Phasic Alertness and the Residual Task-Switching Cost

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Abstract. Participants switched between two randomly ordered discrimination tasks and each trial began with the presentation of a task cue instructing which task to execute. The authors induced phasic alertness by presenting a salient uninformative stimulus after the task cue was provided, and at variable intervals before the target stimulus was presented (Experiments 1–3) or before the task cue (Experiment 4). When the alerting stimulus preceded the target stimulus or the task cue by an optimal interval, RT was faster, indicating an alert state and the task-switching cost was reduced. These results support the suggestion of De Jong (Acta Psychologica, 1999) that alertness improves the overcoming of retrieval competition through improved goal representation, but also show that the effect is specific to the residual task-switching cost.

Keywords: reaction time, alertness, task switching, response selection, executive functions

Executive functions mediate intentional, goal-directed behavior, which permits flexible adaptation to rapidly changing environments. For example, a word may elicit a reading response, a key-press indicating it is a word, an "old" or "new" response, and so forth. The task-switching paradigm taps this aspect of executive functioning. A common finding is that task switching is associated with performance cost in the first trial following the switch (switch trial) compared to when the task is repeated from the previous trial (no-switch trial). It has also been found that providing task identity information in advance reduces switching cost, sometimes dramatically. Although this *advance task preparation* reduces switching cost, it rarely eliminates it, indicating *residual switching cost* (e.g., De Jong, 1995, 2000; De Jong, Berendsen, & Cools, 1999; Fagot, 1994; Goschke, 2000; Kramer, Hahn, & Gopher, 1999; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995). The present results refer to the underlying process of this residual cost. One method of estimating residual cost, used in the present experiments, is based on mixing trials involving two tasks, presenting a task cue in the beginning of each trial and manipulating the amount of advanced preparation by varying the *cue-target interval* (see Figure 1).

There are two groups of theories of residual cost. Hybrid theories (e.g., Fagot, 1994; Mayr & Kliegl, 2000, 2003; Meiran, 1996, 2000a, 2000b; Meiran, et al., 2000; Rogers & Monsell, 1995) suggest that the cost represents processes that are insensitive to advance task preparation. In spite of being insensitive to advance task preparation (namely, preparation that is based on providing task identity information), these other processes may, nonetheless, be sensitive to other forms of preparation. In contrast to the hybrid theories, De Jong and colleagues (De Jong, 2000; De Jong et al., 1999, see also Nieuwenhuis & Monsell, 2002) suggested that switching cost (among normal young adults, at least, see De Jong, 2001) represents a single process of task preparation. The presence of residual cost is explained by the fact that participants do not engage in advance task preparation in every trial. Consequently, the observed difference between switch trials and no-switch trials in mean reaction time (RT) represents a mixture of fully prepared trials and fully unprepared trials. Fully prepared trials are those where the residual task-switching cost is zero, and fully unprepared trials are those where the residual switching cost equals switching cost without preparation.

De Jong's model is based on analyzing Vincentized RT distributions. These are based on representing each experimental condition such as the switch condition by several RT quantiles. De Jong and his colleagues found that without preparation, the Vincentized RTs indicated roughly equal switching cost across the entire RT distribution. However, when advance task information was provided, the Vincentized RTs indicated substantial switching cost among the relatively slow responses located in the upper tail of

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the RT distribution while switching cost was essentially absent among the relatively quick responses. Considerable strength is added to De Jong's arguments by an elegant model with which it was possible to successfully predict the distribution of switch RTs given long preparation from a mixture of two other distributions. These included the distribution of RTs in "fully prepared" trials (no-switch, given long preparation) and the distribution of RTs in "fully unprepared" trials (switch, given short preparation). Additional support for the model is given by examining how various experimental manipulations affect the proportion of prepared trials, a critical parameter in the model. This proportion has been shown to be sensitive to manipulations that promote readiness and alertness, including short blocks of trials (presumably preventing fatigue) and the use of explicit task cues.

We argue that De Jong and his colleagues are probably correct in pointing out that lack of preparation should increase residual cost and that residual cost may even be eliminated under some circumstances (e.g., Meiran, 2000b). Our only dispute is with the single-process assumption, which we believe needs to be relaxed.

There are at least two reasons to consider residual cost as reflecting a separate component process. First, the preparation-sensitive component of switching cost and the residual component are sensitive to different sets of experimental manipulations. We will mention two double-dissociations. The first double-dissociation was reported by Meiran (2000b). It was shown that if the same set of stimuli were used in both tasks, switching cost was reduced. However, the reduction (relative to conditions involving separate sets of stimuli for the two tasks) was mainly seen in conditions in which little opportunity was given for advance task preparation. In other words, the stimulus sharing vs. non-sharing manipulation selectively affected the preparation-sensitive component of switching cost. Another manipulation, the overlap vs. sharing of response keys between the two tasks, affected residual switching cost, mainly (see also Brass et al., 2003; Schuch & Koch, 2003). The second double-dissociation is based on testing special populations. The elderly show normal advance task preparation. Namely, they reduce task-switching cost by advance task preparation to the same degree as younger participants do. Nonetheless, in the same studies they show increased residual cost (e.g., Hartley, Kieley, & Slabach, 1990; Meiran, Gotler, & Perlman, 2001). In contrast, patients suffering from Parkinson's disease show exactly the reverse pattern when tested on the same paradigm that was used by Meiran et al. (2001). They do not exhibit residual switching cost but the preparation-sensitive component of switching cost is remarkably increased for them (Meiran, Friedman, & Yehene, 2004). These dissociations compel us to argue in favor of hybrid theories and against single-process models such as De Jong's. Second, Allport and Wylie (2000), Waszak, Hommel, and Allport (2003), and others have argued that the presentation of the target stimulus leads to an automatic retrieval of the alternative task set, leading to impaired performance in switch trials. Note that these are processes that take place only when this target stimulus is presented and hence may be insensitive to the amount of advance task preparation. In other words, they are expected to selectively impair residual switching cost.

Nonetheless, these arguments are rather weak in that they do not speak directly to the findings of De Jong (2000). Much stronger support of hybrid theories would be to provide an alternative explanation for De Jong's results: notably, an explanation that is not based on single process assumptions. In the present experiments, we provide such an alternative explanation and support it empirically. It should be emphasized that our results do not prove De Jong's model to be incorrect. We only argue that the single-process assumption should be relaxed. In fact, our reasoning is based on the suggestion of De Jong et al. (1999) that alertness reduces switching cost. However, unlike De Jong and his colleagues, we argue that alertness does not affect the proportion of prepared trials. Instead, we argue that it reduces the target-related retrieval competition and, as such, affects the residual component of switching cost.

Our explanation is based on the following premises. First, when the target stimulus is presented, this leads to automatic retrieval of aspects of the alternative task, which is why residual cost is observed (e.g., Allport & Wylie, 2000; Waszak et al., 2003). Second, successful performance depends on overcoming automatic tendencies and these tendencies strongly depend on a robust and clear task goal representation (in the sense discussed by Duncan, Emslie, Williams, Johnson, & Freer, 1996). Third, as argued by De Jong et al. (1999), alertness improves task goal representation, which in turn improves the overcoming of the automatic retrieval of the wrong task rules. For example, based on similar reasoning, De Jong et al. showed that Stroop-like interference was abolished in conditions promoting alertness. The underlying mechanism may be based on the increased top-down activation from the task-goal level to the subordinate task-rule level (see Rubinstein, Meyer, & Evans, 2001, for the distinction between goal setting and task rule activation). Fourth, spontaneous momentary fluctuations in phasic alertness (e.g., Posner & Boies, 1971) are responsible for the difference between quick and slow responses. However, quick responses are also related to strong goal activation and, as such, to a nearly absent residual switching cost. In other words, the analysis of Vincentized RTs, in this case, captures alertness-related variation. Somewhat indirect evidence in favor of our hypothesis is based on the fact that the residual cost is related to prolonged response selection (Meiran, 2000a, 2000b; Schuch & Koch, 2003) and that phasic alertness shortens the duration of this processing stage (Hackley & Valle-Inclan, 1998, 1999).

In conclusion, we suggest that the near elimination of the residual task-switching cost among the relatively quick trials results from the fact that (a) these trials represent a relatively alert state, and (b) alertness reduces residual cost. While the first premise concerning fluctuations in alertness seemed self-evident to us, the second premise needed to be supported by empirical evidence, which we have found in the present experiments.

In all of the experiments, participants were given trials involving two tasks, which were randomly intermixed. In Experiments 1–3, each trial consisted of the following sequence of events (see Figure 1). After fixation, an instructional cue was presented for a relatively long interval, indicating which one of two tasks to execute: UP-DOWN or RIGHT-LEFT. Both of these tasks required indicating the position of a smiley-face character within the 2 × 2 grid. An uninformative salient visual stimulus was presented at varying (short) intervals prior to the presentation of the target stimulus and well after the task cue was provided. The role of the uninformative stimulus was to induce phasic alertness. Critically, since the alerting stimulus was uninformative and was presented well after the (informative) task cue was provided, its effect on residual cost was unlikely to be modulated by the induction of task preparation.

The logic employed in Experiments 1–3 was to use two very long cue-target intervals. The use of long preparatory intervals implies that advanced task preparation has been completed or nearly completed before the target onset. This assumption is based on results obtained by Meiran et al.(2000), who used the same paradigm to show that switching cost was reduced by increasing the preparatory interval to about 500–700 ms. Further prolongation of the preparatory interval was relatively ineffective in reducing switching cost. Based on these results and on the long preparatory intervals that were used, we could assume that the observed task-switching cost represented residual cost. To validate this assumption, we compared the task-switching cost in the two preparatory intervals (both of which were long) in order to show that the

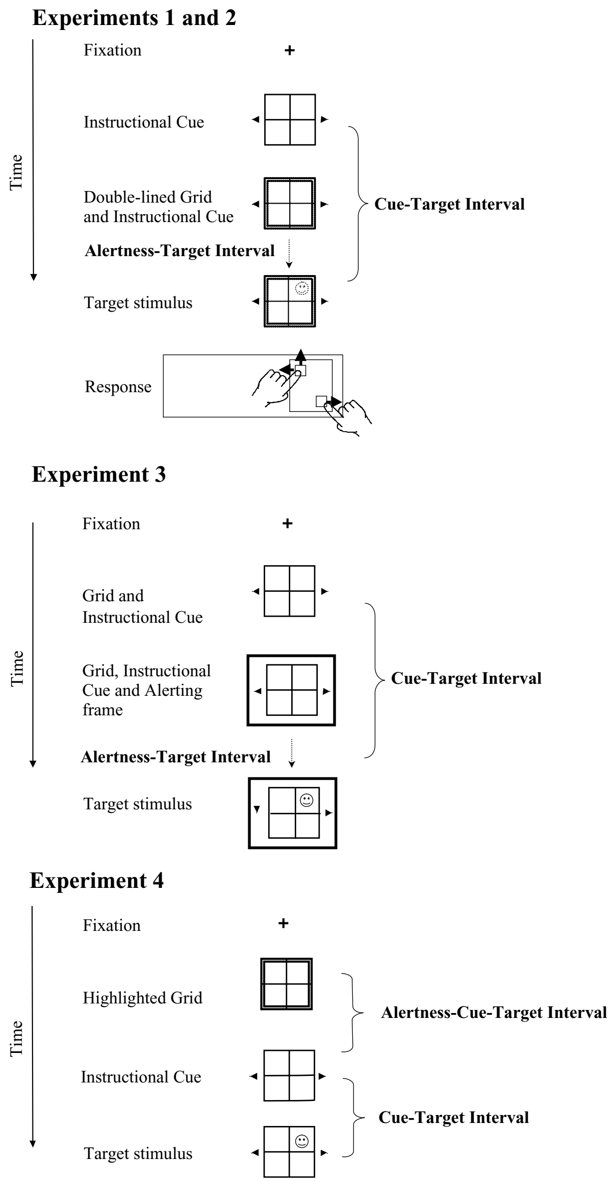

Figure 1. The experimental paradigm.

difference is nonsignificant. An additional justification for using two preparatory intervals is based on recent results by Altmann (in press) and Koch (2001) showing that exposing participants to variability in the preparatory interval is necessary in order to observe a preparation-related reduction in switching cost. Note that the issue is not whether the preparatory interval is blocked or varies randomly (Rogers & Monsell, 1995) but whether it is manipulated within or between participants. We manipulated the alerting-stimulus to target interval to induce variation in phasic alertness. A similar manipulation was used by Posner and Boies (1971), who found that the optimal interval for maximal alertness was approximately 500 ms. The novel aspect here is that the alerting stimulus was presented well after the task cue was provided so that the interval provided for the buildup of alertness was nested within a fixed task preparation interval. Rogers and Monsell (1995, Experiment 5) conducted an experiment in which the participants were pre-warned 0.5 s prior to the presentation of the target stimulus. In that respect, their design is somewhat similar to ours. However, the effect of pre-warning (alertness) in their experiment was minor (10 ms), albeit significant, leading to a small and insignificant reduction in switching cost (5 ms). Nonetheless, the direction of the effect supports our predictions. Shaffer (1965) conducted another relevant experiment. Three of the groups in Shaffer's experiment are relevant to the present study. In the first group, the task cue was presented simultaneously with the target stimulus. In the second group, the task cue was presented ⅓ s before the target stimulus. In the third group, an uninformative (alerting) stimulus was presented ⅓ s before the simultaneous presentation of the task-cue and target. Shaffer found that increasing the task-preparation interval (i.e., comparing Group 1 to Group 2) resulted in a small reduction in switching cost. Interestingly, alertness resulted in a similar reduction in switching cost (i.e., comparing Group 1 to Group 3). Specifically, task-switching cost was 37 ms in Group 1, 23 ms in Group 2 and 27 ms in Group 3. This trend also accords with our hypothesis.

Because alertness presumably results in a clear and robust goal representation and hence helps in overcoming the tendency to execute the alternative task, we included congruency in all of the analyses. The reason being that congruency effects are presumably due to the automatic retrieval of the inappropriate task rules. Specifically, congruent trials are those in which the two task rules produce the same overt key-press. Take, for example, the response-key arrangement presented in Figure 1, in which the upper-left key indicates both UP and LEFT. In this setup, a target stimulus positioned in the upper-left quadrant is said to be congruent. Incongruent trials are those in which one task rule points to Key 1 as the correct response and the other rule points to Key 2. These trials involve competition at the level of specific task rules rather then at the level of task sets. The target stimulus in Figure 1 is incongruent. Note, however, that retrieval competition is not necessarily reflected in congruency effects. For example, Rogers and Monsell (1995) have shown that the presence of information related to the currently irrelevant task was sufficient to increase switching cost even if this information was congruent with the relevant information in the sense of pointing to the same response key as the correct response (the so-called "crosstalk effect").

Experiment 1

In the present experiment, we used a double-lined grid as our alerting stimulus. In order to increase the alerting effect, we used a "+" sign for fixation rather than the empty grid used in most of our previous studies. Accordingly, we presented pairs of arrows without a grid as instructional cues. Thus, the alerting stimulus involved increasing stimulus size as well as increasing the total stimulus intensity. Both of these changes presumably produced an alerting response. The alertness-target intervals were 66, 350, 632 and 1,016 ms (these values are multiples of screen refresh times). The two fixed-cue target intervals (task preparation times) were 1.8 and 2.8 s, both considerably longer than the approximately 0.5 s required for preparation to reduce switching cost to asymptotic levels in the present paradigm (e.g., Meiran et al., 2000). We predicted that the alertness-target intervals associated with the highest alertness (i.e., quickest responses) would also be associated with the smallest task-switching cost.

Method

Participants

Sixteen Ben-Gurion University undergraduates participated as a part of an introductory course requirement. All the participants reported normal or corrected-to-normal vision. Half of the participants used the upper-left key to indicate UP and LEFT, and the lower-right key to indicate DOWN and RIGHT. The remaining participants used the upper-right key (UP, RIGHT) and the lower-left key (DOWN, LEFT). Since the two preparation intervals were blocked, we counterbalanced their order within participants and between participants. Therefore, for half of the participants, the order of intervals within each session was medium, long, long, medium and for the remaining participants, the order was long, medium, medium, long.

Stimuli

The stimuli were drawn in white on black using the graphic symbols of the extended ASCII code (See Figure 1). We describe their size in terms of the visual angle, taking into account that participants sat about 60 cm from the monitor. The stimuli included (1) the fixation point, a + sign, subtending a visual angle of approximately 0.3° (width) × 0.5° (height); (2) a 2 ×

2 grid of double lines that subtended a visual angle of approximately 3.4° (width) × 2.9° (height); and (3) instructional cues consisting of the fixation point and two arrows. One pair of arrows was used to indicate the RIGHT-LEFT task, including a right pointing arrow to the right of the fixation and a left-pointing arrow on the left. The arrows subtended approximately 0.3° (width) × 0.5° (height) and were positioned 2.1° from the fixation point (0.7° from the to-be-presented grid). The arrows for the UP-DOWN task were presented above and below the fixation (2.4,° 0.7° from the to-be-presented grid). The target stimulus subtended approximately 0.3° (width) × 0.5°(height).

Procedure

All testing was performed with an IBM-PC clone with a 14-inch monitor. There were two identical sessions, each consisting of a practice block (20 trials) and four experimental blocks (160 trials). Each trial consisted of the following events: (a) the fixation was presented for 2 s; (b) the instructional cues were presented for cue-target interval minus alertness-target interval ms (for example, if the cue-target interval was 1.8 s, and the alertness-target interval was 362 ms, the arrows were presented for 1,438 ms); (c) the double-lined grid was presented together with the instructional cues for the alertness-target interval; (d) the target stimulus was presented within the double-lined grid and accompanied by the instructional cues until the participant responded. Participants responded by hitting two keys with their index fingers. The keys were located on the keypad part of the computer keyboard, which was aligned with the center of the monitor.

Design

The independent variables were all manipulated within participants and included cue-target interval (1.8 vs. 2.8 s, blocked), alertness-target interval (66, 350, 632, and 1,032 ms, varying randomly), task-switch (switch, no-switch, varying randomly and defined in relation to the task in the preceding trial), and congruency (congruent, incongruent, varying randomly). Congruency was included as a variable because the two tasks indicated the same correct response in half of the trials (congruent). For example, if the upper-left response key was used to indicate UP and LEFT, it was considered as a correct response to an upper-left target stimulus regardless if the task was UP-DOWN or RIGHT-LEFT. In the former case, the response would have indicated UP, while in the latter case it would have indicated LEFT.

Results

Responses in the first trial of a block and those that followed an incorrect or following an exceedingly long (3 s) response were omitted from all analyses. The reason for this is that it could not be determined which task set was adopted in the previous trial, making it uncertain whether the current trial involved a task-switch. In addition, exceedingly long responses (3 s) or incorrect responses were analyzed for accuracy only. Since the number of observations varied between cells (31 to 43, on average), each cell was represented by its mean RT in the analysis of variance (ANOVA). The alpha level was .05. These analytic procedures were used in all the experiments. To save space, we do not report effects if these are qualified by higher order interactions.

RT

As a preliminary analysis, we needed to confirm that the task-switching cost could be considered residual in nature. In support, switching cost was significant, $F(1, 15) = 52.40$, $MSE = 4645.42$, but increasing the cue-target interval from 1.8 s to 2.8 s did not reduce it significantly, $F(1, 15) = 2.60$, $MSE = 1630.58$. In order to test our prediction, we need to first determine which alertness-target intervals were associated with the highest level of alertness. Mean RT in the four alertness-target intervals was 681, 621, 604, and 607 ms, respectively, $F(3, 45) = 41.03$, $MSE = 3977.70$. Hence, the last two intervals were associated with the most alert state and the first interval was associated with the least alert state, according to our definition. We therefore conducted a planned contrast comparing the last two intervals to the first two intervals with respect to switching cost. This analytic strategy maximizes the statistical power because it represents the sharpest contrast with respect to alertness and it is associated with one degree-of-freedom only. As predicted, switching cost was reduced (from 59 ms to 38 ms) by increased alertness, $F(1, 15) = 4.79$, $MSE = 1963.68$.

In the second stage, we conducted a standard analysis of variance (ANOVA) according to congruency, task-switch, cue-target interval and alertness-target interval. There was a significant triple interaction between congruency, alertness-target interval and task-switch, $F(3, 45) = 3.59$, $MSE = 1768.9$, which is

Table 1. Mean RT in experiment 1.

Alertness-Target Interval (ms)	Cue-Target Interval					
	1,800 ms			2,800 ms		
	Switch	Non-Switch	Cost	Switch	Non-Switch	Cost
			Congruent			
66	636	605	31	636	598	38
350	576	541	35	579	553	26
632	557	531	26	558	533	25
1,032	584	520	64	553	531	22
			Incongruent			
66	786	694	92	783	707	76
350	716	660	56	694	652	42
632	698	640	58	687	629	58
1,032	688	654	34	670	653	17

presented in Figure 2. While the two way interaction between alertness-target interval and task-switch was significant for incongruent trials, $F(3, 45) = 3.29$, $MSE = 2781.7$, it was insignificant for congruent trials, $F < 1$. Nonetheless, switching cost was reduced numerically even among congruent trials when alertness-target interval increased from 66 ms to 632 ms (34 vs. 25 ms). Thus, although the predicted effect was significant in the incongruent condition only, a similar, albeit small and insignificant, trend was observed in the congruent condition. This discrepancy between congruent and incongruent trials was not replicated in the equivalent conditions of Experiments 2 and 3.

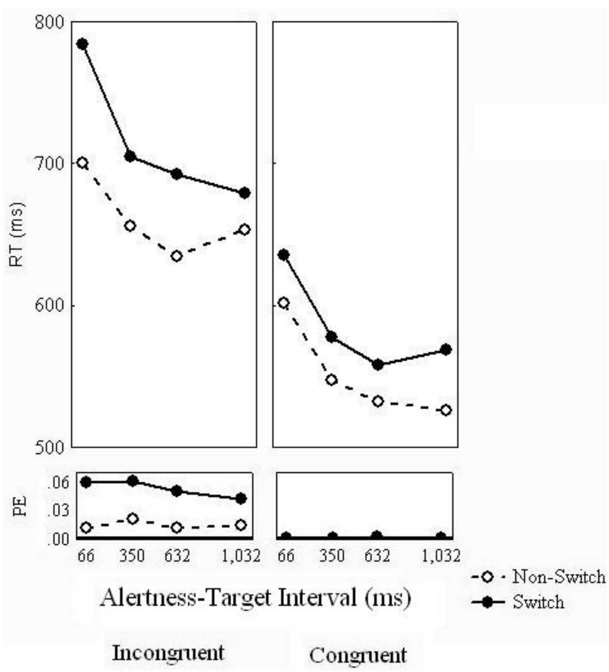

Figure 2. Mean RT and proportion of errors (PE) according to congruency, alertness-target interval, and task-switch – Experiment 1.

Proportion of Errors (PE)

There were virtually no errors in the congruent condition (with all the 16 means smaller than .002). Hence, we analyzed only the results from the incongruent condition. The triple interaction between cue-target interval, alertness-target interval and task-switch was significant, $F(3, 45) = 4.26$, $MSE = .0005$.

Analysis of the Fastest RT Quartile

Given the small number of observations per cell, the finest grain analysis possible was to look at the predicted effect when each cell in the design is represented by the first RT quartile instead of the mean. The triple interaction between alertness-cue interval, task-switch and congruency was found to be significant in this analysis, too, $F(3, 45) = 6.05$, $MSE = 566.69$. Switching cost was virtually absent in the congruent condition. In the incongruent condition it was 53, 27, 14, and 17 ms in the four alertness-target intervals, respectively (584 vs. 531 ms, 514 vs. 487 ms, 499 vs. 485 ms, and 492 vs. 475 ms). This cost was clearly significant in the first two alertness-target intervals, $F = 22.01$, as well as in the last two intervals, $F = 7.24$. These results further support the conclusion that alertness affected residual switching cost.

Differential Effects of Alertness as a Function of Response Speed

The analysis was performed in order to validate our center assumption that differences between fast and slow responses result from fluctuations in alertness as well as to validate our alertness manipulation. To this end, we represented each cell by the fastest RT quartile, the RT median and the slowest quartile. The ANOVA had the same design as before except for adding quartile as an independent variable. Alertness-target interval and quartile interacted overadditively, $F(6, 90) = 2.38$, $MSE = 1{,}745.83$. Mean slowest quartile was reduced from 767 ms to 695 ms (72 ms). Mean median RT was reduced by a similar amount (612 vs. 538 ms, an effect of 74 ms). In contrast, the mean fastest RT quartile was reduced by a lesser amount of 64 ms (514 vs. 450 ms). This result accords with our assumption that trials with fast RT are associated with high alertness. For this reason, these trials benefit little from additional alertness. Slow trials are associated with lesser alertness as compared to the quick trials and hence they benefit mostly from increasing alertness.

Experiment 2

It remains unclear whether the effect of phasic alertness in Experiment 1 was truly selective. Alternatively, any manipulation that speeds response also reduces switching cost. In order to rule out this possibility, we decided to replace the long cue-target interval of 2.8 s with an extremely long interval of 10 s. Based on the extensive literature on foreperiod effects on RT (reviewed by Niemi & Näätänen, 1981, but see also Los & Van Den Heuvel, 2001), we predicted *slower* responses in the very long preparation interval compared with the shorter interval (1.8 s). Importantly, according to these theories, this slowing is not produced by the same factors as those producing phasic alertness. Therefore, we predicted that slowing participants by increasing the preparatory interval would not modulate the effects of phasic alertness on RT and on switching cost. In other words, the present experiment enabled us to replicate the effect of phasic alertness on switching cost at two very different RT baselines, thereby ruling out the possibility that the effect on switching cost merely reflected response speeding.

Method

Participants

Sixteen students with similar characteristics to those who participated in Experiment 1 took part in this experiment.

Procedure

The procedure was similar to that in Experiment 1, except that the two cue-target intervals were 1.8 and 10 s. The very long task preparation intervals of 10 s resulted in very long trials. Hence, including an equal number of trials in blocks with short and long preparatory intervals would have resulted in very different block durations, which, in itself, could have an effect. It was therefore important to have blocks of comparable total duration. For that reason, the blocks with the

Table 2. Mean RT in experiment 2.

Alertness-Target Interval (ms)	Cue-Target Interval					
	1,800 ms			10,000 ms		
	Switch	Non-Switch	Cost	Switch	Non-Switch	Cost
			Congruent			
66	661	610	41	770	732	38
350	576	541	35	627	592	35
632	566	535	31	560	568	–8
1,032	565	520	34	555	556	–1
			Incongruent			
66	754	682	72	847	823	24
350	678	626	52	731	685	46
632	642	603	39	682	655	27
1,032	647	600	47	646	622	24

short preparatory interval included 96 trials, each and the blocks with the long preparatory interval included 64 trials, each. To equate the number of trials in these two conditions, each session included two blocks with short preparatory intervals and three blocks with long preparatory intervals.

Each of the three sessions opened with a single practice block including 10 trials with a short cue-target interval followed by 10 trials with a long cue-target interval. The blocks were ordered according to the preparatory interval as short-long-long-long-short (for half of the participants) and as long-short-long-short-long (for the remaining participants). The participants wore earphones to prevent distraction from minor noises.

Results

RT

The mean number of non-missing responses per cell ranged between 32 and 35. Switching cost was significant, $F(1, 15) = 29.88$, $MSE = 5209.18$, and is to be considered as residual in nature because it was not significantly reduced by increasing the cue-target interval serving for task-preparation, $F(1, 15) = 2.38$, $MSE = 7468.17$. As predicted, using very long task preparation intervals resulted in a significant slowing, $F(1, 15) = 7.41$, $MSE = 48093.61$. Mean RT was 613 and 666 ms in the short and long cue-target intervals, respectively. The alertness manipulation was effective in reducing RT and the mean RT in the four alertness-target intervals was 735, 632, 601, and 589 ms, respectively, $F(3, 45) = 119.67$, $MSE = 4677.61$. Hence, the first interval was associated with the least alert state and the last two intervals were associated with the most alert state, according to our definition. The planned contrast between the first interval and the last two intervals showed that switching cost was significantly reduced by alertness (from 46 ms to 26 ms), $F(1, 15) = 6.04$, $MSE = 1534.68$.

The standard ANOVA design was identical to that in the previous experiment. There were significant 2-way interactions, one between cue-target interval and alertness-target interval, $F(3, 45) = 18.48$, $MSE = 3596$, and one between alertness-target interval and task-switch, $F(3, 45) = 3.04$, $MSE = 1341.66$ (see Figure 3). Although task preparation time did not significantly affect switching cost, the raw trend indicated a decrease from 47 ms to 23 ms, in spite of the significantly slower responses in the long preparation interval. This result clearly shows that response speeding per se does not reduce switching cost, with an insignificant trend in the opposite direction. The results indicate that the effects of alertness are not mediated by response speeding per se. Unlike in Experiment 1, in Experiment 2, the reduction in switching cost by alertness-target interval was not modulated by congruency, $F < 1$.

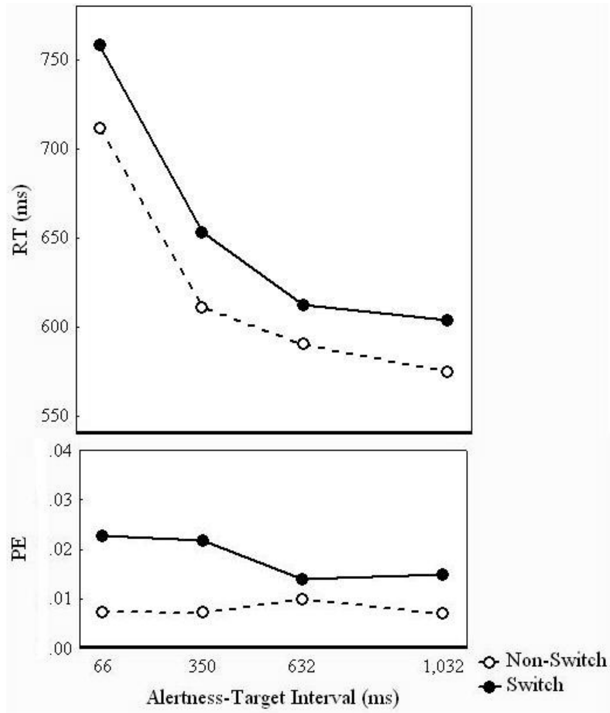

Figure 3. Mean RT and proportion of errors (PE) according to alertness-target interval and task-switch – Experiment 2.

PE

The mean PE in the congruent condition was .001, and thus the analysis was performed on the incongruent trials only. There was a significant interaction between task-switch and cue-target interval, $F(1, 15) = 8.41$, $MSE = .0011$. Switching cost was .03 (.05 vs. .02) in the short preparation interval and .01 (.02 vs. .01) in the long preparation interval.

Differential Effects of Alertness as a Function of Response Speed

The ANOVA had the same design as before except for adding quartile as an independent variable. Alertness-target interval and quartile interacted overadditively, $F(6, 90) = 6.27$, $MSE = 2,929.79$. Mean slowest quartile was reduced from 840 ms to 672 ms (168 ms). Mean median RT was reduced by 147 ms (675 vs.

528 ms). In contrast, the mean fastest RT quartile was reduced by only 116 ms (560 vs. 444 ms). This result accords with our assumption that trials with fast RT are associated with high alertness. For this reason, these trials benefit little from additional alertness. Slow trials are associated with little alertness and hence they benefit from increasing alertness.

Analysis of the Fastest RT Quartile

The 2-way interaction between alertness-target intervals and task-switch failed reaching significance, $F = 1.29$. Switching cost was 31, 17, 19, and 15 ms in the four alertness-target intervals, respectively (575 vs. 544 ms, 483 vs. 466 ms, 462 vs. 443 ms, and 451 vs. 436 ms). This cost was clearly significant in the first two alertness-target intervals, $F = 17.69$, as well as in the last two intervals, $F = 22.16$. A contrast comparing the first two intervals with the last two intervals was nonsignificant, however, $F = 1.19$. Nonetheless, the raw trend supports our hypothesis. The presence of significant cost in the first RT quartile further supports the conclusion that switching cost was residual in nature.

In summary, the presentation of an uninformative salient stimulus resulted in response speeding and a reduction in switching cost regardless of baseline RT, thus ruling out the possibility that any manipulation affecting baseline RT would also affect residual switching cost.

Experiment 3

One potential shortcoming of Experiments 1 and 2 is that the alerting stimulus was the grid within which the target stimulus was to be located. One could therefore argue that the grid aided the participants in preparing for a task-switch. One possible strategy would be to imagine a right-left border or an up-down border within the grid, which seems more plausible when the grid is presented. In that respect, one could argue that the effects of presenting the cue were not mediated by phasic alertness, but were mediated by a strategy specific to task preparation. Put differently, one could argue that the alerting stimulus was in fact informative. In order to rule out this possibility, we replicated Experiment 1, while changing the informative value of the alerting stimulus. In this experiment, the task cues were presented together with the grid (thus allowing for the aforementioned preparation strategy from the outset) and the alerting stimulus was a large heavily highlighted rectangular frame surrounding the entire display. This frame could not serve as a part of the task-stimulus proper. The experiment was otherwise identical to Experiment 1.

Method

Participants

Twenty-nine undergraduate students participated in the experiment. The results of one participant who had PE = .26 errors (as compared to only .02 in the next worst participant) are not analyzed. As a result, we analyzed the data of 28 participants, only.

Stimuli and Procedure

These were the same as in Experiment 1 (See Figure 1) except that the grid was not double-lined and a different alerting stimulus was used. The stimulus was com-

Table 3. Mean RT in experiment 3.

Alertness-Target Interval (ms)	Cue-Target Interval					
	1,800 ms			2,800 ms		
	Switch	Non-Switch	Cost	Switch	Non-Switch	Cost
			Congruent			
66	768	732	36	807	752	55
350	756	707	49	768	748	20
632	717	689	28	760	724	36
1,032	745	698	47	775	715	60
			Incongruent			
66	878	816	62	939	858	81
350	868	783	85	877	829	48
632	813	789	24	874	821	53
1,032	841	791	50	884	828	56

prised of a large rectangular frame 5.3° height and 6.2° width, with wide borders (.5°) surrounding the entire display comprising the instructional cues and the grid.

Results

RT

The mean number of non-missing observations per condition ranged between 37 and 39. Switching cost was significant, $F(1, 27) = 46.17$, $MSE = 11{,}720.86$, and should be considered as residual in nature because increasing the cue-target interval did not reduce it significantly, $F(1, 27) = .13$, $MSE = 3{,}751.40$. The mean RT in the four alertness-target intervals was 819, 791, 773, and 785, respectively, $F(3, 81) = 29.73$, $MSE = 2810.22$. Hence, the first interval was associated with the least alert state and the last two intervals were associated with the most alert state. A planned contrast comparing the first interval with the last two intervals indicated that greater alertness was associated with less switching cost, $F(1, 27) = 4.68$, $MSE = 1566.32$. Switching cost was reduced from 58 ms to 45 ms by increased alertness.

The ANOVA design was identical to that in the previous experiments. Cue-target interval interacted significantly with congruency, $F(1, 27) = 5.79$, $MSE = 1561.57$, indicating the fact that the congruency effect was smaller in the short interval (822 vs. 727 ms, an effect of 95 ms) compared with the long interval (864 vs. 755 ms, an effect of 109 ms). There was also a significant triple interaction between cue-target interval, alertness-target interval, and task-switch, $F(3, 81) = 2.77$, $MSE = 3{,}410.57$. As can be seen in Figure 4, the maximal reduction in switching cost due to alertness was found when alertness preceded the target by 650 ms, when the cue-target interval was short, and 350 ms when it was long. Analysis of simple interactions indicated a marginal 2-way interaction between alertness-target interval and task-switch, $F(3, 81) = 2.64$, 2.47, $p = .055$, .068, $MSE = 3{,}000.83$, 2,935.30, in the short cue-target interval and the long cue-target interval, respectively.

PE

The mean PE in the congruent condition was only .002; thus, we analyzed the incongruent data only. There was a significant interaction between cue-target interval and task-switch, $F(1, 27) = 4.73$, $MSE = .0003$. In the short interval switching cost was .02 (.03 vs. .01), but it was only .01 in the long interval (.02 vs. .01).

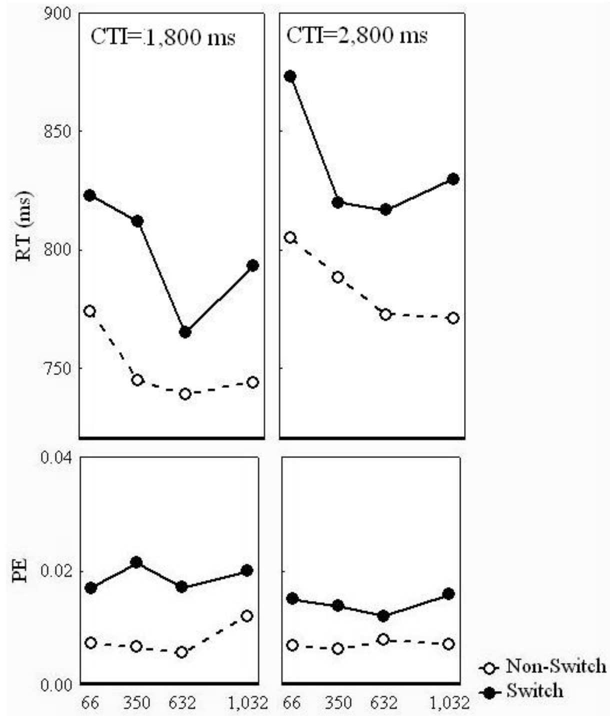

Figure 4. Mean RT and proportion of errors (PE) according to cue-target interval, alertness-target interval and task-switch – Experiment 3.

Analysis of the Fastest RT Quartile

In this analysis, each condition was represented by the first RT quartile and its design was the same as in the previous analyses. The 2-way interaction between alertness-target interval, and task-switch failed to reach significance, $F = 1.96$. Switching cost was 24, 18, 8, and 26 ms in the four alertness-target intervals, respectively (619 vs. 595 ms, 592 vs. 574 ms, 576 vs. 568 ms, and 589 vs. 563 ms). This cost was clearly significant in the first two alertness-target intervals, $F = 38.72$, as well as in the last two intervals, $F = 14.76$. A contrast comparing the first two intervals with the last two intervals was nonsignificant, however, $F < 1$. The presence of significant cost in the first RT quartile further supports the conclusion that switching cost was residual, in nature.

Differential Effects of Alertness as a Function of Response Speed

The ANOVA had the same design as before except for adding quartile as an independent variable. Alertness-target interval and quartile did not interact significantly, but there was a numerical trend of overadditivity, $F < 1$. Mean slowest quartile was reduced from 964 ms to 911 ms (by 53 ms). In contrast, mean median RT and mean fastest quartile were both reduced by 31 ms (737 vs. 706 ms and 607 vs. 576 ms, respectively).

In summary, the critical aspect of the results from Experiments 1 and 2 was replicated. We do not offer an explanation why the effect of alertness-target interval appeared sooner when the cue-target interval was long, but this should not compromise our conclusion that nonspecific alertness reduced both RT and switching cost.

Experiment 4

In Experiments 1–3, we showed that phasic alertness reduced residual switching cost. However, one could argue that the alerting stimulus reminded participants to prepare in those trials in which they did not already begin preparing. In other words, the alerting stimulus acted as a second task cue. One piece of evidence favoring this interpretation is the fact that alertness effects increased with time as does the usual task preparation effect. The goal of Experiment 4 was to test this hypothesis against the hypothesis that improved goal representation affects the residual cost rather than reinstating task identity information.

Instead of presenting the task cue before the alertness stimulus, we reversed the order of stimuli and presented the alertness stimulus first. The experiment was similar to Experiment 4 in Meiran et al. (2000). Participants fixated at a small + sign, followed by a large double-lined grid, followed by the instructional cue and the target. Unlike in Meiran et al., where the cue-target interval was short and constant, we included two cue-target intervals in separate blocks of trials: a very short interval (116 ms) and a relatively long interval (816 ms). This design enabled us to separate the preparation-sensitive component of switching cost from residual cost. Specifically, residual cost was observed at the long cue-target interval, while preparatory cost was the difference in switching cost between the short and the long cue-target intervals. In other words, in contrast to the preceding experiments, in which we did not predict that switching cost would be reduced by increasing task preparation time, in the present experiment we did predict such a reduction. This would be reflected in a significant interaction between cue-target interval and task-switch coupled with a significant simple effect of task-switch in the long cue-target interval, indicating residual cost. Unlike in Experiments 1–3, the manipulation of alertness was enacted *before* the presentation of the instructional cue. Specifically, we manipulated the interval between the alerting stimulus and the cue (alertness-cue interval, 116, 316, 616, and 916 ms).

If phasic alertness improves advance task preparation, presenting an alerting stimulus before the task cue should result in a greater proportion of prepared trials (De Jong, 2000). However, because our shorter cue-target interval was very short, this should not have reduced switching cost in that interval. The consequence would rather be a steeper reduction in switching cost in the more alert state. Such a pattern would be reflected in (a) no effect of alertness on switching cost in the short cue-target interval, coupled with (b) a significant triple interaction between cue-target interval, alertness-cue interval and task-switch. In contrast, if alertness improves the overcoming of target-induced retrieval competition by enhancing goal representation, then it should have a selective influence on residual switching cost. Hence, its effects would also be seen in the short cue-target interval because in this interval, switching cost comprises both the preparation-sensitive component and the residual component. This would be reflected in two significant interactions, cue-target interval by task-switch and alertness-cue interval by task-switch, as well as an insignificant triple interaction between the three variables.

Another advantage of the design of the present experiment is that it permits us once again to rule out the possibility that our alertness manipulation supplied task relevant information. Specifically, because the participants did not know which task is next when the alerting grid was presented, using an alertness-cued task preparation strategy became inefficient because it was as likely to be beneficial as harmful.

Method

Participants

Thirty-three students participated in a single session. The results of one participant who committed many errors (.47 in the incongruent condition as compared with .18 in the next worst participant) were not analyzed. Since the cue-target interval was blocked, the order of cue-target intervals was counterbalanced both within and across participants. This was achieved by ordering the intervals as short-long-long-short for one half of the participants and long-short-short-long for the other half.

Stimuli and Procedure

The stimuli were the same as in Experiment 1 and 2. The experiment consisted of a single session that began with a practice block of 20 trials, followed by 4 experimental blocks of 160 trials. Each trial consisted of the following events: (a) the fixation was presented for 2 s; (b) the double-lined grid was presented for a variable alertness-cue interval; (c) the double-lined grid was replaced with instructional cues that were presented with a standard grid for a cue-target interval, which was constant throughout the block but varied across blocks; (d) the target stimulus was presented within the grid until the participant's response.

Design

The independent variables were all manipulated within participants and included cue-target interval (116 vs. 816 ms, blocked), alertness-cue interval (116, 316, 616, and 916 ms, varying randomly), task-switch (switch, no-switch, varying randomly and defined in relation to the task in the preceding trial), and congruency (congruent, incongruent, varying randomly).

Results

RT

The mean number of non-missing responses per cell ranged between 17 and 20. The predicted interaction between cue-target interval and task-switch was significant, $F(1, 31) = 29.49$, $MSE = 3963.23$. This interaction indicates that switching cost in the short cue-target interval (79 ms, 767 vs. 688 ms) was larger than in the long cue-target interval (37 ms, 640 vs. 603 ms), which is consistent with the claim that, with little preparation, the effect consisted of two components: a preparation-sensitive component and a residual component. However, residual cost (switching cost given a long cue-target interval) was also significant, as indicated by the simple effect of task-switch in the long cue-target interval, $F(1, 31) = 14.96$, $MSE = 11{,}740.16$. The fact that the size of residual cost was quite similar to that seen in the preceding experiments supports our contention that, in these experiments, switching cost was residual in nature.

Alertness was effective in reducing mean RT, which was 685, 671, 668, and 673 in the four alertness-cue intervals, respectively, $F(3, 93) = 3.88$, $MSE = 3{,}899.55$. Hence, the first interval was associated with the least alertness and the last *three* intervals were associated with the most alertness. Note that this effect was statistically the same for the short and the long cue-target intervals, $F < 1$. We therefore computed two planned contrasts. The first planned contrast indicated that switching cost was smaller (54 ms) in the last three alertness-cue intervals than in the first interval (71 ms), although the effect was marginal, $F(1, 31) = 4.08$, $MSE = 3{,}288.53$, $p = .052$. When we compared the first alertness-cue interval to the last two intervals as in the previous experiments (switching cost = 49 ms), the planned contrast was significant, $F(1, 31) = 6.07$, $MSE = 3{,}516.77$. The effect of alertness on switching cost was not significantly different in the two cue-target intervals, as examined by a planned contrast (in which alertness was based on comparing the first alertness-cue interval to the remaining intervals), $F < 1$. Using the same definition of alertness, we obtained a marginal

Table 4. Mean RT in experiment 4.

Alertness-Cue Interval (ms)	Cue-Target Interval					
	116 ms			816 ms		
	Switch	Non-Switch	Cost	Switch	Non-Switch	Cost
			Congruent			
116	733	645	88	608	571	37
316	700	641	59	597	552	45
616	696	642	54	551	564	−13
916	716	646	70	579	563	16
			Incongruent			
116	837	735	102	706	649	57
316	821	726	95	699	635	64
616	825	719	106	695	649	46
916	812	745	67	682	638	44

reduction in switching cost even in the short cue-target interval, $F(1, 31) = 3.38$, $MSE = 2{,}821.06$, $p = .07$ (from 95 to 75 ms).

The standard ANOVA indicated, in addition, a significant interaction between alertness-cue interval and task-switch, $F(3, 93) = 2.77$, $MSE = 3{,}103.11$, and between congruency and task-switch, $F(1, 31) = 11.10$, $MSE = 4{,}538.16$. The triple interaction between alertness-cue interval, cue-target interval, and task-switch was not significant, $F = 1.68$. Critically, neither the linear component of the triple interaction nor its quadratic component approached significance, F values $< .05$.

PE

The mean PE in the congruent condition was .004, and we thus restricted the analysis to the incongruent condition. Only the main effect of task-switch reached significance, $F(1, 31) = 25.80$, $MSE = .0049$, representing the difference between PE = .07 in the switch condition compared with only PE = .04 in the no-switch condition.

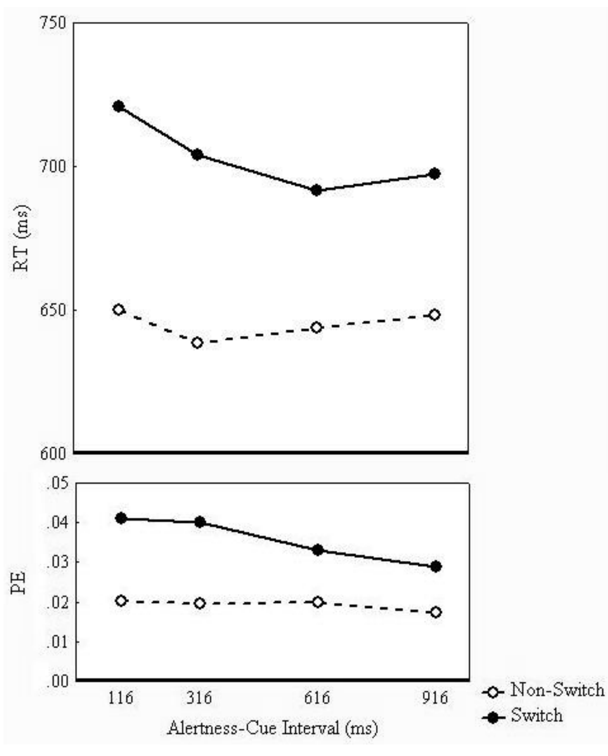

Figure 5. Mean RT and proportion of errors (PE) according to alertness-cue interval and task-switch – Experiment 4.

Analysis of the Fastest RT Quartile

The 2-way interaction between alertness-cue intervals and task-switch failed reaching significance, $F = 1.75$. Switching cost was 37, 34, 22, and 29 ms in the four alertness-cue intervals, respectively (552 vs. 515 ms, 539 vs. 505 ms, 537 vs. 515 ms, and 542 vs. 513 ms). This cost was clearly significant in the first two alertness-cue intervals, $F = 15.31$, as well as in the last two intervals, $F = 12.09$. A contrast comparing the first two intervals with the last two intervals was significant, $F = 4.76$. These results further support the conclusion that alertness reduced the residual cost.

In the present experiment we contrasted two hypotheses. According to the first hypothesis, our alertness manipulation increases the rate of prepared trials. According to the second hypothesis, alertness improves task goal representation, which in turn improves overcoming the target-induced retrieval conflict. The results support the second hypothesis and are incongruent with the first hypothesis. In addition, the results show that the effect observed in the preceding experiments was not due to the alertness stimulus acting as a second task cue. Moreover, the results of the present experiment show that alertness improves the processing of cue information (goal identity). The reasoning goes as follows: If alertness improved target processing directly, the critical interval is the alertness-target interval, which is the combination of the alertness-cue and cue-target intervals. However, we found that only the alertness-to-cue interval mattered. In fact, the raw trend of means showed that the most marked reduction in the alertness-cue interval of 350 ms when the cue-target interval was short (116 ms). However, when the cue-target interval was long (816 ms), the most marked reduction in switching cost was seen when the alertness-cue interval was 650 ms. This insignificant trend is in the opposite direction to that predicted under the assumption that alertness affected target processing directly.

In summary, the present experiment shows that presenting an alerting stimulus before the task cue reduced switching cost but also that, importantly, the effect was statistically the same in the short and the long cue target interval. Given the fact that the shorter cue-target interval was very short, it is unlikely that alertness increased the proportion of prepared trials (by reminding participants to prepare, for example), which should have affected switching cost only in the long cue-target interval. Moreover, the effect appears to be mediated by the improved processing of cue information, which accords with the hypothesis of De Jong et al. (1999) that alertness improves goal representation.

General Discussion

In the present work, we have offered an alternative explanation for the dramatic results of De Jong (2000) concerning the near elimination of residual switching cost among relatively *fast* responses. De Jong's results, combined with the model he suggested can potentially undermine hybrid theories of switching cost (e.g., Fagot, 1994; Mayr & Kliegl, 2000, 2003; Meiran, 1996, 2000a, 2000b; Meiran et al., 2000; Rogers & Monsell, 1995).

Our explanation was based on two premises. First, trial-by-trial fluctuations in alertness are critically responsible for the difference between relatively *fast* responses and relatively slow responses within the switch/no-switch conditions. Second, alertness reduces residual cost. Therefore, the near elimination of switching cost among the relatively fast within-condition trials results from the facts that (a) these trials represent high momentary alertness, and (b) that alertness reduces residual cost. We decided to concentrate on supporting the second premise because the first premise seemed self-evident to us. In accordance with our predictions, we found in Experiments 1–3 that presenting an uninformative alerting stimulus after the task cue was provided and before the target stimulus was presented produced alertness (as seen in faster RT), and at the same time reduced switching cost. The fact that the reduction in switching cost was relatively modest is probably due to the weak manipulation. Trial-by-trial spontaneous fluctuations in alertness are probably much larger than the modest effects of the experimentally induced alertness, and result in more pronounced effects on residual switching cost.

Importantly, our explanation of the results of De Jong (2000) is not based on a single process of task preparation but distinguishes between two distinct preparatory processes. The first is advance task preparation. This process is affected by providing task identity information in advance and it is presumably responsible for some of the task preparation-related reduction in switching cost. Nonetheless, it leaves a residual cost. The second process, phasic alertness, reduces residual switching cost. Given these features, our explanation is consistent with hybrid theories of the residual task-switching cost. To substantiate our conclusions we will rule out a number of alternative explanations.

First, the effect we identified did not result (only) from supplying task-related information by the alerting cue. This was evident in the results of Experiment 3. The alerting stimulus in Experiment 3 was (a) not part of the target stimulus proper, and thus (b), if anything, could potentially have distracted participants rather than helped them in task preparation. Furthermore, providing the alerting stimulus before the task cue had a similar effect on switching cost. Because the alerting stimulus was given before task identity was known, it is unlikely that participants used it to prepare for a given task. Such preparation could be based on dissecting the grid in imagination. Second, the effect does not reflect response speeding per se because increasing baseline RT (Experiment 2) did not significantly modulate it. Third, one could argue that the alerting stimulus was not truly alerting – it simply interrupted the task set adopted in the previous trial. There are two reasons to reject this hypothesis. One is that, in most cases, alertness affected no-switch trials in the same direction as it affected switch trials although to a lesser extent. However, if the alerting stimulus disrupted the task set adopted in the previous trial, this would be expected to result in slowing the responses in no-switch trials, whereas we found a trend towards faster response times. Moreover, there was an alerting stimulus in all the conditions and we found that the relative timing of this stimulus rather than its mere presence affected the residual switching cost in contrast to the set-interruption hypothesis which predicts that the mere presence of an interruption is sufficient. Another version of the same hypothesis could suggest that, in no-switch trials, the task set adopted in the previous trial gains strength from the appearance of the task cue in the current trial. As a result, the alerting stimulus can no longer disrupt it. However, we observed a similar effect of alertness in Experiment 4, in which the alerting stimulus was provided before the task cue. Fourth, one could argue that the alerting stimulus reminded participants to prepare, which resulted in an increased proportion of prepared trials and a consequently smaller residual cost. However, alertness reduced switching cost even when the alerting stimulus was presented before the task cue. Moreover, the effect was statistically the same for short and long cue-target intervals, showing that alertness did not increase the rate of prepared trials.

One reason why alertness reduces residual switching cost is the fact that alertness improved task execution by generating a robust representation of the task-goal (De Jong et al., 1999). The results of Experiment 4 are especially relevant here. One interpretation of these results is that, when alertness was optimal, it improved the operation of goal encoding taking place in response to the task cue, which eventually helped in target processing. One reason why residual cost is differentially affected by alertness and goal representation is the fact that the competing goal may be invoked by the target stimulus but not by the task cue.

The reason is that the target stimulus is linked to both task sets and may serve as a retrieval cue for the wrong goal (Waszak, et al., 2003), while the task cue is linked to the correct goal only. Thus, a robust goal representation is more strongly needed when the target is presented, because the target may lead to the retrieval of the wrong task identity. This line of reasoning is especially true for the presently used paradigm in which there were only four target stimuli, so that each one of them became repeatedly linked with both tasks. Moreover, this interference is reduced under conditions promoting high alertness (De Jong et al., 1999). The present results therefore indicate two main things. First, they indicate that the model of De Jong (2000) should be modified in a manner that would treat the residual cost as reflecting, in part, processes that are truly insensitive to preparation. Here we mean the kind of preparation that is based on providing task identity in advance. The reason for this cautionary note is that we have shown before (Meiran et al., 2000) that preparation should not be treated as a unitary concept. The present results, especially those of Experiment 2, provide additional support for this notion. Specifically, while the very long cue-target interval resulted in a significant slowing (collapsed over switch and non-switch trials) this long preparatory interval was, nonetheless, accompanied by a numerical reduction in switching cost. This dissociation shows that very long preparatory intervals induced greater readiness in one respect but lesser readiness in another respect. Second, the present results add to other observations that point to the importance of energetic factors (Sanders, 1998), intentional effort (Kleinsorge, 2001), and emotional (Dreisbach & Goschke, 2004) modulations of executive control operations.

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