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More Efficient Shielding for Internal Than External Attention? Evidence From Asymmetrical Switch Costs

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At present, the process of switching attention between external stimuli and internal representations is not well understood. To address this, Verschooren, Liefooghe, Brass, and Pourtois (2019) recently designed a novel paradigm where participants were cued to switch attention between external and internal information on a trial-by-trial basis. The authors observed an asymmetrical switch cost, which was larger when switching toward internal than external material, even though participants performed internal trials faster. In the current study, we sought to establish the cause of this asymmetry by adjudicating among predictions from three theoretical accounts: associative interference, priming, and memory retrieval. After replicating the original asymmetry (Experiment 1), we demonstrated that trial-by-trial carryover of attentional settings is not a necessary precondition (Experiment 2). The results from Experiment 3 indicate that the cost asymmetry can be best explained by an associative interference account, against a memory retrieval one. Together, these results therefor provide evidence in favor of an associative interference account and document that shielding attention for internal representations from external intrusions is more efficient than the other way around. This finding advances our understanding of a core aspect of cognitive flexibility and the relationship between external and internal attention. More research on this question and novel ones raised by it are necessary, however.

Public Significance Statement

We demonstrate that the larger cost for switching attention toward internal representations compared to external stimuli cannot be explained in terms of a priming or memory retrieval account. The data seem to be best accounted for by an associative interference account. This account entails that internal attention can be better shielded from external intrusions than the other way around, which raises some intriguing further research questions.

Keywords: attentional flexibility, cost asymmetry, internal attention, external attention, associative interference

Attention can be broadly subdivided into two categories by distinguishing between the main substrates it acts upon, that is, external stimuli versus internal representations (Chun, Golomb, & Turk-Browne, 2011; Myers, Stokes, & Nobre, 2017; Verschooren, Schindler, De Raedt, & Pourtois, 2019). Whereas external attention directly depends on currently available perceptual input, internal attention operates on long-term memory (LTM) representations, which are considered to enter working memory (WM) once attention is allocated to them (Oberauer, 2002, 2009). In our interaction with the environment, we often switch attention between both substrates. For example, when we are looking for a grocery item in the store, after having found it, we retrieve the next item on our memorized grocery list and hence transit from external to internal attention. Even though the regulation of attention between external stimuli and internal representations is thus clearly central to successful everyday cognition, relatively little is known currently about the mechanisms involved in switching attention to and fro between these modes.

Recently, Verschooren and colleagues (Verschooren, Liefooghe, Brass, and Pourtois, 2019) validated a novel experimental procedure in which participants randomly switch attention between external stimuli and internal representations on a trial-by-trial basis. After memorizing four figures at the beginning of the experiment, they performed a probe-to-target matching task where the target figure

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was either presented on screen (external trial) or retrieved from memory based on a location cue (internal trial; see Figure 1). The trial-to-trial transitions created four conditions of interest: external repetitions, switches toward external, internal repetitions, and switches toward internal. The authors reported a cost for switch trials, with participants being slower and more error prone on switch than repetition trials. Furthermore, this switch cost was clearly asymmetric: It was larger when switching attention to an internal representation after processing an external stimulus than in the reverse direction. Crucially, despite the larger switch cost, participants performed internal trials faster than external trials, thereby ruling out a simple interpretation in terms of asymmetrical task difficulty.

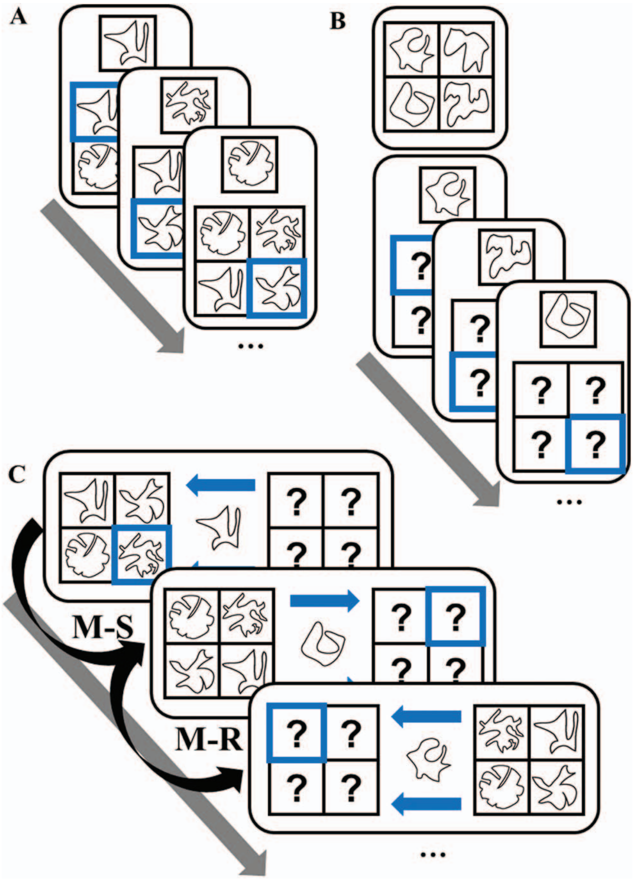

Figure 1. Experimental paradigm. A. External training phase. Participants decided whether the figure above (probe) matched the figure selected in a blue frame, until they reached the accuracy criterion (both > .85 and at least 18 total correct trials). B. Internal training phase. Participants memorized four figures and their locations. On each trial, they decided whether the figure above (probe) was in the selected location (in blue/dark gray) for the memorized set. The same accuracy criterion was used. C. Experimental task: On each trial, participant decided whether the selected figure (in blue/dark gray) matched the centrally presented probe. The selected figure was either presented on screen (external trial; first in sequence) or retrieved from the figures memorized in 1B based on the selected location (internal trial; last two). We were interested in the four possible trial-to-trial transitions: External–Repetition (E–R), External–Switch (E–S), Internal–Repetition (I–R), or Internal–Switch (I–S). See the online article for the color version of this figure.

In the task-switching literature, such a pattern of results has been observed previously when participants switch between a dominant or highly practiced task and a nondominant one. For example, in the Stroop task (Stroop, 1935), color words are printed in different color fonts (e.g., the word "blue" printed in red) and participants respond either to the name of the word (here: blue) or its color (here: red). When the relevant stimulus dimension on the current trial (e.g., word meaning) is different from that on the previous trial (e.g., color of the word), a cost is observed compared to a task repetition (e.g., two successive word-naming trials). Crucially, when switching between (more automatic/dominant) word naming and (less automatic/nondominant) color naming, participants usually show a larger switch cost when switching toward word naming, despite the overall reaction time (RT) advantage on word-naming trials (Allport, Styles, & Hsieh, 1994). Two important accounts in the task-switching literature, associative interference and priming, provide competing explanations for this phenomenon. We discuss both in detail below.

It should nonetheless be noted that mapping this pattern onto the findings reported by Verschooren, Liefooghe et al. (2019) implies that internal attention is more automatic (or dominant) than external attention. However, we know of no other prior empirical evidence supporting this idea, and an advantage for internal over external attention might seem counterintuitive at first sight. Consequently, we cannot take this assumption for granted. Alternatively, it may be the case that external and internal attention are not necessarily imbalanced, but instead, memory retrieval differs between them, and hence this factor would account for this asymmetry. That is, it is usually more difficult to access internal representations (from memory) than external stimuli (perceptually available), but this retrieval cost may be reduced when the internal representations are repeated. If this were the case, a larger internal than external switch cost is expected as well. Even though this account seems to be a priori more plausible, it nonetheless fails to address the origin of the faster mean response times for internal trials.

The aim of the present study was to adjudicate between these three different explanations. The common denominator among these three accounts is that they can all provide an explanation for the switch cost asymmetry. In the following, we discuss the two (opposing) task-switching and memory retrieval accounts, and their mutually exclusive predictions under specific experimental manipulations, separately. We then assess these predictions empirically, to take an important step toward better understanding the processes underlying transitions between external and internal attentional states.

Associative Interference

The associative interference hypothesis is an account developed to explain task-switching costs (for reviews, see Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010). It attributes this cost to the activation of task-irrelevant (or competing) memory traces in a task-switching context (e.g., Waszak, Hommel, & Allport, 2003). These traces, more specifically, are automatically encoded into LTM when engaging with a stimulus, which serves as a retrieval cue during subsequent encounters (Logan, 1988). Retrieval includes the reactivation of the specific attentional settings (e.g., focusing on the ink color vs. semantic meaning of the stimulus). Moreover, it has been demonstrated that these traces include abstract control setting as well, such as a flexible versus stable mental state (for recent reviews, see Abrahamse, Braem, Notebaert, & Verguts, 2016; Braem & Egner, 2018; Chiu & Egner, 2017). For example, Chiu and Egner (2017) demonstrated that participants show a decreased switch cost for stimuli that are associated with frequent task switches compared to stimuli associated with low switch frequency. Thus, we similarly assume that an external or internal attentional focus would be encoded with other trial features (i.e., the cues and/or target stimuli), and subsequently retrieved by these features; as a consequence, they could cause interference if retrieved in a situation where the other type of attention is required.

Crucially, interference from the irrelevant attentional setting is especially detrimental on switch trials, as a WM update takes place, making ongoing performance more susceptible to intrusions (Dreisbach & Haider, 2008, 2009; Dreisbach & Wenke, 2011). This is in line with an influential model of WM function, which proposes that its content is controlled by a gating mechanism (Frank, Loughry, & Reilly, 2001; Reilly & Frank, 2006). The gate is closed when the content is maintained but opened when it needs to be updated. In this state, irrelevant stimulus features (and associated actions and attentional states) can enter WM and have a detrimental effect on task execution. Switch trials are a specific instance of a situation in which a transition from a maintenance to an updating mode is required, and the gate is opened (Mayr, Kuhns, & Hubbard, 2014). As traces for both competing task sets are retrieved in a task-switching context, they can both access WM and influence behavior. The interference resulting from this competition leads to a switch cost.

To account for asymmetrical switch costs, the associative interference hypothesis assumes that dominant and nondominant task sets differ in the efficiency with which the relevant attentional focus is shielded (Mayr et al., 2014). When switching between a dominant and nondominant task, the memory traces activating the nondominant attentional focus are usually not sufficiently strong to interfere on repetition trials of the dominant one. Consequently, robust maintenance prevails. On trials of the nondominant task, on the other hand, the dominant task can interfere with maintenance of the nondominant task set, even when the task is repeated. On switch trials of both tasks, however, WM needs to be updated with the relevant attentional setting, during which memory traces from the competing task set can interfere equally for the dominant and nondominant task. The larger switch cost for the dominant task is caused by the difference between robust maintenance on repetition and updating on switch trials.

When applied to the cost asymmetry between external and internal switching, this account entails that the memory traces for their two competing attentional states, that is, external versus internal attention, are learned associatively when performing the task. On external repetition trials, external attention suffers interference from the internal one. On internal repetition trials, on the other hand, internal attention does not suffer much interference and can be robustly maintained. On switch trials, both attentional states are affecting behavior, resulting in the large internal and smaller external switch cost.

Priming

The task priming or "task set inertia" hypothesis was developed to account for task-switching costs as well (Allport et al., 1994; Gilbert & Shallice, 2002; Yeung & Monsell, 2003). The key difference with the associative interference hypothesis is that it proposes that task sets are carried over from one trial to the next—often with a recency gradient (Yeung & Monsell, 2003). That is, the cost is not due to retrieval of competing task sets, but to their positive priming from trial to trial, defined as the transient increases in activation for recently performed tasks (but see Allport et al., 1994 for an inhibition account).

This account has similarly been applied to asymmetrical switch costs between dominant and nondominant tasks. Yeung and Monsell (2003) argued that priming of task sets interacts differently with dominant and nondominant tasks. More specifically, in their model, positive priming is assumed to be especially strong following trials of the nondominant task (see also Gilbert & Shallice, 2002). On these trials, control is required to enhance attention to the relevant stimulus features. On trials of the dominant task, on the other hand, attention is more automatically allocated to the dominant stimulus features, without the involvement of additional control (which is assumed to be costly, and therefore minimized when possible). Together, these opposing effects can explain the cost asymmetry: On nondominant repetition and switch trials, interference from the dominant task set's activation is largely stable. As a result, there is only a small performance difference on both trial types. On dominant trials, on the other hand, the amount of interference from the nondominant task set differs greatly between switch trials, where control has recently increased the nondominant task-set's activation, and repetition trials, where its activation has returned to a default low state.

We can again use this account to interpret the asymmetric cost for switches between external and internal attention (Verschooren, Liefooghe et al., 2019). According to this account, additional (controlled) activation of external attention on external trials is required, while internal attention is activated more automatically. When switching from an external to an internal trial, the resulting additional activation of external attention is primed and results in a large switch cost. On external trials, on the other hand, there is a stable detrimental effect from the more automatic internal attention on both repetition and switch trials. As a result, no large cost emerges.

Retrieval Cost for Switches to Memory

In contrast to the two previous accounts, we can also formulate an explanation that does not assume an imbalance between external and internal attention. That is, one important difference between external and internal trials is the degree to which they rely on information stored in declarative memory. On internal trials, accessing and retrieving this information can incur an independent cost. Dark (1990) previously argued for such an account after observing a cost asymmetry for switches between perceiving individual letters on screen and retrieving them from memory. Participants performed lists in which letters were either only perceived or only retrieved to performance on lists where a single switch between them occurred. Dark (1990) found a cost only for switches toward memory retrieval, which disappeared when participants were precued and could retrieve the letter in advance.

Consequently, she concluded that switches between perception and memory in themselves did not incur a cost, but memory retrieval did (but see Carlson, Wenger, & Sullivan, 1993; Verschooren, Liefooghe et al., 2019 for methodological limitations).

This memory retrieval account can also be applied to interpret the asymmetric switch cost observed in the procedure of Verschooren, Liefooghe et al. (2019), where external and internal trials were intermixed. That is, we can interpret the larger internal switch cost as resulting from two independently contributing effects: the switch cost itself and a memory retrieval cost. In this interpretation, the presence of the basic switch cost is caused either by associative interference or by priming. In addition, specifically on internal trials, participants need to retrieve the memorized figures from declarative memory. If we further assume that recently refreshed memories are more accessible for retrieval, an additive memory retrieval cost during this switch can explain the larger switch cost for internal trials. This assumption entails that the memory retrieval cost will be especially large when switching to internal trials, compared to internal repetitions. In this situation, the internal representations have not recently been refreshed and need to be actively retrieved. In other words, even though there is a similar cost for the switch itself on both external and internal switch trials, an additional memory retrieval cost is present on internal switch trials, which would drive the larger cost observed there.

The Current Study

The three accounts discussed above, that is, associative interference, priming, and memory retrieval, have competing predictions under specific experimental settings. These predictions relate specifically to the relative magnitude of the switch costs (i.e., their asymmetry). According to the priming hypothesis, the cost asymmetry will be present only when participants switch between external and internal trials within a mixed block. The associative interference hypothesis, on the other hand, predicts that the asymmetry will be present even in blocks where only external or only internal trials are presented, as long as participants have previously learned the association between bottom-up stimulus features and both (external and internal) attentional states. Finally, the memory retrieval account predicts that a cost asymmetry will be present whenever a switch to an internal trial takes place, independent of any prior associations.

We tested these different predictions in a series of three experiments. Experiment 1 was a replication attempt of the switch cost asymmetry previously observed in a mixed-block design (Verschooren, Liefooghe et al., 2019). The three accounts predict that we would find a cost asymmetry in this experiment. In Experiment 2, participants alternated between pure blocks of either external or internal trials. On a subset of the trials, participants were interrupted by an unrelated task that required them to solve a simple mathematical equation. In this design, a priming account predicts no asymmetry, as there are no trial-to-trial transitions between the attentional states (see also Mayr et al., 2014). That is, as there is no additional external activation preceding an internal switch trial, the internal switch cost should be reduced, blunting the interaction effect. The other two accounts do predict a cost asymmetry, as in this design traces for the competing attentional states are present (associative interference) and switches toward internal representations occur (memory retrieval). Finally, Experiment 3 was a between-subjects design, where one group received external trials only and the other internal trials only. Here again, participants performed the mathematical task on a subset of trials. With this design, there is no opportunity to form associations of the competing attentional state, so the associative interference account predicts that the cost asymmetry would be absent in this experiment. More specifically, as the external repetition trials suffer less from the internal interference, the external switch cost should increase. Conversely, as the internal repetition trials never suffered from external interference, the magnitude of the internal switch cost should stay the same. Memory retrieval, on the other hand, assumes that the external switch cost should remain small and the internal one larger, resulting from the (effortful) retrieval operation. To summarize, in Experiment 2 we can compare the predictions from the priming account with the other two accounts. In Experiment 3, associative interference and memory retrieval can be pitted against each other.

Experiment 1

Participants

We recruited 47 participants on Amazon Turk, an online recruiting platform. The sample size was motivated by an a priori power analysis to detect a small effect size (partial η^2 of 0.04) in a repeated measures analysis of variance with 85% power, which revealed a required sample size of 39 (see also Verschooren, Liefooghe et al., 2019). We accepted data submission for participants who performed at >75%[1] accuracy on the experimental task, which resulted in the rejection of 6 participants (final sample of 41 participants).[2] Participants signed informed consents and received $3.3 for participation.

Method

Materials. The experiment was programmed in JavaScript, using the jQuery library (see https://osf.io/t8ery/ for the experiment script). The stimuli were 16 nonverbalizable figures from a larger set of stimuli created by Endo and colleagues (Endo, Saiki, Nakao, & Saito, 2003). These black figures were 60 by 60 pixels on a white background screen (900 × 900 pixels). In each run, two sets of four figures were used (one set for the external and another one for the internal trials). The same two sets were used for half of the participants and two other sets for the other half. For each participant, the set used for the internal and external trials was randomized.

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[1] This criterion was chosen to screen out participants who did not memorize the figures and answered randomly on this part of the task, which could theoretically result in an average accuracy of 75% (100% on external trials and 50% on internal ones).

[2] Demographic information for the participants was not saved due to a technical error. Difallah and colleagues (Difallah, Filatova, & Ipeirotis, 2018) recently investigated the demographic characteristics of Amazon Turk workers and reported a mean age of approximately 35 years old and an approximately balanced gender ratio. We have found this consistently as well in other (unpublished) experiments with similar sample sizes and in the published literature (e.g. Whitehead & Egner, 2018). Hence, we operate under the assumption that this describes the current samples.

Procedure. The experiment began with a training phase, which consisted of an external and internal training task (their order was counterbalanced over participants). The external training task was not strictly necessary to be able to carry out the perceptual trials of the main task, but was included to equate the amount of practice for the external and internal stimuli (see Verschooren, Liefooghe et al., 2019, Experiment 2). On each external training trial, a square was presented with one of the external figures in each of its four compartments for 15 s or until response (see Figure 1A). The locations of these figures were randomized on each trial. One of the four figures would be highlighted in a blue frame, indicating that this figure was the target figure. Simultaneously as well, one of the figures (the probe) would be presented above the square. Participants had to decide whether the target figure was identical to the probe figure. The internal training task began with the presentation of the four figures of the internal set (see Figure 1B). Participants pressed the space bar after memorizing these figures and their locations to continue to the internal training phase (or after 15 s had passed). Each internal training trial started with a 350-ms fixation cross (to remove the afterimage of the correct stimulus–location associations presented following an error; see below). Similar to the external training phase, for 15 s (or until response), a square with four compartments was presented on each trial, with one of them highlighted in a blue frame (the target location) and one of the four figures from the external set above presented above the square (the probe). Different from the perceptual training, however, the compartments of the square were filled with question marks. Participants needed to retrieve the figure that was in the target location from memory and decide whether this figure was identical to the probe figure. If participants made a mistake, the four figures were presented on screen for 5 s to allow re-encoding of the correct stimulus–location associations. Participants moved on to the experiment proper (the practice and main task) once their accuracy was higher than .85 on each of these tasks (and at least 18 trials were performed correctly in total). This criterion was set to assure that all participants memorized the set sufficiently (and equally).

In the experimental task, each trial started with a 250-ms fixation cross, after which a square (with four compartments) appeared on either side of it for 300 ms (See Figure 1C). One of the squares would contain four figures (perceptual set), and the other one four question marks (cues for LTM set). The locations of these external figures were randomized on each trial. Simultaneously, two arrows, one above and one below the fixation cross, would point to the relevant square for that trial (figures and question marks on perceptual and memory trials, respectively). At the same time, one of the four compartments in this square would be highlighted in a blue frame, indicating that this was the target that needed to be matched to the probe. On external trials, the target figure was presented on screen. On internal trials, participants needed to use the target location as a cue to retrieve the figure previously memorized in this location (see next paragraph). Finally, after this 300-ms window, a central probe replaced the fixation cross (all other stimuli remained on screen), which needed to be compared by the participants to the target. This final screen was presented for 2500 ms or until response.

For both the training tasks and experimental task, participants responded with the “d” key if the target and probe were identical and “k” key if they were not. This response mapping was counterbalanced over participants. Participants received feedback after each trial of the training tasks and after each trial of the practice block of the experimental task. After each block, they received feedback on their accuracy in that block.

The main experiment consisted of one practice block and eight experimental blocks. In each block, there were 2 warm-up trials and 80 experimental trials. Trial order was counterbalanced within each bock to create an equal number of trials in each of the four conditions. In addition, for each of these conditions, there was an equal number of match and mismatch trials (probe–target compatibility). On each trial, there was a .50 chance for the perceptual figures to appear on the left or right side and a .25 chance for each of the four locations to be the target (immediate repetitions of target position or probe were excluded). The order of the nine blocks was randomized for each participant, but the trial sequence within these blocks was predefined to meet the above restrictions.

Design. The task formed a repeated-measures 2 (Modality: external, internal) × 2 (Switch: repeat, switch) factorial design. The figures were presented on screen and retrieved from memory on external and internal trials, respectively. On repetition trials, the Modality of the current trial was the same as that on the preceding trial versus different on switch trials. This design resulted in four conditions: External–Repetition (Ext–Rep), External–Switch (Ext–Swi), Internal–Repetition (Int–Rep), and Internal–Switch (Int–Swi). The main dependent variables were the RTs and error rates (ERs) in each condition.

Data Analysis

The raw data and analysis scripts can be found online (https://osf.io/t8ery/). We removed the practice trials, the trials of the external and internal training phase, and the first two trials from each experimental block. In addition, we removed trials on which an error was made and those preceded by an error. The data were preprocessed and visualized using the tidyverse (Wickham, 2017) and ggplot2 (Wickham, 2016) libraries in R (R Core Team, 2018; Version 1.1.456).

Participants had very low error rates (ERs; sample mean around .05 in the least accurate condition), and there was no evidence for a speed–accuracy trade-off (see Table 1), so we focused the analysis on RTs. We analyzed the data with a Bayesian generalized linear multilevel model (BGLMM) approach, using the brms (Bürkner, 2017) and emmeans (Lenth, 2019) libraries. When there are repeated observations for each participant, a linear multilevel model is preferable over ordinary linear regression, as it considers variability at different levels of the dataset and allows them to inform each other (McElreath, 2016; Nalborczyk, Batailler, Lœvenbruck, Vilain, & Bürkner, 2019). Moreover, it is advisable to use a generalized linear multilevel model (GLMM) when analyzing RT data, which are rarely normally distributed and often show a skewed distribution (Lo & Andrews, 2015; Speelman & McGann, 2013). We opted for a GLMM with an inverse Gaussian with natural logarithmic function, which we previously found to describe RT data on this type of protocol best (Verschooren, Liefooghe et al., 2019). Finally, we specified the model using a full random structure, as has been recommended in the literature (see Barr, Levy, Scheepers, & Tily, 2013). That is, in addition to estimating the group-level effects for Modality, Switch, and their interaction, we estimated these effects for each participant as well.

Table 1
Reaction Times and Error Rates for Experiments 1–3

Experiment	Src.	Seq	RT (*SD*)	ER (*SD*)	RT cost	ER cost
1	Ext	Rep	815 (165)	.03 (.04)	36	.01
		Swi	851 (177)	.04 (.05)		
	Int	Rep	912 (204)	.07 (.06)	59	.01
		Swi	971 (212)	.08 (.06)		
2	Ext	Rep	744 (113)	.03 (.03)	52	.00
		Swi	796 (136)	.03 (.03)		
	Int	Rep	875 (154)	.05 (.04)	80	.01
		Swi	955 (184)	.06 (.05)		
3	Ext	Rep	822 (176)	.03 (.04)	62	.01
		Swi	884 (194)	.04 (.04)		
	Int	Rep	885 (194)	.05 (.06)	72	.01
		Swi	957 (209)	.06 (.07)		

Note. Src. = source; Seq = sequence; RT = reaction time; ER = error rate; Ext = external; Int = internal; Rep = repetition; Swi = switch.

Within this model, we then looked at the presence or absence of the fixed effects of interest. We provide the model summary (fixed effects) and planned contrasts, which give the model estimate of the switch cost for external and internal trials. As the model estimates are not in the response scale, we back-transformed them using the emmeans package. For all effects, we present the 95% high probability density interval (HPDI) of the posterior distribution.

We analyzed the data in a Bayesian framework because our critical test consisted of detecting evidence for the presence or absence of the interaction effect. Within a Bayesian framework, evidence in favor of or against the null hypothesis can be obtained in the form of a Bayes factor (BF). We obtained BFs using the Savage-Dickey density ratio method from the brms package (see Wagenmakers, Lodewyckx, Kuriyal, & Grasman, 2010). This method is very sensitive to the specific prior set by the researcher, so we used weakly informative priors on the fixed effects (a normal distribution centered around 0 with a standard deviation of 0.03). The BF testing for evidence in favor of or against the null hypothesis then represents the amount of posterior updating after the data are fit by the model. In addition to these BFs, we use a region of practical equivalence (ROPE), which is less reliant on priors. Kruschke (2018) suggests setting the width of the ROPE to −0.1 to 0.1 times the standard deviation of the posterior distribution, corresponding to a negligible effect size. We used 0.2 as a more conservative estimate, but this cutoff did not influence the results. If the 89% CI falls completely outside the ROPE, we can conclude that we have a non-negligible effect.

Results

The model summary revealed a main effect for Modality (β = 0.079, *95% HPDI* = [0.046; 0.109]) and for Switch (β = 0.038, *95% HPDI* = [0.025; 0.051]; see Figure 2C). More specifically, participants were slower on internal than external trials and on switch than repetition trials (see Figure 2A). Crucially, the interaction effect was present as well, providing evidence for the switch cost asymmetry (β = 0.023, *95% HPDI* = [0.007; 0.039]; see Figure 2B–C). Converted back to the response scale, the model estimated the intercepts of the conditions to be 805 ms (*95% HPDI* = [754; 860]), 836 ms (*95% HPDI* = [781; 893]), 871 ms (*95% HPDI* = [811; 933]), and 926 ms (*95% HPDI* = [862; 993]) for Ext–Rep, Ext–Swi, Int–Rep, and Int–Swi, respectively. Planned contrasts for the effect of Switch in both modalities revealed that the switch cost was indeed asymmetric in the expected direction, with a smaller cost when switching attention to external stimuli (31 ms, *95% HPDI* = [21; v 41]) than to internal representations (55 ms, *95% HPDI* = [42; v 68]; see Figure 2). Crucially, when we look at the BF (12.9), we can conclude that we have strong evidence in favor of the presence of an interaction effect (Kass & Raftery, 1995; see Figure 2D). This agrees with the evidence gathered through the ROPE as well, which falls completely outside the 89% HPDI (see Figure 2D).

Discussion

In Experiment 1, participants responded more slowly when the modality (external vs. internal) of the current trial was different than the modality of the previous one, compared to a repetition. Moreover, the model estimated this cost as larger when switching toward internal (55 ms) than external (31 ms) trials. In other words, we replicated the asymmetric cost (BF = 12.9) for these switches reported in Verschooren, Liefooghe et al. (2019).[3]

In the introduction, we presented three competing hypotheses that could account for this asymmetry, that is, associative interference, priming, and memory retrieval. The associative interference account predicts that the asymmetry occurs whenever participants had the opportunity to learn both competing attentional settings and an interruption takes place (which does not have to be the competing task). The priming account, on the other hand, states that trial-to-trial transitions between both competing attentional settings are a necessary precondition. The memory retrieval account, finally, claims that the asymmetry will be present whenever participants switch toward an internal trial. In Experiment 2, we

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[3] This replication was successful despite profound differences in the sample pool characteristics (Amazon Turk participants primarily from the U.S. and India versus undergraduate psychology students from Belgium) and minor changes in the experimental protocol (most notably the amount and presentation of the training phases and the order of the target–probe appearance; see Verschooren, Liefooghe, et al., 2019). This further demonstrates the robustness of this effect.

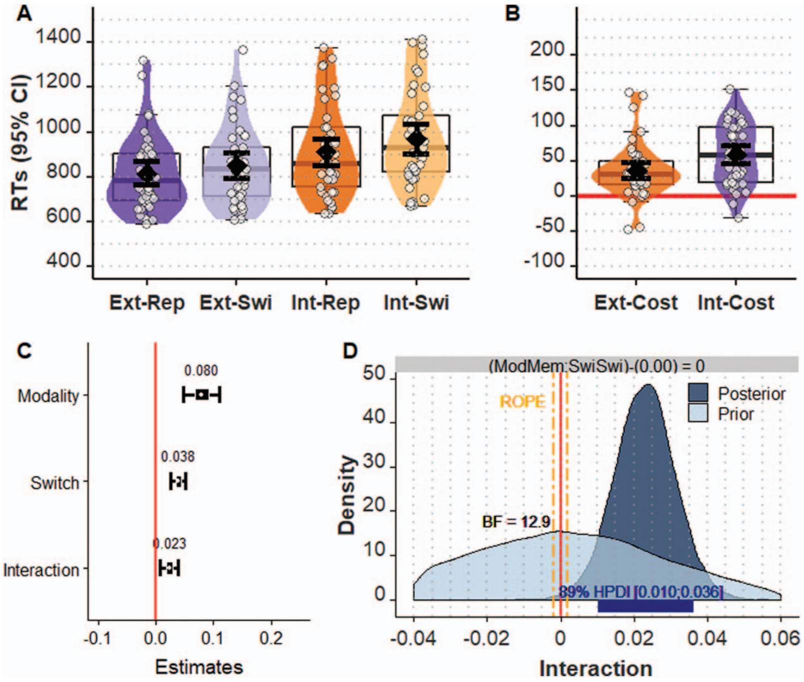

Figure 2. Response times for Experiment 1. In black: Mean response time and 95% confidence interval (CI). In white: individual participants' means. A. External–Repetition (E–R), External–Switch (Ext–Swi), Internal–Repetition (Int–Rep) and Internal–Switch (Int–Swi) conditions. B. Switch cost for External (Ext–Swi > Ext–Rep) and Internal (Int–Swi > Int–Rep). C. The (transformed) model estimates for the fixed effects. The thick line and error bars represent the 55% and *95% HPDI*, respectively. D. The prior (light blue/light gray) and posterior (dark blue/dark gray) distribution for the interaction effect. The BF (12.9) represents their ratio for the hypothesis that there is an interaction effect. The ROPE (orange/pale gray) and 89% HDPI (blue/dark gray) do not overlap (see Kruschke, 2018). See the online article for the color version of this figure.

pitted the priming hypothesis against the other two hypotheses by evaluating whether trial-to-trial carryover of attentional settings is a necessary condition for the cost asymmetry to occur. More specifically, in Experiment 2, participants carried out pure blocks of either perceptual or memory trials and were occasionally interrupted by a third, independent task in which they solved simple math equations. If we were to observe larger costs in the internal blocks than perceptual blocks, we would be able to infer that carryover of attentional settings from one modality to the other is not a necessary condition for the asymmetry.

Experiment 2

Participants

Fifty-four participants were recruited through Amazon Turk (see power analysis for Experiment 1). We rejected 9 participants with accuracy lower than 75% (45 included). Participants signed informed consent and received $3.30 for participation.

Method

Materials. Materials were the same as in Experiment 1 (see https://osf.io/t8ery/ for the experiment script). For the interrupting task, we used a list of simple mathematical equations (Vassena et al., 2014).

Procedure. The training task and experimental trials were identical to Experiment 1. However, on one in four experimental trials, a simple mathematical equation followed the probe-to-target matching. These trials consisted of a single screen in which three digits needed to be added ("A + B + C = ?"). On each trial, one correct and one incorrect solution was provided ("Press the 'd' key if the correct answer is X and press the 'k' key if the correct answer is Y"). The correct result never exceeded 9 and the incorrect answer differed by 1 or 2 from the correct one. This interrupting task was taken from earlier research addressing a similar question (Mayr et al., 2014) and arguably relies on both external and internal attention.

Participants responded with the "d" and "k" keys on all trials (counterbalanced over participants), but there was no consistent response mapping for correct and incorrect trials on the interrupting task. That is, on each of these trials, two response options were provided ("Press 'd' key if answer is X and 'k' if answer is Y"), and the correct response (X vs. Y) differed from trial to trial.

Design. The same independent variables were used as in Experiment 1 (Modality and Switch), but Modality was alternated from block to block instead of trial to trial. For the Switch variable, switch trials were those preceded by the interrupting task and repetition trials those that were not. The dependent variables were RT and ER in the different conditions.

The experiment consisted of two practice blocks (one external and one internal) and eight experimental blocks (four external and four internal). The block order alternated between external and internal, but their sequence was counterbalanced over participants (A–B vs. B–A). Each trial had a .25 chance to be followed by the interrupting task (160 experimental trials). Within each block, there was an equal number of trials following the interruption from each Modality (10 per Modality per block). For these trials, there were an equal number of match and mismatch responses for each Modality. Side of presentation, probe identity, and target location were randomized as in Experiment 1.

The training tasks were the same as in Experiment 1 and were provided two times for each block type (i.e., once before the practice block and first experimental block for each modality).

Data Analysis

The same preprocessing steps were taken as in Experiment 1 (see https://osf.io/t8ery/). In addition, the interrupting task trials and experimental trials following an error on the interrupting task were removed. The same BGLMM analysis with a full random model was used.

Results

The model summary revealed a main effect for Modality (β = 0.111, *95% HPDI* = [0.074; 0.144]) and for Switch (β = 0.055, *95% HPDI* = [0.0.034; 0.075]; see Figure 3C), with participants being slower on internal and switch trials compared to external and repetition trials, respectively (see Figure 3A). In addition, an interaction effect was present as well (β = 0.020, *95% HPDI* = [0.002; 0.038]; see Figure 3B–C). The model estimated the intercepts for Ext–Rep, Ext–Swi, Int–Rep, and Int–Swi to be 743 ms (*95% HPDI* = [708; 780]), 786 ms (*95% HPDI* = [744; 828]), 831 ms (*95% HPDI* = [784; 877]), and 897 ms (*95% HPDI* = [839; 951]), respectively. Planned contrasts revealed that the switch cost was indeed asymmetric in the expected direction, with a smaller cost to switch toward external trials (42 ms, *95% HPDI* = [27; 57]) than to internal trials (65 ms, *95% HPDI* = [46; 82]). From the BF (3.5), we can conclude that there is substantial evidence in favor of the interaction effect (Kass & Raftery, 1995; see Figure 3D). Here again, this conclusion is further corroborated by the lack of overlap between the ROPE and the 89% HPDI (see Figure 3D).

Discussion

In Experiment 2, we tested the competing predictions of the priming hypothesis versus the associative interference and memory retrieval hypotheses. Participants switched between external and internal blocks and were occasionally interrupted to solve a mathematical equation. The priming hypothesis predicted no switch cost asymmetry in this situation, as there was no opportunity for trial-by-trial carryover of attentional settings from external to internal and vice versa. The associative interference and mem-

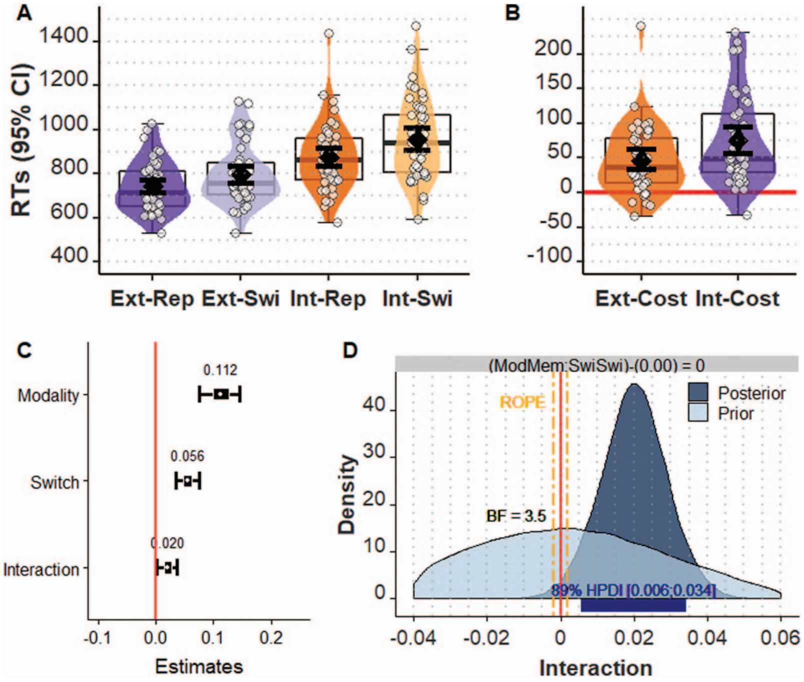

Figure 3. Response times for Experiment 2. In black: Mean response time and 95% confidence interval (CI). In white: individual participants' means. A. (Ext–Rep, Ext–Swi, Int–Rep, and Int–Swi) conditions. B. Switch cost for External (Ext–Swi > Ext–Rep) and Internal (Int–Swi > Int–Rep). C. The (transformed) model estimates for the fixed effects. The thick line and error bars represent the 55% and *95% HPDI*, respectively. D. The prior (light blue/light gray) and posterior (dark blue/dark gray) distribution for the interaction effect. The BF (3.5) represents their ratio for the hypothesis that there is an interaction effect. The ROPE (orange/pale gray) and 89% HDPI (blue/dark gray) do not overlap (see Kruschke, 2018). See the online article for the color version of this figure.

ory retrieval hypotheses, in contrast, both predicted the presence of a cost asymmetry (see introduction). We found clear statistical evidence for the latter result, with a larger switch cost for internal (80 ms) than external (52 ms) trials. Even though the evidence is less strong compared to Experiment 1, it is still substantial (BF = 3.5). Therefore, we can reasonably exclude the priming account as a viable explanation for this asymmetry.

However, we cannot yet distinguish between the other two competing accounts, as both had their prediction of the presence of an interaction effect confirmed in Experiment 2. Under certain experimental settings, they nonetheless have opposing predictions. The associative interference hypothesis proposes that the cost asymmetry results from worse shielding against competing attentional states on Ext–Rep than Int–Rep trials. In other words, if there is no opportunity to learn these competing attentional states, the asymmetry should disappear. The memory retrieval hypothesis, on the other hand, predicts that switching toward internal representations will always (e.g., even though a competing attentional state, here external, is not activated) be more costly than switching to external stimuli. To adjudicate between these two accounts, we used a between-subjects design in Experiment 3 (with one group of participants that performed solely external blocks and the other one solely internal blocks) because it allowed us to explore the behavior of the switch cost under pure experimental conditions, that is, participants in each group had no experience whatsoever with the other attentional set, and thus a modulation of the switch cost across the two main conditions/groups could not be explained by the presence of this competing attentional set. If we were to find no cost asymmetry in Experiment 3, we would be able to reject the memory retrieval hypothesis. Furthermore, the associative interference hypothesis predicts that the external switch cost will actually become larger in this situation than Experiment 1 because participants could better shield external attention on Ext–Rep trials (i.e., faster RTs on Ext–Rep trials). In other words, if the asymmetry were to disappear because of the external cost increases, this would be considered strong evidence in support of the associative interference hypothesis.

Experiment 3

Participants

We recruited 91 participants on Amazon Turk, 47 and 44 for the external and internal condition, respectively. This sample size was based on an a priori power analysis in G*Power to find a small effect size (partial η^2 of 0.03) in a repeated measures ANOVA with a within–between interaction with 85% power, which revealed a required sample size of 76 participants. Six were excluded in the external condition and 3 in the internal conditions, resulting in 41 participants in each condition. Participants signed informed consent and received $3.30 for participation.

Method

The materials from Experiment 2 were also used in Experiment 3. The design from Experiment 2 was adapted to a between-subjects one, but was otherwise identical. In the external condition, participants carried out one practice block and eight experimental blocks of the external trials. Before the practice block and first block, they received the external training task. The participants in the internal condition did the same for the internal trials and the internal training task.

Data Analysis

The data preprocessing and analysis was identical as in Experiment 2 (see https://osf.io/t8ery/).

Results

The model showed a significant main effect for Switch (β = 0.065, *95% HPDI* = [0.046; 0.083]; see Figure 4C), with participants being slower on switch than repetition trials (see Figure 4A). The effect for Modality (β = 0.020, *95% HPDI* = [−0.030; 0.070]) and the interaction between these two factors (β = 0.013, *95% HPDI* = [−0.010; 0.036]) were not present, however (see Figure 4A–C). The model estimated the intercepts at 826 ms (*95% HPDI* = [780; 870]), 881 ms (*95% HPDI* = [831; 932]), 843 ms (*95% HPDI* = [796; 889]), and 911 ms (*95% HPDI* = [859; 962]) for the Ext–Rep, Ext–Swi, Int–Rep, and Int–Swi trials. The external switch cost was estimated at 56 ms (*95% HPDI* = [40; 71]) and the internal one at 68 ms (*95% HPDI* = [56; 81]). Crucially, compared to Experiments 1 and 2, the BF (0.8) changes direction and no longer provides evidence in favor of the presence of an interaction (see Figure 4D). This is confirmed by the ROPE, which falls completely within the 89% HPDI. The evidence in favor of the absence of an interaction is not conclusive, however.

Discussion

Experiment 3 was designed to adjudicate between rival predictions of the associative interference and memory retrieval hypotheses. To this aim, a between-subjects experimental design was used. According to the associative interference account, no cost asymmetry should emerge, as there was no opportunity to learn (and subsequently retrieve) competing attentional states. The memory retrieval account, on the other hand, did predict an asymmetry, as switching toward memory should always be more costly than switching toward perception. Whereas we again found a robust switch cost in Experiment 3, this cost was no longer asymmetric. However, the current data do not allow us to claim evidence in favor of the absence of the interaction, even though the evidence is going in that direction (BF = 0.8).

Notwithstanding this caveat, two additional pieces of evidence in favor of an associative interference account are worth noting here. First, the cost on external trials actually increased in this experiment compared to the two previous ones (see Figure 5). This was confirmed by two-sided independent samples t-tests, which showed that there was no difference between the magnitude of the external switch cost in Experiments 1 and 2 (31 ms vs. 42 ms; $T_{84} = -1.35$, $p = .18$, Cohen's d = −0.29). This cost was statistically different between Experiment 1 and Experiment 3 (31 ms vs. 56 ms; $T_{80} = -3.79$, $p < .001$, Cohen's d = −0.84). Between Experiments 2 and 3, it was numerically different and trending toward significance (42 ms vs. 56 ms; $T_{84} = -1.79$, $p = .07$, Cohen's d = −0.39). This is a counterintuitive finding that was predicted exclusively by the associative interference hypothesis, that is, it naturally follows from the more efficient shielding

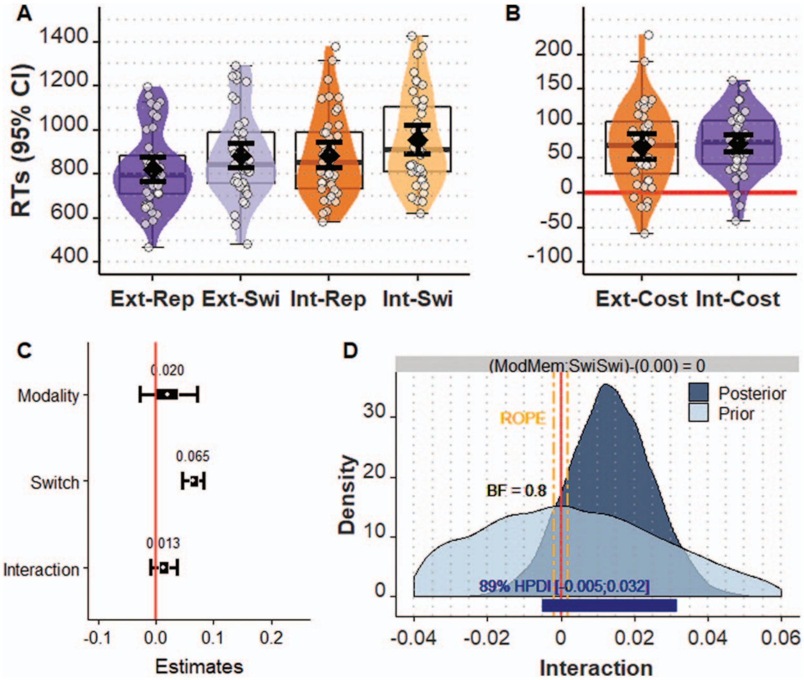

Figure 4. Response times for Experiment 3. In black: Mean response time and 95% confidence interval (CI). In white: individual participants' means. A. Ext–Rep, Ext–Swi, Int–Rep, and Int–Swi conditions. B. Switch cost for External (Ext–Swi > Ext–Rep) and Internal (Int–Swi > Int–Rep). C. The (transformed) model estimates for the fixed effects. The thick line and error bars represent the 55% and *96% HPDI*, respectively. D. The prior (light blue/light gray) and posterior (dark blue/dark gray) distribution for the interaction effect. The BF (0.8) represents their ratio for the hypothesis that there is an interaction effect. The ROPE (orange/pale gray) and 89% HDPI (blue/dark gray) do not overlap (see Kruschke, 2018). See the online article for the color version of this figure.

on Ext–Rep trials when no competing attentional states are stored. The memory retrieval account, on the other hand, would predict that the external (and internal) switch costs are equivalent in all experiments, which is not what we observed.

Second, there were no differences in the magnitude of the internal switch costs in Experiments 1–3 (T*s* < 1.62, *p*s > 0.11). This finding serves as an argument against an alternative interpretation at the methodological level. That is, one might argue that an important remaining difference between Experiments 1 and 2, on the one hand, and Experiment 3, on the other, is that participants in the internal condition of Experiments 1 and 2 sometimes needed to attend to the external stimuli. This in turn might have disrupted the stable maintenance of the internal representations and resulted in an increased internal retrieval cost when switching toward them (as the memory retrieval account predicts as well). In Experiment 3, participants did not have to attend to the external stimuli, so,

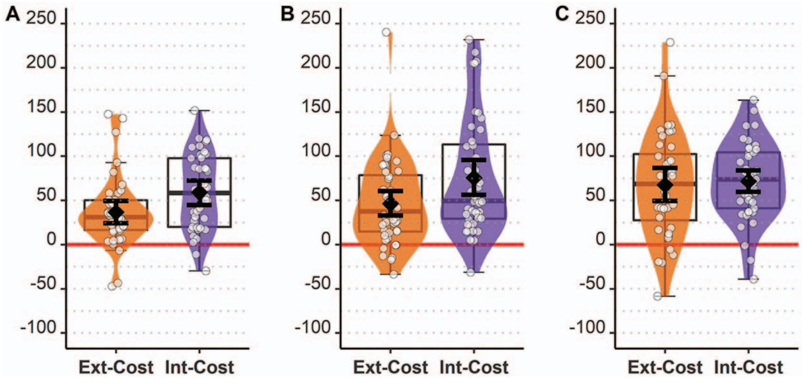

Figure 5. Switch costs for Experiment 1–3. In black: Mean response time and 95% confidence interval (CI). In white: individual participants' means. A. Asymmetric switch cost in Experiment 1. B. Asymmetric in Experiment 2. C. Nonasymmetric cost in Experiment 3. See the online article for the color version of this figure.

following this reasoning, internal maintenance would not have suffered. This would reduce the internal switch cost in Experiment 3, blunting the interaction effect. However, what we actually observe is that the internal switch cost stays the same and the external one increases. Here again, the associative interference account predicts that the internal cost should not be affected by the presence or absence of external trials. Overall, we therefore conclude that the statistical evidence gathered in Experiment 3 favors the associative interference over the memory retrieval account.

General Discussion

In this series of experiments, we aimed to contrast three rival accounts for the finding that even though participants are faster on internal than external attention trials, they show a larger cost when switching attention to internal representations than to external stimuli. These accounts, that is, associative interference, priming, and memory retrieval, make different predictions under specific experimental settings. More specifically, the priming hypothesis predicts a larger cost for switching attention to internal representations than to external stimuli only when an internal trial is preceded by an external trial, and vice versa. The associative interference account, on the other hand, hypothesizes that the asymmetry occurs in updating situations in which associations have been previously learned between bottom-up stimulus features and competing (external and internal) attentional settings for that stimulus. According to this account, if there are no competing traces, then no cost asymmetry arises. Finally, the memory retrieval account predicts that the cost to switch to an internal representation will systematically be larger than that to switch to an external stimulus, as an additive memory retrieval process takes place, irrespective of the presence or absence of a competing attentional set. Crucially, whereas the first two accounts rely on the assumption that there is an imbalance between external and internal attention, the third one does not. We pitted these predictions against each other in three experiments and found that the data could be best explained in terms of an associative interference account. Even though we are cautious in drawing definite conclusions on the basis of these data alone, these novel findings raise some intriguing research questions, as discussed below.

In Experiment 1, we attempted to replicate using an online experiment (by means of Amazon Mechanical Turk), as opposed to a lab experiment (Verschooren, Liefooghe et al., 2019), the cost asymmetry found previously when participants switched randomly on a trial-by-trial basis between external and internal trials in mixed blocks. We found that participants show a cost when switching between external stimuli and internal representations and that this cost was indeed larger for switching attention toward internal representations (model estimate: 55 ms) than toward external stimuli (31 ms; see Figure 5A), thereby closely replicating Verschooren, Liefooghe et al. (2019). Experiment 2 was designed to arbitrate between the associative interference and memory retrieval hypotheses on the one hand and the priming hypothesis on the other. All participants alternated between pure blocks of either external or internal trials and solved a simple mathematical equation on a subset of trials. We found a switch cost asymmetry following this interruption that was estimated at 65 ms when switching toward an internal representation and 42 ms when switching toward an external stimulus (see Figure 5B). This finding excludes priming as a plausible explanation of the cost asymmetry, as trial-by-trial switching is a necessary condition for this account. Finally, Experiment 3 was used to disentangle the associative interference from the memory retrieval account. Half of the participants were exclusively confronted with external trials while the other half exclusively with internal trials, a between-subjects manipulation which ensured that external and internal attentional settings did not compete or interfere with each other. Here again, participants solved simple mathematical equations on a subset of the trials. Unlike Experiments 1 and 2, we found no statistical evidence for a cost asymmetry following the interruptions in this experiment (the switch cost was estimated at 68 ms and 56 ms for internal and external trials, respectively; see Figure 5C), which allows us to exclude memory retrieval as a viable explanation for the asymmetry. However, even though the BF reversed direction toward favoring the null, the evidence provided by it was not conclusive (BF = 0.8). That being said, the associative interference account also predicted that the external switch cost would become larger in this single task design (compared to situations where the other task had also been experienced, as in Experiments 1 and 2), which is precisely what we observed (see Figure 5). That is, according to this account, the smaller cost in a mixed task design is not due to the fact that switching toward external stimuli might be easier, but instead to less efficient (or more difficult) shielding on external repetition trials. In a single task design, there are no competing attentional states that can trigger updating attempts during this inefficient shielding, but the RTs on switch trials are not affected (as updating is still required here). This increased cost is not something one would intuitively expect in a single task setting otherwise, as one would expect that it is less effortful to return to the main task. In addition, the internal switch cost was not smaller in Experiment 3 than in Experiments 1 and 2, which excludes further alternative explanations in terms of a disruption of internal maintenance by the external stimuli (see Experiment 3 Discussion).

Taken together, these results therefore provide strong evidence against a priming and some evidence against a memory retrieval account, and for the associative interference hypothesis. To recapitulate (see introduction), associative interference proposes that three conditions need to be met for a cost asymmetry to arise: (i) memory traces for both competing attentional states have been paired to stimulus features and are automatically retrieved when the stimulus is encountered; (ii) the WM gate is opened when transitioning to an updating mode, allowing both traces to simultaneously enter; (iii) when the gate is closed, the more dominant attentional state can efficiently shield against interference from the other, but not the other way around. When these three conditions are met, the cost asymmetry results from the large difference between efficient shielding on repetition trials and inefficient shielding on switch trials for one task and the inefficient shielding on both repetition and switch trials for the other. In the paradigm used here, the actual interference is likely driven by the associative encoding of an external and internal attentional focus with a certain spatial location in the stimulus array, as the same locations are used on external and internal trials. Subsequently, when such a location is selected on a trial, both attentional foci are activated and (asymmetrically) interfere with one another.

One observation nonetheless deserves further attention. Our theoretical framing in the introduction was strongly influenced by the findings presented in Verschooren, Liefooghe et al. (2019). These authors observed a larger cost for switches toward internal representations, but faster RTs on internal trials in general. This pattern of results suggested the existence of dominant versus nondominant attentional sets (see introduction section) and partly motivated the current study. In the series of experiments reported here, however, we did not find a general RT benefit for internal trials—even though the cost asymmetry remained. As a matter of fact, participants were faster on external trials in Experiments 1 and 2. This might be due to a reduction in the number of training phases administered to the participants. Whereas a (external and internal) training phase was administered before each block in Verschooren, Liefooghe et al. (2019), here we did it only before the practice and first block. As the internal training is arguably more task-relevant, given the importance of the learned stimulus–location associations for performing the task, compared to mere stimulus familiarization in the external case, this may have affected the response speed of the participants (in general). Hence, although training could potentially influence performance (especially on internal trials), it appears that this effect can be dissociated from that related to switches between external and internal attention, likely caused by associative interference. The asymmetry we observe, then, might be more inherent and stem from the enhanced shielding of internal compared to external attention, as our new results suggest. In this context, it should also be noted that this main effect (general response speed difference between internal and external conditions) was never of theoretical interest: The common denominator among the three different theoretical accounts considered in our work was their potential to predict the presence or absence of the cost asymmetry in different experimental contexts. As stated in the introduction, we did not assume internal dominance because evidence in favor of it is lacking in the extant literature. Although we did not focus on this main effect, which is arguably of a lower theoretical importance than the robust cost asymmetry found in this study, its actual relationship to internal shielding remains to be established and explored in future studies. That being said, among the three competing accounts considered in this study, associative interference appears to provide the best one to account for the cost asymmetry observed here, which implies an imbalance in shielding between external and internal attention.

This raises the question as to what exactly causes this imbalance in shielding efficiency between external and internal attention. That is, an important potential implication of our results is that (internal) attention to memory can be shielded more efficiently than attention to perception.

More Efficient Shielding for Internal Than External Attention?

At face value, this imbalance in shielding implies that internal attention is more readily deployable—and more easily shielded—than external attention. This conclusion might seem counterintuitive given the historical bias for using external stimuli in attention research, but it can provide a useful new perspective on the relationship between external and internal attention. In addition, some indirect evidence for the idea that internal attention is dominant over external attention is available in the literature.

First, a large body of neuroimaging data have shown that when participants are unconstrained by an external task, they reliably revert to a cognitive default mode ("resting-state"), characterized by increased activity in a network of midline and temporal brain regions (Raichle, 2015, for a review). This network has been associated with spontaneous, internally directed cognition, for example daydreaming, autobiographical memory retrieval, or mentation about the future. This suggests that internally directed attention represents the "default" cognitive mode when we are not actively engaged with an external task. Second, we know from mind-wandering research that, even when performing a task, attention often is drawn inwardly and "mind-wandering" intrusions occur that disrupt task performance (Seli, Risko, Smilek, & Schacter, 2016, for a review). Finally, research on WM guidance (i.e., internal attention) of external attention reports strong and automatic internal intrusions in external attention (e.g., Kiyonaga, Egner, & Soto, 2012; Olivers, Peters, Houtkamp, & Roelfsema, 2011). On the other hand, however, it has also been found that external distractors can disrupt internal maintenance in WM (e.g., Hakim, Feldmann-Wüstefeld, Awh, & Vogel, 2020; Whitehead, Ooi, Egner, & Woldorff, 2019). A direct and systematic comparison of these effects may prove insightful, but has to our knowledge not been carried out yet.

Alternatively, Tarder-Stoll, Jayakumar, Dimsdale-Zucker, Gunseli, & Aly (2019) argue that the imbalance between external and internal attention is more state-dependent. The argument goes that the balance between external and internal attention is determined by "encoding" and "retrieval" states (see also Tulving, 2002). In the former state, attention is primarily externally oriented, whereas it is mostly internally oriented in the latter. Among other factors, exposure to novel stimuli promotes an (external) "encoding" state by increasing acetylcholine levels in the hippocampus. Conversely, a familiar context reduces these levels and brings about a retrieval mode by reducing these levels. In the study presented here and in our previous work (Verschooren, Liefooghe et al., 2019), we have reused the same eight stimuli throughout the task, which may have potentially promoted a dominant retrieval mode.

Based on the new data presented here, it is not possible to distinguish between a more inherent versus more state-dependent view, but this issue represents an interesting avenue for further research.

Limitations

While we observed strong evidence for the robustness of the asymmetric switch effect between internal and external attention, and also obtained strong evidence against a priming-based explanation for that effect, it is important to emphasize that we did not find conclusive evidence in favor of associative interference over memory retrieval mediating that effect in the current series of studies. With this caveat in mind, it is however important to note that the Bayesian evidence in Experiment 3 goes in the direction of the absence of an effect, and the external switch cost did increase, two effects that are compatible solely with the associative interference account. Furthermore, in the literature, there is accumulating evidence in favor of associative interference and, more broadly, memory representations that can modulate cognitive control (Abrahamse et al., 2016; Braem & Egner, 2018; Egner, 2014; Mayr et al., 2014; Spapé & Hommel, 2008). Hence, it appears important to explore this question further in future studies, preferably using a variety of experimental procedures. In this context, it would probably be interesting to consider the possibility of a hybrid model, assuming that associative interference (procedural level) and memory retrieval (declarative level) might both contribute to the asymmetric switch cost found here. Finally, another important question raised by this work is whether the increased interference on external trials originates from the presence of competing external stimuli, from stimulus–location associations activated in memory, or both. Research on this topic should determine whether differences in shielding efficiency are general or rather tied to the quality of the distractor.

In addition, it should be noted that in the between-subjects design (Experiment 3), we did not find a general RT difference between the internal and external conditions. In other words, participants are slower in general when performing an external single-task condition, which is somewhat unexpected. One potential explanation is that this condition is not very engaging in the absence of the competing internal task. As argued above, however, this main effect is tangential only, and it does not invalidate our interpretation of the asymmetric switch cost in terms of associative interference. At any rate, some caution is needed in the interpretation of this effect, and further research is desirable to confirm that it is rooted in associative interference, as we contend based on these results.

Conclusions

We report evidence for the notion that associative interference can account for the cost asymmetry found when switching between (external) perception and (internal) memory. In comparison, priming and memory retrieval do not provide viable accounts of it. An important new hypothesis derived from this interpretation is that internal attention may be more easily shielded from external intrusions than the other way around. We discussed several potential factors creating this imbalance, but additional research is needed to establish which of them most likely causes it. More broadly, our findings provide further support for a currently developing framework that places high-level cognitive functions under learning and memory-driven control (Abrahamse et al., 2016; Braem & Egner, 2018; Egner, 2014; Mayr et al., 2014; Spapé & Hommel, 2008). We advocate that this framework can also be used to explain attention flexibility, and more specifically the remarkable ability to switch between external and internal attention.

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