory stimulus intensity on response force in simple, go/no-go, and choice RT tasks. *Perception & Psychophysics, 61*, 107–119.
Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin, 89*, 133–162.
Notebaert, W., Soetens, E., & Melis, A. (2001). Sequential analysis of a Simon task – Evidence for an attention-shift account. *Psychological Research, 65*, 170–184.
Proctor, R. W., & Vu, K.-P. (2006). *Stimulus-response compatibility principles: Data, theory, and application*. Boca Raton, FL: CRC Press.
Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review, 95*, 385–408.
Rolke, B., & Hofmann, P. (2007). Temporal uncertainty degrades perceptual processing. *Psychonomic Bulletin & Review, 14*, 522–526.
Sanders, A. F. (1980). Stage analysis of reaction processes. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behaviour* (pp. 331–353). Amsterdam: North-Holland.
Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus-response compatibility* (pp. 31–86). Amsterdam: Elsevier.
Stahl, J., & Rammsayer, T. H. (2005). Accessory stimulation in the time course of visuomotor information processing: Stimulus intensity effects on reaction time and response force. *Acta Psychologica, 120*, 1–18.
Stoffels, E. J., van der Molen, M. W., & Keuss, P. J. G. (1985). Intersensory facilitation and inhibition: Immediate arousal and location effects of auditory noise on visual choice reaction time. *Acta Psychologica, 58*, 45–62.
Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1345–1363.
Ulrich, R., & Mattes, S. (1996). Does immediate arousal enhance response force in simple reaction time? *Quarterly Journal of Experimental Psychology A, 49*, 972–990.
Wühr, P., & Ansorge, U. (2005). Exploring trial-by-trial modulations of the Simon effect. *Quarterly Journal of Experimental Psychology A, 58*, 705–731.

Appendix

Simon Experiment with Geometrical Forms

Methods

Participants

Thirty new students (20 females, *M* age = 22.6 years) of the Technische Universität Dresden participated in the experiment for course credits and had normal or corrected-to-normal vision. All except for two participants claimed right-handedness.

Apparatus, Stimuli, and Procedure

The right and left pointing arrows from Experiment 1 were replaced by a white square or a diamond (1.81° side length) with an inner black cut-out. Half of the participants responded with the left key to the square and with the right key to the diamond. The other half used the reversed mapping. Other than that, Experiment 2 was identical to Experiment 1.

Results

Prime-Trial

Errors (5.1%) and prime-RTs below 150 ms or above 1,000 ms (1.8%) were excluded. The same ANOVA as in Experiment 1 was conducted on RT and error rates alike. Results are summarized in Table 4A and Figure 2A. Responses were again faster in trials with an accessory stimulus (489 ms) than in trials without one (544 ms), $F(1, 29) = 255.59$, $MSE = 356.78$, $p < .001$. The factor Simon compatibility revealed shorter RTs in Simon compatible (505 ms) than in Simon incompatible trials (529 ms), $F(1, 29) = 47.60$, $MSE = 366.12$, $p < .001$. Most importantly, for the aim of the present experiment, the interaction between accessory stimulus and Simon compatibility was significant, $F(1, 29) = 28.20$, $MSE = 91.31$, $p < .001$. That is, the Simon effect was larger in accessory (34 ms),

Table 4A. Prime-trial reaction times (RT in ms), percent error (PE), Simon effect (in ms/%), and standard error of the mean (in parentheses) for conditions with accessory stimulus (AS) and without an accessory stimulus (no AS). C, Simon compatible; I, Simon incompatible

Prime		C	I	Simon effect
RT	No AS	537 (10.0)	552 (10.9)	**15**
	AS	472 (11.2)	506 (11.3)	**34**
PE	No AS	4.3 (0.6)	5.8 (0.7)	**2**
	AS	3.2 (0.5)	7.3 (1.0)	**4**

$t(29) = -8.25$, $p < .001$ than in no-accessory conditions (15 ms), $t(29) = -3.94$, $p < .001$. We analyzed cumulative distribution functions to rule out that larger Simon effects in accessory stimulus conditions are a result of generally faster RTs. The interaction among Simon compatibility and percentile confirmed decreasing Simon effects with increasing RTs as typical in a standard Simon task, $F(8, 232) = 46.37$, $MSE = 500.10$, $p < .001$. The three-way interaction among Simon compatibility, accessory stimulus, and percentile on the other hand was not significant, $F(8, 232) = 1.20$, $MSE = 996.72$, $p = .308$. As in Experiment 1, we aimed at evaluating the size of the Simon effect for RT percentiles containing *comparable RT-levels* between the no-accessory and the accessory stimulus condition. The results are presented in Table 5A.

Error rates were not affected by accessory stimuli, $F < 1$. Yet, we found a Simon effect, $F(1, 29) = 17.13$, $MSE = 13.34$, $p < .001$, and an interaction between accessory

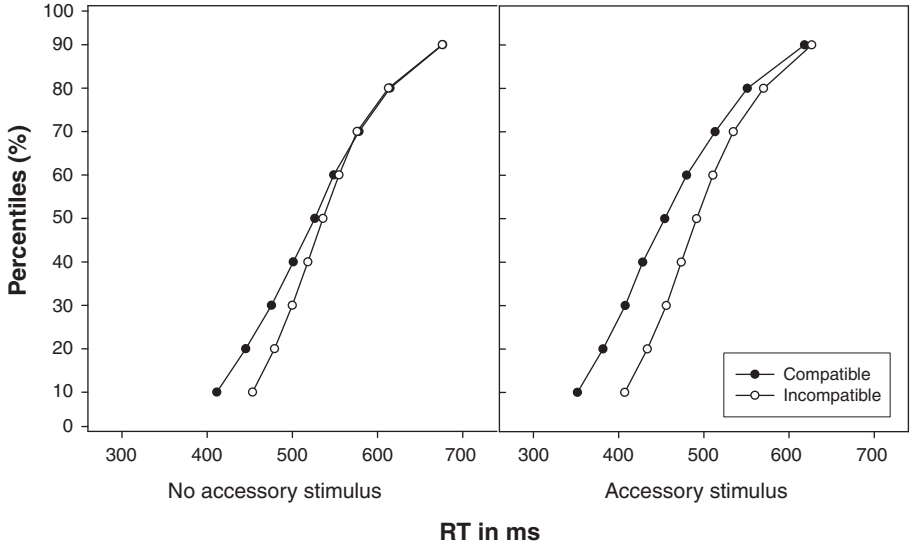

Figure 2A. Percentiles (10–90%) of Simon compatible and incompatible reaction times (RTs) separately for conditions with and without an accessory stimulus in Experiment 2.

Table 5A. Comparison of Simon effects (in ms) across the RT distribution. Comparisons are made for percentiles with similar RT-level (i.e., RT values differing maximally ±11 ms) between the accessory and no-accessory conditions, respectively. The respective RT-level for each percentile is given in parenthesis (in ms)

Comparable RT percentile		Simon effect		
No-accessory	Accessory	No-accessory	Accessory	ANOVA
10% (432)	30% (432)	42	48	$F(1, 29) = 1.83$, $p = .187$
20% (462)	40% (451)	34	45	$F(1, 29) = 7.12$, $p < .05$
30% (488)	60% (495)	24	31	$F(1, 29) = 2.0$, $p = .168$
50% (531)	70% (524)	10	22	$F(1, 29) = 4.97$, $p < .05$
60% (552)	80% (561)	6	19	$F(1, 29) = 5.06$, $p < .05$

Table 6A. Probe-trial reaction times (RT in ms), percent error (PE), Simon effect (in ms/%) and standard error of the mean (in parentheses) for conditions with accessory stimulus (AS) and without an accessory stimulus (no AS). Probe RT are presented depending on previous Simon compatibility in prime-trials. C, Simon compatible; I, Simon incompatible

		C			I		
Prime probe		C	I	Simon effect	C	I	Simon effect
RT	No AS	463 (10.6)	520 (10.2)	**57**	505 (10.2)	490 (9.8)	**−15**
	AS	476 (11.4)	525 (9.8)	**49**	513 (10.3)	499 (10.2)	**−14**
PE	No AS	1.0 (0.3)	10.2 (1.6)	**9**	5.1 (0.9)	2.1 (0.5)	**−3**
	AS	1.5 (0.4)	8.4 (1.1)	**7**	4.3 (0.8)	3.6 (0.6)	**−1**

stimulus and Simon compatibility that closely mirrored the RT data, $F(1, 29) = 8.64$, $MSE = 5.89$, $p < .01$.

Probe-Trial

Prime- and probe-trial errors (9.4%) and prime and probe RTs that did not fit the outlier criterion (2.6%) were excluded prior to analyses. Probe responses were faster in Simon compatible trials (489 ms) compared to incompatible trials (508 ms), $F(1, 29) = 27.80$, $MSE = 770.49$, $p < .001$. A sequential modulation of this Simon effect was confirmed by the interaction between $Simon_{PRIME}$ and $Simon_{PROBE}$, $F(1, 29) = 132.48$, $MSE = 520.68$, $p < .001$. Accessory stimuli influenced probe-trial responses in the same way as in Experiment 1, $F(1, 29) = 10.81$, $MSE = 412.22$, $p < .005$ (see Table 6A). Although in its direction comparable to Experiment 1, the interaction between $Simon_{PRIME}$ and $Simon_{PROBE}$ was not significantly affected by accessory stimuli, $F(1, 29) = 1.79$, $MSE = 158.94$, $p = .192$. Probe-trial responses were also 6 ms faster following Simon compatible than Simon incompatible prime-trials, $F(1, 29) = 6.64$, $MSE = 320.91$, $p < .05$.

Participants committed 4.5% errors in the probe-trial. A Simon effect, $F(1, 29) = 24.84$, $MSE = 23.79$, $p < .001$, as well as a sequential modulation of the Simon effect, $F(1, 29) = 41.12$, $MSE = 36.16$, $p < .001$, was also found in the error rates. As in Experiment 1, accessory stimuli affected the sequential modulation of the Simon effect, $F(1, 29) = 9.33$, $MSE = 8.43$, $p < .01$ (see also Table 6A). Furthermore, probe error rates were increased after Simon compatible prime-trials (5.3%) compared to Simon incompatible prime-trials (3.8%), $F(1, 29) = 14.82$, $MSE = 8.90$, $p < .005$.

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