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ORIGINAL ARTICLE

Stimulus–response bindings contribute to item switch costs in working memory

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Abstract In counter updating tasks, responses are typically faster when items repeat than when they change (item switch costs). The present study explored the contribution of stimulus–response bindings to these item switch costs. In two experiments, we orthogonally manipulated the repetition/switch of to-be-counted items and the repetition/switch of required manual responses. Item switch costs were considerably lower when item switches were accompanied by response switches than when accompanied by response repetitions. Experiment 2 showed that, although there was also a smaller contribution from stimulus–stimulus bindings (i.e., shape-location), the major part was due to stimulus-response bindings. These results show that in the widely used standard version of the counter updating task, a considerable portion of item switch costs is caused by the unbinding of stimulus–response bindings rather than by processes of switching items in working memory.

Introduction

Since Baddeley and Hitch's seminal paper (1974) working memory (WM) has become one of the most often investigated topics in cognitive psychology, both in theoretically oriented research and applied settings such as, for example, education or developmental disorders. Although the 1974 model comprised three different components—the central executive and two modality-specific slave systems termed the phonological loop and the visuospatial sketchpad—more recent models describe WM as a preferentially accessible part of long-term memory (e.g., Cowan, 1988, 2005; Oberauer 2002) or as a resource shared between storage and processing (e.g., Just & Carpenter, 1992). However, despite the differences in how WM is exactly conceptualized, researchers agree in that WM is of limited capacity. Thus, it is clear that humans quite often need to displace items from and retrieve new items into WM.

At present, there is a controversy about how many items within WM are accessible to cognitive processes at any moment, or in other words: What is the size of the 'focus of attention' in WM? Although, for example, Cowan (2005) argues that the focus of attention comprises about four items, others argue that it is merely one item or chunk (e.g., Garavan, 1998; Oberauer, 2002, 2003, 2006; Oberauer & Bialkova, 2009; for a still different concept see Verhaeghen, Cerella & Basak, 2004). Latter researchers often base their claim on item switch costs: applying a cognitive process twice to the same item allows for faster processing than applying it to two different items in succession. The difference in processing time is referred to as item switch costs and presumably reflects the time necessary to relocate the focus of attention.

Probably the most often employed task used in item switching research is the counter updating task originally introduced by Garavan (1998). In this task, participants are confronted with a number of single instances of items belonging to one of two (or more) different categories (e.g., geometrical figures). The quite simple task is to count how often each category appeared on the screen during one trial. Consider a case where circles and rectangles are used and let the first item be a circle. Participants then need to establish two counters as WM items, and shall count 'one circle, zero rectangles'. Once they have finished updating the respective (circle-) counter, participants press a response

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button and the next item comes up. The time it takes to update the counter and to press the button [=the response time (RT)] is the main dependent variable in this task. The subsequent item can either be another circle ('two circles, zero rectangles': a repetition item) or a rectangle ('one circle, one rectangle': a switch item). After a random number of such updates, the final values are probed to ensure diligent counting. A robust finding is that RTs to repetition items are reliably shorter than RTs to switch items (=switch costs). These switch costs are interpreted as indicating the necessary time to retrieve a new item into the focus of attention (e.g., Garavan, 1998; Janczyk, Wienrich, & Kunde, 2008).

Additional evidence suggests that other processes contribute to item switch costs to a considerable degree, at least in this paradigm. Specifically, it has been shown that a small, but reliable, part originates from (perceptual) priming speeding up responses to repetition items through facilitating perceptual encoding of the same stimulus in close succession (Gehring, Bryck, Jonides, Albin, & Badre, 2003; Li et al., 2006). Hence, there is a contribution of *afferent* processes to item switch costs. However, despite the task's wide use (e.g., Janczyk et al., 2008; Unsworth & Engle, 2008) little has been said about its *efferent* side, such as response-related processes. In this respect, it is important to note that responses to all stimuli (both repetition and switch items) are typically the same: the depressing of a single response button. Ironically spoken, motor actions appear as little more than an exhaust pipe of cognition. However, there is clear evidence of (automatic) integration of features across perception and action yielding so-called 'event files' (Hommel, 1998, 2005, 2007). Basically, with *full repetitions* (i.e., stimulus and response are the same as in the previous trial) RTs are comparable to trials where neither the stimulus nor the response is repeated. In contrast, *partial repetitions* (i.e., only the stimulus or the response is repeated, but not both) slow down the responses. Hence, in the counter updating task, repetition items represent full repetitions (same stimulus and same response), whereas switch items represent partial repetitions (different stimulus, but same response). As a consequence, it might be that a part of the item switch costs, as measured with the counter updating task, is not due to item switching per se, but to the necessity to overcome an existing binding across stimulus and response (henceforth referred to as S–R binding). Although the counter updating task appears somewhat different than the type of tasks typically employed for studying S–R bindings, both are conceptually similar: a (visual) stimulus appears and after some cognitive processing a (speeded) response is required. Furthermore, another important ingredient is the obvious task relevance of the stimuli's identity, and we can, thus, expect to observe S–R bindings within the counter updating task as well. On the other hand, there are reasons to doubt this: with the RTs usually measured with the counter updating task the integration window of $\pm$500 ms is easily exceeded and this should work against an integration of stimulus and response (features). Thus, the question whether S–R unbinding costs contribute to item switch costs deserves a closer empirical examination.

We report two experiments here designed to investigate if S–R bindings evolve in the counter updating task. As a consequence, a positive answer means that the confound of full/partial repetitions (in terms of S–R episodes) and item repetitions/switches can pose a problem for common interpretations derived from the counter updating task. Specifically, updating tasks with multiple stimuli and a unique motor response might overestimate the costs of refocusing an item. Experiment 1 explored whether S–R bindings are observable in the counter updating task—what turned out to be true. Experiment 2 addresses the role of stimulus–stimulus (S–S) bindings, i.e., bindings of the stimuli's identity and location. Stimulus location has been shown to be an important factor for binding processes in (working) memory (Hommel, 2002).

Experiment 1

To test whether S–R bindings do evolve in the counter updating task, we used a modified version of this task where we replaced the single response (that usually indicates finished updating) with two different response alternatives. To indicate the completion of WM updating participants pressed a response key that corresponded to the horizontal position of the respective stimulus (i.e., left or right). This was done to orthogonally manipulate the repetition/switch of to-be-updated stimulus identity and the repetition/switch of the required responses. If S–R episodes would be integrated in a comparable fashion as observed in previous studies on S–R binding, we can expect responses to switch items to be facilitated when they are accompanied by a response switch, whereas responses to repetition items should be slowed down when accompanied by a response switch. The vertical stimulus location switched from trial to trial in any case, in an attempt to make item repetition and item switch trials as comparable as possible by having stimulus location changing in both cases (Fig. 1). The role of stimulus location will be addressed in more detail in Experiment 2.

Method

Participants

Twelve undergraduate students from Dortmund University of Technology participated in this experiment. Participants were naive regarding the hypotheses underlying this

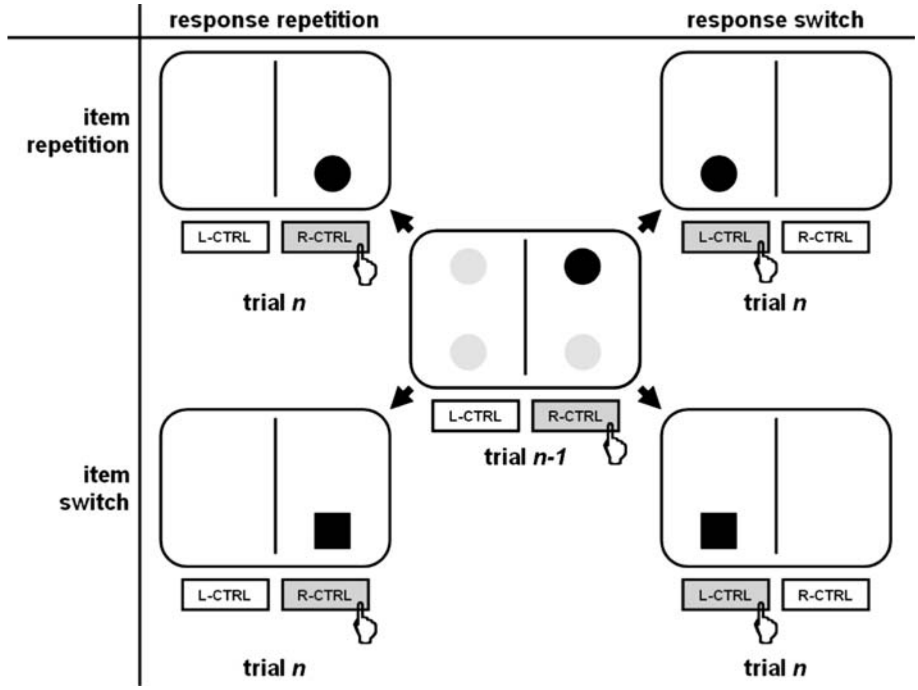

Fig. 1 Illustration of the four possible trial transitions resulting from the factorial combination of item and response repetitions versus switches: trial $n-1$ is depicted in the *center* of this figure, where the *light gray circles* mark the other three possible stimulus locations. The four possible combinations of the following trial *n* are depicted to the sides. In the upper part, the stimulus repeats, whereas it switches in the lower part. Likewise, in the left part the response repeats, whereas it switches in the right part

experiment, and received course credit in return for their participation.

Design

Participants worked on two versions of a (modified) counter updating task. In each trial, a random series of 20–25 items (circles and rectangles) appeared in succession on a computer screen. Participants were asked to count how many circles and rectangles were presented during one trial. Following each trial, the participants were prompted to type the final values of both categories in a random order. Stimuli occurred at one of four possible locations on the computer screen (see Fig. 1, center frame) with the two left and the two right positions being separated by a vertical line. The vertical location of the stimuli alternated with each item, but their identity (circle or rectangle) and their horizontal position (to the left or to the right of the vertical line) were determined independently with equal probability. In one half of the experiment, the responses were mapped to the stimuli's horizontal location: finished updating was indicated by pressing the (left or right) 'control' key on a computer keyboard depending on the current stimulus' horizontal location. Combined with two possible item/stimulus characteristics (item repetition or item switch), this results in four different analyzed conditions. These are illustrated in Fig. 1, where the center frame represents a trial $n-1$, and the outer frames the possible four types of trial *n*: item repetition + response repetition (upper left), item repetition + response switch (upper right), item switch + response repetition (lower left), and item switch + response switch (lower right). In the other half of the experiment, the task was the same, only with a change regarding the response mode: regardless of the stimulus location the response was always the same (either the left or the right control key), similar to the ordinary counter updating task.

Apparatus and stimuli

Stimuli were presented in white color against a black background on a 32 × 24 cm computer screen. A personal computer controlled the stimulus presentation and response collection. Viewing distance was approximately 60 cm. The central line covered the whole vertical screen size. Each side of the rectangle and the diameter of the circle were 2.5 cm. The stimuli were presented with their center about 1.6 cm to the right or the left of the central line, and 1.6 cm above or below the screen center.

Procedure

The participants were tested individually in a single 1-h session. Participants performed in 8 blocks of 12 trials each. Each trial comprised 20–25 items (two of each length in a random order). In four blocks, participants worked on the two responses variant of the task, in the remaining four blocks on the one response variant. The order of the two variants and the response key in the one response variant (left or right control key) were counterbalanced across the participants. Written instructions emphasizing speed and accuracy were given before the experiment started and after the forth block, when the response mode changed.

Data treatment and analyses

Trials were considered correct only if both counts were correct at probing. The first and the fifth block (training blocks) and all incorrect trials were excluded from analyses. Of the remaining trials, the first item was excluded (as it cannot be a repetition or a switch item), as were RTs <300 ms and RTs exceeding the individual's mean by more than 2.5 individual standard deviations (calculated separately for each participant and analyzed condition). Further, in the two responses variant, an item n was included into the analyses only if the responses to both items n and $n-1$ were correct. An α level of 0.05 was adopted throughout this paper and sample effect sizes are reported as partial η^2.

Results

Error analyses

Mean percentage of correct trials was 83.8 (SD = 11.6) in the one response variant. In 54.3% of the incorrect trials, one counter was wrong, and in 45.7% both counters were wrong. In the two responses variant mean percentage of correct trials was 79.6 (SD = 17.9). In 64.8% one counter was wrong; both counters were wrong in 35.2%. In the vast majority of incorrect trials (85.3% with one response, and 68.9% with two responses) participants' counts were only one above or below the correct count. The distributions of deviations were symmetrical in both variants. 98.4% of the item-level responses in the two responses variant were correct.

Response time analyses

A first analysis included only the 'one response' blocks and was carried out to demonstrate item switch costs as such. Mean RTs were 1,052 ms (SD = 286) to item repetitions and 1,529 ms (SD = 264) to item switches. An ANOVA with item switch as a within-subject factor showed a significant effect, F (1, 11) = 114.53, $P < 0.01$, partial $\eta^2 = 0.91$. Thus, standard item switch costs were obtained with this 1 response variant of the task.

To address the hypotheses outlined in the introduction, the following analysis included only the 'two responses' blocks. As illustrated in Fig. 2, participants responded to item repetitions faster than to item switches, and this was true for both response repetitions and response switches. However, the expected interaction is evident, too: item *repetitions* paired with response repetitions were *faster*, M = 1,091 ms (SD = 253), than when paired with a response switch, M = 1,253 ms (SD = 361). In contrast, item *switches* paired with response repetitions were *slower*, M = 1,892 ms (SD = 356), than when paired with a response switch,

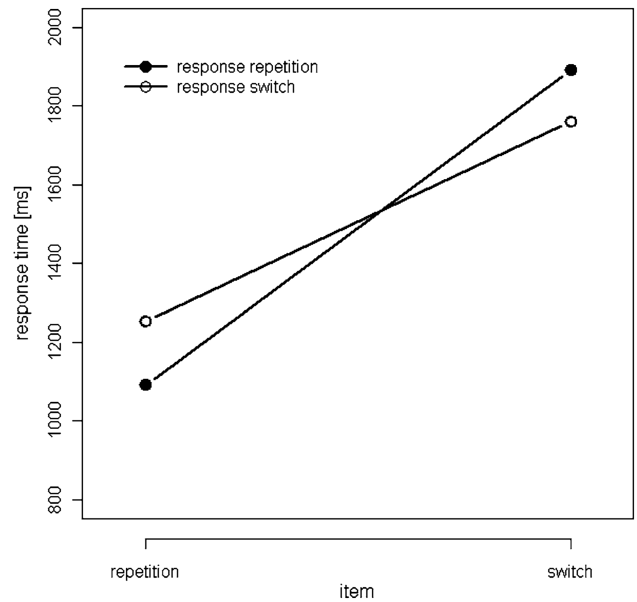

Fig. 2 Response times (ms) in Experiment 1 as a function of item and response repetitions and switches

M = 1,761 ms (SD = 360). This pattern was supported by an ANOVA with item switch and response switch as within-subject factors. Item switch yielded a significant effect, F (1, 11) = 139.20, $P < 0.01$, partial $\eta^2 = 0.93$, response switch did not, F (1, 11) = 0.15, $P = 0.70$, partial $\eta^2 = 0.01$. Most importantly, however, the interaction was significant, F (1, 11) = 29.90, $P < 0.01$, partial $\eta^2 = 0.73$. (As there was no effect related to the order of the one and the two responses variants of the task, we collapsed data across both orders in these analyses.)

Discussion

In Experiment 1, participants worked on a modified version of the counter updating task (Garavan, 1998). In the original task, switch items represent partial repetitions of S–R episodes (since the same response is always required), while repetition items are full repetitions of such episodes. As partial repetitions hamper responses (Hommel, 1998, 2005, 2007), we hypothesized that a part of the item switch costs, as measured with this specific and widely used task, are due to the necessity of unbinding an evolved S–R episode. Our modification was to introduce a second response and make the proper response contingent on the item's horizontal location. In accordance with our hypothesis, switch items were responded to faster when they coincided with a response switch, i.e., when they were made a full repetition. The opposite pattern was evident for repetition items.

On closer reflection, however, it appears possible that not unbinding of S–R episodes is the source of these differences, but rather stimulus identity and location were integrated (i.e., an S–S binding). This is quite likely because location seems to play an important role in binding processes (Hommel, 2002) and in cross-referencing features making up a single object. Experiment 2 was run to assess the contribution of such S–S bindings.

Experiment 2

We attributed the RT increase with item repetitions and response switches compared with item repetitions and response repetitions to the unbinding of stimulus identity and response, hence an S–R binding. But, not only did the response change between these conditions, but also the horizontal location of the stimulus did so. It might be that stimulus identity (circle or square) and stimulus location (left or right) were bound together as well and that unbinding these features caused the RT increase between response switches and response repetitions when item identity repeated. Accordingly, one may argue that S–S bindings contributed to these costs as well (or perhaps represent the major part of these costs). Therefore, we repeated the two responses variant of Experiment 1 with an additional manipulation. In half of the trials, the vertical position remained constant, whereas it changed in the other half of the trials (like in Experiment 1). Specifically, the comparison of these conditions allows us to test, whether switching (compared with repeating) the stimulus location results in an RT cost, if stimulus identity and response remain constant.

Method

Participants

Twenty undergraduate students from Dortmund University of Technology participated in this experiment. Participants were naive regarding the hypotheses underlying this experiment, and received course credit in return for their participation. One participant had only 51.2% correct item-level responses and was excluded from analyses. Thus, the reported data are based on 19 participants.

Design, apparatus, stimuli, and procedure

Experiment 2 widely resembled Experiment 1 with three changes: (1) We omitted the one response variant, (2) each participant worked on eight blocks (of 12 trials each) of which the first one was considered practice and remained unanalyzed, and (3) most importantly, the vertical position of the stimuli was switched on only half of the items, what we refer to as location repetition and location switch, respectively.

Data treatment and analyses

The overall data treatment was described as above for Experiment 1. To evaluate the possible S–S bindings and whether S–R bindings contribute a unique part to the RT difference, we categorized repetition items into three levels: (1) response repetition and location repetition, (2) response repetition and location switch, and (3) response switch. Note that level 3 necessarily implicated a change of the item's location. While the comparison of levels 1 and 2 assesses a contribution of S–S bindings, the comparison of levels 2 and 3 assesses an additional contribution of S–R bindings. Both comparisons were evaluated with repeated contrasts.

Results

Error analyses

Mean percentage of correct trials was 80.3 (SD = 11.4). In 58.9% of the incorrect trials one counter was wrong, and in 41.1% both counters were wrong. In 58% of the incorrect trials the participants' counts were only one above or below the correct count, and the distribution of deviations was symmetrical. 98.3% of the item-level responses were correct.

Response time analyses

The first analysis replicated the pattern already observed in Experiment 1 (for better comparability with Experiment 1 we included only location switch items). The known effect of item repetition versus item switch was evident, as was again the interaction. In the case of item repetitions, response repetitions were faster, $M = 877$ ms (SD = 243), than response switches, $M = 996$ ms (SD = 264). In contrast, in the case of item switches, response repetitions were slower, $M = 1{,}509$ ms (SD = 357) than response switches, $M = 1{,}452$ ms (SD = 387). Overall, response repetitions were slightly faster than response switches. Accordingly, an ANOVA with item switch and response switch as within-subject factors yielded a significant effect of item switch, $F\ (1,\ 18) = 138.41$, $P < 0.01$, partial $\eta^2 = 0.89$, while response switch marginally failed significance, $F\ (1,\ 18) = 4.00$, $P = 0.06$, partial $\eta^2 = 0.18$. The interaction was significant, $F\ (1,\ 18) = 38.55$, $P < 0.01$, partial $\eta^2 = 0.68$.

The results from the second analysis are illustrated in Fig. 3. Mean RTs (and SDs) of the three compared levels were 833 ms (214), 877 ms (243), and 981 ms (264). Thus, although there was a large increase in RTs from level 1 to level 3 (148 ms), we also observed an increase of 44 ms from level 1 to level 2. This increase indicates a contribution of S–S bindings, $F\ (1,\ 18) = 4.61$, $P < 0.05$, partial $\eta^2 = 20$.

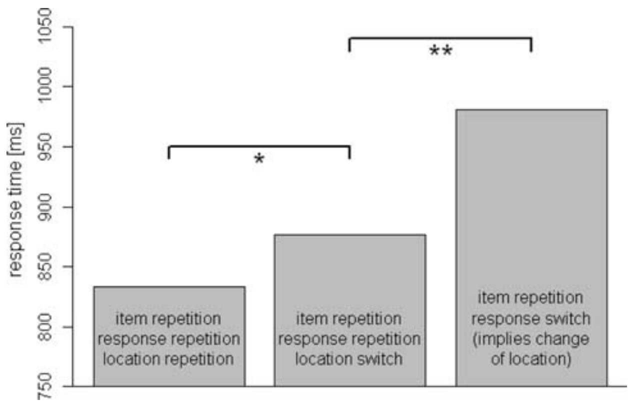

Fig. 3 Response times (ms) to item repetitions in Experiment 2 as categorized into three different levels: the *leftmost column* represents those item repetitions where the item's location and the response were kept constant, in the *middle column* the location was switched, and in the *rightmost* the response was switched (implying a location switch). Please see text for further details

Importantly, the second comparison (level 2 vs. level 3; 104 ms) was significant, too, F (1, 18) = 35.16, $P < 0.01$, partial $\eta^2 = 66$.

Discussion

The pattern we observed in Experiment 1 was replicated in Experiment 2. However, the main goal of Experiment 2 was to investigate whether S–S bindings (of stimulus identity and location) instead of S–R bindings can account for the RT differences between response repetitions and switches in our modified counter updating task. We did this by keeping the vertical position constant for half of the items. The respective analyses revealed that indeed S–S bindings of stimulus identity and location were present in our task: changing the vertical location, while keeping everything else constant, yielded about 44 ms longer RTs (one might suspect this being a slight overestimation partly being due to a confound with a necessary switch of visual attention). Still, additionally switching the response added another 104 ms to the RTs. This indicates that, although a part of the RT differences observed in Experiment 1 were presumably due to S–S bindings, the major part (both in numerical and effect size) came from the unbinding of evolved S–R episodes.

General discussion

The present research explored whether a necessary unbinding of S–R episodes contributes to item switch costs as measured with the widely used counter updating task (Garavan, 1998). The answer is clear cut: yes, it does. In both experiments, when an item repeated, responding was slower when the response switched than when the response repeated. In contrast, when an item switched, responding was slower when the response repeated than when the responses switched. This suggests the emergence of S–R episodes, so-called event files (Hommel, 1998, 2005, 2007), resulting from an automatic integration of features across perception and action. The results of Experiment 2 additionally suggest that indeed S–R bindings seem to be primarily responsible for this pattern, although we also found a smaller contribution of S–S bindings (stimulus location and identity). However, a slight qualification is necessary here: in Experiment 2, we manipulated the task-irrelevant vertical stimulus location. Hence, we can only speculate what the RT difference would be, would we have manipulated the task-relevant horizontal stimulus location instead. Presumably, the resulting RT increase in this case would not be less, but equal to or even larger than the one observed in Experiment 2 (see Fig. 3).

In the following, we will direct our attention to some aspects of the study that should be commented on. First, we used a modified counter updating task with two response alternatives to demonstrate S–R bindings. However, the counter updating task usually involves only a single response alternative, and therefore, assuming the emergence of S–R bindings in situations with only a single response alternative is crucial for evaluating our results. Hence, our approach raises two questions: first, is there S–R binding with only one response? Yes, we believe. In studies that demonstrate S–R bindings participants typically perform two responses per trial and only the second response is contingent on specific stimulus features. In contrast, the first response, that gives rise to the S–R binding, is mostly cued and prepared for a long time and thus essentially represents "always a simple reaction" (Hommel, 1998, p. 193). Similarly, S–R bindings are evident even when the second response does not depend on stimulus features at all, that is, when participants can select it freely from the set of response alternatives (thus a free-choice task; Hommel, 2007). In addition, the effortlessness (Hommel, 2005) and the reason why binding mechanisms make sense in general (the transient integration of distributed features) render it counterintuitive that the cognitive system evaluates the number of possible response alternatives before applying proper binding mechanisms—or not. A second issue is: did using two response alternatives change the task demands in comparison to the standard counter updating task (with only a single response alternative)? Yes, possibly it did. However, the low error rates (1.6 and 1.7%) of responses on the item-level suggest that the added demands were not overly heavy. Moreover, the interaction of item and response repetition/switch was still evident when we analyzed only the participants' last 'two responses blocks' of Experiment 1, a point of time where the location-contingent response requirement should be well learned. Still, in Experiment 1, the RTs were somewhat higher in the two response variant as they were in the one response variant, but this difference might explain a puzzling aspect of the data. In particular, the switch costs in the response switch condition of the two responses variant (presumably without S–R binding) were numerically somewhat higher (508 ms) than the switch costs in the one response variant (477 ms). However, given the baseline RT difference between the one and two responses variants, it is probable that a more appropriate measure of switch costs is the *relative* increase in RTs from repetition items to switch items—and this increase was actually slightly smaller in the response switch condition (40.5%) than in the one response variant (45.3%). Finally, a third comment aims at the question of why S–R bindings presumably evolved even though the time from stimulus onset to response production exceeded an integration window of ±500 ms. We suggest success-induced binding (Hommel, 2005) as a likely explanation. Note that the stimuli were visible until a response was made. Thus, if response initiation signaled success and both the response code and the relevant stimulus code were sufficiently active at that same time, the integration of both codes would be favored.

The theoretical motivation for this study was not to demonstrate S–R bindings in a task different from the common paradigms used to investigate them. Rather it was the identification of a confound in the counter updating task and the intention to provide some evidence for its potential contribution to what has been called item switch costs. Indeed, our results suggest that S–R bindings (Experiment 1) and possibly also S–S bindings (Experiment 2) exist in our modified task. Consequently, assuming the existence of such bindings with only one response alternative (like in the standard version of the counter updating task), they clearly contribute to the observed item switch costs as does repetition priming (Gehring et al., 2003; Li et al., 2006). In other words, they show that item switch costs as measured with the counter updating task might overestimate the actual costs of switching the focus of attention between different WM items. Hence, the results presented here corroborate recent suggestions that parts of the apparent 'higher order' switch costs reflect some relatively lower-level processes involved in stimulus perception (Gehring et al., 2003; Li et al., 2006) and response production. In a broader context, such reasoning is not limited to this very special paradigm; it might turn out to be only another example. For example, Hommel, Proctor and VuIronically spoken, (2004) suggested similar mechanisms considering sequential effects in the Simon task, and retrieval of S–R episodes has also been made responsible for (residual) switch costs in task-switching paradigms (Waszak, Hommel, & Allport, 2003). Taken together an important question arises: Is there an executive process of item switching or are item switch costs completely attributable to lower-level processes? If the latter turns out to be true, this necessarily challenges the concept of a '1 item focus of attention' (e.g., Garavan, 1998; Oberauer, 2002) and supports alternative accounts (Cowan, 2005). Albeit this would be a theoretically interesting outcome, we remain skeptical for the following reasons. First, there are other paradigms where supportive evidence for the '1 item focus of attention' have been reported from, and where neither binding nor perceptual priming are likely (McElree, 2001; Oberauer, 2002, 2003, 2006; Oberauer & Bialkova, 2009). Second, a comparison of the *slowest stimulus identity repetition* condition in Experiment 2 (response switch/position switch) and the *fastest stimulus identity switch* condition (response switch/position switch) shows a remaining significant difference of 456 ms [$|t|(18) = 9.36$, $P < 0.01$] that we currently must ascribe to 'true' item switching. Future research, of course, may decompose item switch costs more thoroughly, but at present there is little reason to dismiss the idea of 'true' item switching.

Given how easy the counter updating task is implemented: What should careful research bear in mind? The results of our study (1) suggest an overestimation of item switch costs with this task, but (2) at the same time do not entirely question the benefit of this task. However, in an attempt to identify true item switch costs we recommend to vary the stimuli's locations and to modify the counter updating task in a way that it has several different motor responses (such as different key presses or verbal utterances). In view of the potential contribution of S–R and S–S unbinding effects, item switch costs should be assessed from trials where both stimulus location and response switch. Tasks that also meet these criteria, and thus render a contribution of S–R binding unlikely, are variants of arithmetic updating tasks (Oberauer, 2003) or *n*-back tasks (Oberauer, 2006; Verhaeghen et al., 2004), because here the motor responses vary from trial to trial. At the same time our results raise some questions that should be addressed in future research. For example, in our experiments, stimulus repetitions were perfectly correlated with repeated updating of the associated hypothetical WM item. We accounted for the observed interaction by S–R binding, but it would be interesting to see whether there also exists binding between hypothetical WM items (such as the counters in the counter updating task) and, for example, responses. In a broader context, it is conjecturable that bindings themselves place some burden on WM, and the role of WM for binding mechanisms should be addressed. Perhaps, the efficiency of binding mechanisms depends on WM capacity or processing ability.

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