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# Selective Attention to Perceptual Dimensions and Switching Between Dimensions

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In the present experiments, the question being addressed was whether switching attention between perceptual dimensions and selective attention to dimensions are processes that compete over a common resource? Attention to perceptual dimensions is usually studied by requiring participants to ignore a never-relevant dimension. Selection failure (Garner's Interference, GI) is indicated by poorer performance in the filtering condition (when this dimension varies) as compared with baseline (when it is fixed). Switching between perceptual dimensions is usually studied with the task switching paradigm. In the present experiments, attention switching was manipulated by using single-task blocks and blocks in which participants switched between tasks or dimensions in reaction to task cues, and attention to dimensions was assessed by including a third, never-relevant dimension that was either fixed or varied randomly. In Experiments 1 (long cue-target interval, CTI) and 2 (short CTI), the tasks involved shape and color and the never-relevant dimension (texture) was chosen to be separable from them. In Experiments 3 (long CTI) and 4 (short CTI), the tasks involved shape and brightness and the never-relevant dimension, saturation, was chosen to be separable from shape and integral with brightness. Task switching did not generate GI but a short CTI did. Thus, switching and filtering generally do not compete over central limited resources unless under tight time pressure. Experiment 3 shows GI in the brightness task but not in the shape task, suggesting that participants switched their attention between brightness and shape when they switched tasks.

*Keywords:* task switching, Garner interference, reaction time (RT)

People can effectively ignore an irrelevant dimension such as shape when they attend to another dimension such as color. They can also effectively switch their attention from one dimension to another. The question addressed in this paper is how these two abilities relate? Specifically, we asked whether attention switching would (temporarily) compromise the ability to ignore irrelevant information. Surprisingly, the two abilities have been studied in two separate traditions with very little exchange between them (e.g., see Hanania & Smith, 2010). Below we briefly introduce relevant issues and terms from the two literatures, review the few studies that combined the two traditions and describe our specific questions and hypotheses.

## Selective Attention to Stimulus Dimensions

Garner and his colleagues (e.g., Garner, 1974; Garner & Foldy, 1970) asked participants to classify multidimensional stimuli into categories, based on a classification rule that was defined

in terms of a single perceptual dimension such as stimulus color. The task was carried out in three blocked conditions, varying in terms of the attentional requirement context. In the *orthogonal filtering* condition ("filtering" for short), in addition to varying along the task-relevant dimension (e.g., color: some were red and some were green), the stimuli also varied along an irrelevant dimension (e.g., shape: some were squares and some were circles). The filtering condition thus requires effectively ignoring this irrelevant variation. In the *baseline* condition, the stimuli varied only along the relevant dimension and the irrelevant dimension was held constant (e.g., when judging color, all the stimuli were squares). The poorer performance in the filtering than in the baseline condition is termed "Garner Interference" (GI). Although unrelated to the present study, we note that many studies also incorporated a *correlated* (or redundant) condition, in which the irrelevant dimension was correlated with the relevant dimension.

Garner's paradigm makes it possible to distinguish between *Separable dimensions*, showing no GI, and *Integral dimensions*, showing GI. Thus, separable dimension pairs are ones in which participants can effectively ignore one dimension when the other dimension is relevant. Integral dimension pairs are ones in which participants cannot ignore one dimension when the other dimension is relevant.

## Switching Between Dimensions

In task switching studies, participants are typically asked to switch between two or more speeded classification tasks. Many studies use speeded semantic classification tasks such as magni-

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tude and parity (e.g., Allport, Styles, & Hsieh, 1994; Sudevan & Taylor, 1987). However, many other studies use speeded perceptual classification tasks (e.g., Arrington, Altmann, & Carr, 2003; Hartley, Kieley, & Slabach, 1990; Hübner, Futterer, & Steinhäuser, 2001; Meiran, 1996; Rubin & Meiran, 2005; Yeung, Nystrom, Aronson, & Cohen, 2006). The fact that the speeded classification tasks are defined in terms of perceptual dimensions makes the connection with Garner's paradigm straightforward.

A common finding is the behavioral cost associated with task switching (Kiesel et al., 2010; Meiran, 2010; Vandierendonck, Liefoghe, & Verbruggen, 2010, for recent reviews). This cost is often broken down into *switching cost* and *mixing cost* (e.g., Braver, Reynolds, & Donaldson, 2003; Fagot, 1994; Koch, Prinz, & Allport, 2005; Kray & Lindenberger, 2000; Mayr, 2001; Meiran, 2000; Poljac, Koch, & Bekkering, 2009; Rubin & Meiran, 2005). The design that permits this specification involves two types of experimental blocks and three conditions. There are *mixed-tasks blocks* involving task switching and *single-task blocks* without task switching. There is an additional distinction between *switch* trials (involving an immediate task switch) and *repeat* trials (involving an immediate task repetition) within the mixed-tasks blocks. Switching cost (or task repetition gain) is defined as the decrement in performance in switch trials relative to repeat trials. Mixing cost is typically defined as the decrement in performance in repeat trials relative to single-task trials.<sup>1</sup>

Importantly, most of the theories in this literature attribute switching cost to the change in "task set." While there is no consensus on the definition of "task set," some theories suggest that it encompasses the assembly of task execution parameters such as those determining the relevant stimuli, stimulus-categories, responses, and importantly, the direction of attention (especially Logan & Gordon, 2001) including attention to dimensions (Meiran, 2000; Meiran, Kessler, & Adi-Japha, 2008). Moreover, it seems that switching cost is caused by a change in these task set parameters, and in this regard, a change in the relevant stimulus dimension appears to have no special status (Vandierendonck, Christiaens, & Liefoghe, 2008).

### The Relation Between Selective Attention to Dimensions and Switching Between Dimensions

We mainly considered two tentative hypotheses. According to the "independence" hypothesis, switching attention between dimensions and selectively attending to dimensions are two independent abilities. The second hypothesis is "shared central resources." It is driven by theories such as Diamond's (2009), suggesting that limitations in central control resources prevent humans from making accurate distinctions. Such distinctions are needed in selectively attending to dimensions as well as for changing the course of action during task switching. This line of theorizing is commensurate with Logan and Gordon's (2001) claim that the task-set parameters are held in limited capacity working memory. A recent dual task study provides support for these claims. Specifically, Kunde, Landgraf, Paelecke, and Kiesel (2007; see also Janczyk & Kunde, 2010) presented a tone (for auditory choice reaction time [RT]) and a rectangle (for width judgment) and varied the (short) stimulus onset asynchrony. In addition, they manipulated the (never relevant) rectangle length (or kept it constant) to assess GI. The width task's results indicated GI and the

usual response facilitation that resulted from increasing the stimulus onset asynchrony. However, these two effects were additive. Such additivity consists of strong evidence that GI occupied central resources (see Pashler, 1994; Pashler & Johnston, 1989). Note that this result, by itself, does not support the shared central resources hypothesis. To provide such support, one needs to additionally show that task switching too involves the same central resources. Other dual task studies provide this evidence (Oriet & Jolicœur, 2003; see also Luria & Meiran, 2005; Vachon & Jolicœur, 2011). However, there are alternative interpretations to these results (Gilbert, 2005). Moreover, we are unaware of any dual task study that made a direct connection between GI and task switching.

Strong support for the shared central resources hypothesis comes from developmental studies on the Dimensional Change Card Sort task (DCCS, see Garon, Bryson, & Smith, 2008, for review) that closely resembles task switching. For example, Brooks, Hanauer, Padowska, and Rosman (2003) showed that the requirement to filter a never-relevant dimension impaired 3-year olds' ability to switch between two rules both involving another dimension and caused perseveration. Concomitantly, Diamond, Carlson, and Beck (2005) showed that reducing filtering load (by separating the objects carrying the dimensional information) reduced perseveration rates on the DCCS among preschoolers.

While the developmental literature supports the shared central resources hypothesis, it is unclear if a similar dependence also holds among adults. On the one hand, Shedden, Marsman, Paul, and Nelson's (2003) study supports the hypothesis. These authors designed a task requiring participants to switch attention between the global and local levels of a hierarchical stimulus (Navon, 1977). They showed that variation along the irrelevant dimension was sufficient to cause switching cost ("level repetition effect"). Along a similar line, Meiran and Marciano's (2002) showed that conditions known to compromise selective attention to dimensions (same-different judgments) also compromised the ability to prepare toward a task switch.

However, the picture is far from being clear. Specifically, if the shared central resource hypothesis were correct, one would expect that switching would become more difficult when the tasks involve integral (as compared with separable) dimensions. The reasoning is that selective attention is more demanding (and requires more resources) with integral (than with separable) dimensions and thus, lesser resources would be left for task switching. Contrary to this expectation, Arrington et al. (2003, Experiment 1) showed *smaller* switching cost when switching was between integral dimensions (e.g., height and width) than when it was between separable dimensions (e.g., color and width).

Additional studies that seemingly support the shared central resources hypothesis are difficult to interpret. In Biederman's (1972) experiment, there were eight stimuli varying along three dimensions: shape, size, and tilt. There was a *contingent* task, in which one dimension served as a task cue and indicated which one of the other two dimensions is relevant. For example, the color red could indicate the tilt dimension is relevant while the color green

<sup>1</sup> This set of contrasts is nonorthogonal but see Kray and Lindenberger (2000) and Yehene and Meiran (2007) for a definition involving orthogonal contrasts.

could indicate that the size dimension is relevant. Thus, this task involved switching attention between dimensions. It also required the processing of two dimensions: the cuing dimension (color) and the cued dimension (either tilt or size). There was also a filtering task in which two dimensions were always relevant and one was never relevant. Thus, in both the contingent and the filtering tasks, one dimension had to be ignored and two dimensions had to be processed. The results indicated poorer performance in the contingent condition as compared with the filtering condition, suggesting that switching impaired participants' ability to ignore a never relevant dimension. However, the contingent condition required ignoring a dimension (e.g., color) that was sometimes relevant (it was relevant in other trials in the same block) as well as ignoring the values of that dimension (e.g., red and green) that were also sometimes-relevant. In this regard, Rubin and Meiran (2005, Experiment 1) showed that such conditions are sufficient to cause mixing cost. For example, mixing cost was found in their study if the to-be-ignored shapes in the color task were the same shapes that were used in the shape task. However, there was no mixing cost when the shapes in the color task were different from the shapes that were used in the shape task.

Dreisbach and Wenke's (2011) recent study, although not examining GI, is also relevant here. These authors required participants to switch between a digit task and a letter task. The never-relevant color (or font) also varied. The results indicated an interaction between color (or font) repetition and response repetition, but only in switch trials. Dreisbach and Wenke concluded that when the task repeats, the task goal is shielded against interference to ensure smooth and distraction-free performance. However, this shielding must be lifted in switch trials, to make the task switch possible (see also Dreisbach & Haider, 2009). Note, however, that Dreisbach and Wenke included only a filtering condition in their study and did not compare it to a baseline condition and thus could not assess GI. Interestingly, their "relaxed goal shielding" hypothesis makes similar predictions as those of the "shared central resources" hypothesis, albeit for completely different reasons. Namely, both hypotheses predict poorer filtering in switch trials than in single-task trials. The hypotheses seemingly differ in their predictions regarding repeat trials. Whereas the relaxed goal shielding hypothesis predicts successful selectivity in repeat trials, the shared central resources hypothesis apparently predicts that selectivity would become poorer with increasing switching demands, namely, when moving from single-task to repeat to switch.

To test between the aforementioned hypotheses, we examined whether participants can effectively ignore a never-relevant dimension when they switch tasks. A similar investigation was carried out by Brooks et al. (2003) who studied preschoolers (see above). To our knowledge, the only directly comparable study on adults is Meiran, Hommel, Bibi, and Lev's (2002, Experiment 3). In this experiment, participants switched between 2, 3, or 4 tasks. The tasks involved the separable dimensions of shape, fill, size, and the tilt of the line crossing the shape (horizontal vs. vertical). There were two versions of the experiment. In one version, the stimuli varied along all the four dimensions even if some of the dimensions were task-irrelevant. This condition involved filtering of never-relevant dimensions when switching involved 2 or 3 tasks (because all the four dimensions varied orthogonally). In the other version of the experiment, the stimuli varied only along the task-relevant dimensions. For example, for participants who switched

between tilt and shape, size, and fill were held constant. Thus, there was no need to filter out variation along the never-relevant dimensions. If the shared central resource hypothesis is correct, one would expect switching ability to be poorer when all the dimensions vary as compared with when only the relevant dimensions vary. In fact, Meiran et al.'s results indicate lack of significant difference between the two versions of the experiment, suggesting that task switching does *not* compromise filtering ability and vice versa.

Because Meiran et al.'s (2002) experiment did not address the interplay between switching and filtering (and thus, was not optimally designed for this purpose) we decided to launch a systematic exploration of this issue. In all the present experiments, the stimuli had three dimensions. Two dimensions were (sometimes) relevant and defined two speeded classification tasks. In any given block of the experiment, the participants either executed only one task (single-task) or switched between the two tasks. In the mixed-tasks blocks, in which there was task switching, the order of the tasks was random and each trial started with the presentation of a task cue instructing participants which task is next (Meiran, 1996; Shaffer, 1965). The novel aspect about the present experiments was the inclusion of a third, never-relevant dimension to assess GI. This dimension was either constant (creating a baseline condition) or varied (creating a filtering condition).<sup>2</sup> In an attempt to create especially challenging switching conditions, in some experiments (Experiments 2 and 4), the interval between the task cue and the target stimulus (henceforth, cue-target interval, CTI) was very short. In Experiments 1 and 3, the CTI was relatively long (500 ms). The CTIs were determined on the basis of previous results with similar paradigms (e.g., Meiran et al., 2002; Meiran, Chorev, & Sapir, 2000) such that the short CTI was expected to yield poorer performance and enlarged switching cost and mixing cost as compared with the long CTI.

In Experiments 1 and 2, the relevant dimensions were shape and color and the never-relevant dimension (texture) was chosen to be separable from the two relevant dimensions. In Experiments 3 and 4, we increased filtering demands as follows. We asked the participants to switch between the separable dimensions of shape and brightness and held constant (baseline) or varied (filtering) the never-relevant saturation dimension. This dimension was chosen because it is separable from shape and integral with brightness.

## General Method

### Participants

The participants were undergraduate students from Ben-Gurion University of the Negev and Achva Academic College. They took part in the present experiments in return for partial course credit or

<sup>2</sup> We wish to note that the conditions in our experiments were not Garnerian proper. This is because we either varied two or three dimensions and not one or two dimensions as usually done in studies using Garner's paradigm (but see Ganel, 2011). Nonetheless, our Filtering manipulation clearly involved the ability to filter a never-relevant dimension. Moreover, this deviation from the "proper" Garnerian design did not change the known status of dimension pairs as separable versus integral, as indicated by the results.

for 30 NIS (~\$8). All the participants reported having normal or corrected-to-normal vision including color vision.

### Stimuli and Procedure

The experiments were run on a Pentium 4 computer with a 17-in (43.18-cm) monitor. The procedures were programmed in E-Prime 1.0 (Schneider, Eschman, & Zuccolotto, 2002). The stimuli were presented with a black background and consisted of the task cue and the target stimulus that appeared beneath it. Assuming a viewing distance of 60 cm, the target and the cue were vertically separated by ~3.5 degrees of visual angle. The shape-task cue was a white square that subtended a visual angle of 3.1 (width)  $\times$  3.1 (height) degrees and the color-task cue (Experiments 1 and 2) or the brightness task cue (Experiments 3 and 4) was a blue rectangle in size of 3.7  $\times$  1.5 degrees (blue was never used as a color in the color task). The target stimuli consisted of two shapes: a circle (6 degrees in diameter) and a triangle (6.2  $\times$  6.5 degrees). There were 2 (shape)  $\times$  2 (color or brightness, depending on the experiment)  $\times$  2 (texture or saturation, depending on the experiment) = 8 possible targets.

There were 24 experimental blocks, each consisting of 48 trials. These included single-task blocks and mixed blocks. In the single-task blocks, the participants had to accomplish only one of the tasks throughout the block, while in mixed blocks, they switched between the two tasks. There were two types of each: Mixed tasks blocks and single-task blocks, such that in some mixed-tasks/single-task blocks there was variation along a never-relevant dimension (filtering) while in other mixed-tasks/single-task blocks this never relevant dimension was fixed (baseline).

The experiment began with oral explanation and illustration of the tasks and the stimuli. Afterward, the participants started the first practice block that was followed by the relevant experimental block. Each time the participant started a new type of block, he or she received an explanation and a practice block. The total session took ~45–50 min to accomplish.

Each trial started with a black screen presented for a fixed response-cue interval of 500 ms. It was followed by the presentation of the task cue for the duration of the CTI that was either 500 ms (Experiments 1 and 3) or 150 ms (Experiments 2 and 4). This task cue was pseudorandomly chosen in the mixed-tasks conditions and was fixed in the single-tasks condition. Then, the target was added below the task-cue and both of them were kept on the screen until the response was given. The target stimulus was pseudorandomly chosen with the restriction that the value of the third, never-relevant dimension remained constant in the baseline condition. A beep sound of 400 MHz was presented for 100 ms if an error was made. The keypad was aligned with the center of the screen and the participants were instructed to respond by pressing the “A” (left) and “L” (right) keys with their two index fingers, according to the specific task instructions. They were also asked to be as accurate and quick as possible.

### Counterbalancing

To control for the effect of block position within the experiment, we adopted a “sandwich” design (Rubin & Meiran, 2005) that included six block types. In Experiments 1 and 2, they were shape-baseline, shape-filtering, color-baseline, color-filtering,

mixed-baseline, and mixed-filtering. In Experiments 3 and 4, color was replaced by brightness.

Each participant started and finished the experiment with the single-task blocks, while the mixed task blocks were in the middle. This sandwich structure applied also to the ordering of the single-task blocks and the mixed-task blocks. This means that we determined the ordering of the conditions that was used in the first half of the experiment and the reversed order was used in the second half of the experiment. Thus, the ordering of the conditions for a given participant could be shape-base, shape filtering, color-base, color-filtering, mixed blocks, color-filtering-color-base, shape-filtering, or shape-base.

Additionally, we partly counterbalanced (A) the assignment of target values to response keys (four conditions), (B) the constant texture value (Experiments 1 and 2) or saturation value (Experiments 3 and 4) that was used in the baseline condition (two conditions), (C) the order of the baseline versus filtering condition (baseline  $\rightarrow$  filtering vs. filtering  $\rightarrow$  baseline, 2 conditions), as well as (D) the order in which the tasks appeared in the single-task conditions (shape  $\rightarrow$  color [or brightness] vs. color [or brightness]  $\rightarrow$  shape, 2 conditions). Full counterbalancing would have required  $4 \times 2 \times 2 \times 2 = 32$  conditions. However, we had only 16 counterbalancing conditions. This was done as follows. We fully counterbalanced for Factor A. We also included all the possible combinations of Factors C and D (creating four  $C \times D$  combinations). However, only two  $C \times D$  combinations were combined with a given level of Factor B, while the other two  $C \times D$  combinations were combined with the other level of Factor B. For example, in Experiments 1 and 2, the constant dot pattern was combined with two  $C \times D$  combinations while the constant line pattern was combined with the other two  $C \times D$  combinations. Thus, each one of the 16 participants (in Experiments 1 and 3) received a different counterbalancing condition while in Experiments 2 and 4 there were two participants who received each counterbalancing condition.

The same order of the baseline and filtering conditions was used in the two tasks in the single-task blocks. Thus, as order could be shape-base, shape-filtering, color-base, or color filtering but could never be shape-base, shape-filtering, color-filtering, or color-base.

### Experiments 1 and 2

In Experiments 1 and 2, participants switched between the separable dimensions shape and color (e.g., Gottwald & Garner, 1972). A third dimension, texture, was either constant (baseline) or varied orthogonally (filtering). This third dimension was chosen to be separable from the other two dimensions. Cant, Large, McCall, and Goodale (2008) provide evidence suggesting that pattern is separable from color and shape. The results of Experiment 1 (below) verify this assumption in showing tiny and nonsignificant GI.

If the shared central resources hypothesis is correct, switching consumes the limited resources that are also needed to treat dimensions as separable, and thus GI should be higher in mixed tasks conditions than in pure task conditions and possibly also in switch trials relative to repeat trials for the same reason. Using analysis of variance (ANOVA) terms, we reasoned that the hypothesis predicts an interaction between Transition (the variable discriminating between single-task, switch, and repeat) and Filtering (baseline vs.

filtering). Because the demand for resources is presumably higher in less prepared states, the aforementioned interaction was predicted (by the shared central resources hypothesis) to be more pronounced with a short (Experiment 2) than with a long (Experiment 1) CTI.

## Method

**Participants.** Sixteen participants took part in Experiments 1 and 2. An initial analysis indicated several marginal effects in Experiment 2, and therefore, to clarify the picture by increasing the statistical power, 16 additional participants were recruited to this experiment. Thus, Experiment 2 eventually involved 32 participants in total.

**Stimuli and procedure.** The stimuli were presented in red and green color and in two textures: dots and lines.

## Results

RT served as the primary dependent variable. The first trial in a block and trials after an error were excluded from all the analyses (6% in Experiment 1 and 5% in Experiment 2). In addition, trials with errors and RTs falling outside the 100–3,000 range (0.5 and 2.2% of the correct trials that were not excluded by the other criteria, respectively) were analyzed for accuracy and not for RT.

The ANOVA design used to analyze the means of the 12 conditions included three independent variables, all manipulated within participants: Task (shape vs. color), Transition (single-task, repeat, and switch), and Filtering (baseline vs. filtering).

**Experiment 1.** Across participants, the mean number of trials per condition was 82–90 and the minimum number of trials per condition was 55–82.

**RT.** The only significant effect was the main effect of Transition,  $F(2, 30) = 65.48, p < .0001, MSE = 31,397.98, \eta_p^2 = .82$ . All the remaining effects and interaction did not approach significance,  $F < 0.85, \eta_p^2 < .05$ . Mean RT was 430, 611, and 788 ms in single-task, repeat, and switch trials, respectively, indicating mixing cost of 181 ms and switching cost of 177 ms. The clearly nonsignificant GI was 5 ms (607 vs. 612 ms). This lack of significant GI verifies our assumption that texture is separable from shape and color.

**Proportion of Errors (PE).** There were significant main effects of Task,  $F(1, 15) = 5.45, p < .05, MSE = 0.002, \eta_p^2 = .27$ ; Transition,  $F(2, 30) = 8.97, p < .001, MSE = 0.004, \eta_p^2 = .37$ ; and a significant interaction between Task and Transition,  $F(2, 30) = 8.55, p < .005, MSE = 0.001, \eta_p^2 = .37$ . Mean proportion of errors (PE) was .02 and .03 in single-task and repeat trials in both tasks. However, in switch trials, there was a task difference because PE was .09 in the color task and .04 in the shape task. All the remaining effects and interactions did not approach significance,  $F < 0.62, \eta_p^2 < .04$ .

**Response Repetition and Pattern Repetition.** To further examine whether participants truly ignored the irrelevant pattern information, we ran an additional analysis on the RT data. This analysis was carried out only on the filtering blocks in which pattern varied. The independent variables were Task, Transition, Pattern Repetition, and Response-Repetition. The logic behind this analysis is that if the Pattern Repetition variable influences performance, this would show that participants processed the irrelevant pattern information.

Only the main effects of Transition (reported already) and Response Repetition,  $F(1, 15) = 19.25, MSE = 6,002.14, p < .0005, \eta_p^2 = .56$ , as well as their interaction,  $F(2, 30) = 17.10, MSE = 9,054.27, p < .0001, \eta_p^2 = .53$ , were significant. All the remaining sources of variance were nonsignificant. Importantly for the present focus, the sources of variance involving Pattern Repetition had  $F_s < 1.34, p > .28, \eta_p^2 < .08$ . Thus, this examination too indicates that the participants did not (or had barely) processed the never-relevant pattern information in this experiment.

**Experiment 2.** The mean number of trials per condition was 86–90 and the minimum number of trials per condition was 65–82.

**RT.** There were significant main effects for Task,  $F(1, 31) = 15.22, MSE = 5,927.79, p < .0005, \eta_p^2 = .33$ ; Transition,  $F(2, 62) = 233.78, MSE = 37,332.45, p < .0001, \eta_p^2 = .88$ ; and Filtering,  $F(1, 31) = 5.27, MSE = 2,134.98, p < .05, \eta_p^2 = .14$ . Mean RT was 677 and 708 ms in the color and shape tasks, respectively, 425, 708, and 946 ms in single-task, repeat and switch, respectively (indicating mixing cost of 283 ms and switching cost of 238 ms), and 687 versus 698 ms in the baseline and filtering conditions, respectively (GI = 11 ms). Despite the clearly nonsignificant interaction between Transition and Filtering,  $F = 0.40$ , we examined the simple effect of Filtering (GI) in the three Transition conditions, separately. GI was 9 ms in the single-task condition,  $F(1, 31) = 5.44, p < .05, 7$  ms in the repeat condition,  $F < 1$ , and 26 ms in the switch condition in which it approached significance,  $F(1, 31) = 3.50, p = .07$ . The fact that GI was significant only in the single-task blocks is exactly the opposite to the prediction of the shared central resources hypothesis. Nonetheless, we remind that the influence of Transition on GI was nonsignificant, also in contrast with the shared central resources hypothesis.

**PE.** The only significant source of variance was Transition,  $F(2, 62) = 22.14, MSE = .0006, p < .0001, \eta_p^2 = .42$ . Mean PE was .02 in single-task and repeat and .04 in switch.

## Discussion of Experiments 1 and 2

The experiments were set to test the shared central resources hypothesis according to which the ability to treat perceptual dimensions separately requires the same central resources as those needed for task switching. Experiment 1 tested the hypothesis in conditions with a relatively long CTI. In this experiment, there was no hint for any dependence of GI on Transition. To strengthen this conclusion we examined the role of pattern repetition and the results further showed that this information did not influence performance. In Experiment 2, in which the CTI was short, there was poorer performance in general, enlarged switching cost and mixing cost. This resulted in a significant GI of 11 ms. Therefore, one can cautiously conclude that, at least within the range of conditions that we studied, there is little sharing of resources between switching ability and filtering ability. This is unlikely because of a weak switching manipulation since the switch condition almost doubled (Experiment 1) and more than doubled (Experiment 2) RT relative the single-task condition. Moreover, the statistical power was generally sufficiently high as seen in a significant GI as small as 9 ms (the single-task condition, Experiment 2).

### Experiments 3 and 4

In Experiments 3 and 4, we tried to increase filtering demands and see if this would result in impaired switching ability. The experiments were similar to Experiments 1 and 2 except that the color task was replaced by a brightness task and the third, never relevant dimension was saturation rather than texture. Saturation was chosen because it is integral with the sometimes-relevant dimension, brightness (Garner & Felfoldy, 1970) and as far as we could estimate in advance, it is separable from the other, sometimes-relevant dimension shape. Our results support this assumption.

In addition to examining switching ability under highly demanding filtering conditions, the current design allowed us to determine if participants treat the relevant dimensions of shape and brightness as separable even under switching load. To this end, we examined an index that this design affords. Specifically, if brightness and shape are treated analytically, only brightness responses should be influenced by saturation while shape responses should not be influenced by it. In ANOVA terms, we predicted an interaction between Task and Filtering such that there would be GI only in the brightness task and not in the shape task. If, however, switching makes brightness and shape integral because of shortage of central resources, there should be a significant triple interaction between Task, Filtering, and Transition. The pattern of this interaction should show that the simple interaction between Task and Filtering becomes less pronounced moving from switch to repeat and single-task. More specifically, we predicted (based on the shared central resources hypothesis) that, when examining shape task performance, the absence of GI in single-task conditions would be replaced by presence of GI in switch conditions. As before, the two experiments varied in terms of the CTI that was 500 in Experiment 3 and 150 ms in Experiment 4.

### Method

**Participants.** Sixteen participants took part in Experiments 3 and 4. An initial analysis indicated marginal GIs in Experiment 4, and therefore, to clarify the picture by increasing the statistical power, 16 additional participants were recruited to this experiment. Thus, Experiment 4 involved 32 participants in total.

**Stimuli and procedure.** The stimuli were the same circle and triangle that were used in Experiments 1 and 2 but in the present experiments all of them were presented in red color and had two brightness values and two saturation values. The colors were created using Windows Vista basic edition's "Paint" software and the values below are taken from this software. The hue of the red color was 239. The bright red was of luminance 144 and the dark red was of luminance 120. The high saturation was of 120 and the less saturated color was of 80.

The only procedural difference was the addition of two practice blocks—before the brightness-filtering block and before the mixed-filtering block. The reason for this change was the relatively more taxing nature of the filtering condition as compared with Experiments 1 and 2. Therefore, Experiments 3 and 4 had five short practice blocks overall instead of three.

### Results

The results were treated exactly as before. The first trial in a block and trials after an error were excluded from all the analyses

(6.5% in Experiment 3 and 6.0% in Experiment 4). In addition, trials with errors and RTs falling outside the 100–3,000 range (0.3 and 3.4% of the correct trials that were not excluded by the other criteria, respectively) were analyzed for accuracy and not for RT.

**Experiment 3.** The mean number of trials per condition was 81–88 (minimal number 61–78).

**RT.** All the main effects were significant including Task,  $F(1, 15) = 35.52$ ,  $MSE = 6,511.90$ ,  $p < .0001$ ,  $\eta_p^2 = .70$ ; Transition,  $F(2, 30) = 64.64$ ,  $MSE = 19,415.26$ ,  $p < .0001$ ,  $\eta_p^2 = .81$ ; and Filtering,  $F(1, 15) = 17.62$ ,  $MSE = 7,716.23$ ,  $p < .001$ ,  $\eta_p^2 = .54$ . In addition, the two-way interactions between Task and Transition,  $F(2, 30) = 7.12$ ,  $MSE = 4,093.69$ ,  $p < .005$ ,  $\eta_p^2 = .32$ ; and Task and Filtering,  $F(1, 15) = 45.98$ ,  $MSE = 3,848.72$ ,  $p < .0001$ ,  $\eta_p^2 = .75$ , were significant. All the above effects were qualified by a significant triple interaction,  $F(2, 30) = 7.05$ ,  $MSE = 1,788.72$ ,  $p < .005$ ,  $\eta_p^2 = .32$  (see Figure 1).

Responses were quickest in the single-task condition (463 ms) followed by repeat (602 ms) and slowest in switch (744 ms), indicating overall mixing cost of 139 ms and overall switching cost of 142 ms. Because of its theoretical importance, we began by exploring the Task by Filtering interaction. There was a significant GI of 114 ms in the brightness task,  $F(1, 15) = 36.46$ ,  $p < .0001$ , and a nonsignificant GI of 7 ms in the shape task,  $F = .44$ ,  $ns$ . This last result confirms the fact that shape and saturation are separable dimensions.

Next we probed the triple interaction. As can be seen in Figure 1, the simple interaction between Task and Filtering diminished moving from single-task through repeat to switch as predicted by the shared central resources hypothesis. However, contrary to this prediction, the trend reflected diminishing GI in the brightness task moving from single-task to switch whereas the hypothesis suggests that GI in the shape task would increase moving in this direction. We computed the simple interaction between Transition and Filtering separately for each task. This simple interaction was significant in the brightness task,  $F(2, 30) = 8.03$ ,  $p < .005$ , and nonsignificant in the shape task,  $F(2, 30) = 1.06$ ,  $ns$ . The significant simple interaction between Filtering and Transition in the brightness task reflects the diminishing GI when moving from single-task (162 ms),  $F = 59.88$ ,  $p < .0001$ ,

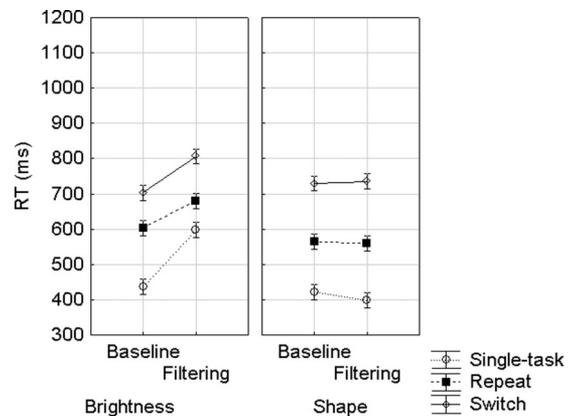


Figure 1. RT as a function of Task, Transition, and Filtering, Experiment 3 (error bars represent 95% confidence intervals, based on the MSE of the triple interaction and Hollands and Jarmasz, 2010, formulae).

to mixed task conditions including repeat (77 ms),  $F = 13.07$ ,  $p < .005$ , and switch (103 ms),  $F = 16.61$ ,  $p < .001$ .

**PE.** There were significant main effects of Transition,  $F(2, 30) = 8.94$ ,  $MSE = 0.001$ ,  $p < .001$ ,  $\eta_p^2 = .37$ ; and Filtering,  $F(1, 15) = 18.70$ ,  $MSE = .001$ ,  $p < .001$ ,  $\eta_p^2 = .55$ . In addition, the two-way interactions between Task and Transition and between Task and Filtering were significant,  $F(2, 30) = 12.92$ ,  $F(1, 15) = 21.82$ ,  $MSE = .001$ ,  $.0005$ ,  $p < .0001$  and  $.0005$ ,  $\eta_p^2 = .46$  and  $.59$ , respectively.

The interactions reflect the lack of GI in the shape task and the GI of .03 in the brightness task. In addition, they reflect the fact that in the brightness task, PE was .05 in single-task and switch and only .03 in repeat trials. In the shape task, PE was .03 in single-task and repeat and .07 in switch.

**Response Repetition and Saturation Repetition.** The results so far indicate that participants were able to ignore saturation information when they performed the shape task. To probe this issue further, we conducted an ANOVA on the shape RT results in the filtering blocks in which saturation varied. The independent variables were Saturation Repetition (whether saturation level in the current trial was the same as it were in the previous trial), Transition and Response Repetition. The only significant sources of variance were Transition (reported already); Response-Repetition,  $F(1, 15) = 5.90$ ,  $MSE = 7,234.35$ ,  $p < .05$ ,  $\eta_p^2 = .28$ ; and their interaction,  $F(2, 30) = 7.95$ ,  $MSE = 6,461.78$ ,  $p < .005$ ,  $\eta_p^2 = .35$ . Of interest here is the lack of any significant source of variance involving Saturation Repetition suggesting that saturation information was efficiently ignored. All but one source of variance involving this variable were associated with negligible effects,  $F_s < .50$ ,  $\eta_p^2 < .02$ . However, there is one exception that is the interaction between Saturation Repetition and Transition that was non-negligible,  $F(2, 30) = 2.14$ ,  $MSE = 4,294.58$ ,  $p = .13$ ,  $\eta_p^2 = .12$ . This trend reflects the fact that, in single-task conditions, the repetition of saturation level led to a nonsignificant ( $p = .62$ ) slowing of 4 ms (402 vs. 398 ms). In Repeat trials, it led to a nonsignificant ( $p = .18$ ) but non-negligible facilitation of 28 ms (575 vs. 547 ms). In switch trials it led to a nonsignificant ( $p = .26$ ) but again, non-negligible slowing of 19 ms (722 vs. 741 ms). Notably, the last two simple effects were found in mixed tasks and were in opposite directions (facilitation in repeat trials and slowing in switch trials). This difference in trends was substantiated by the interaction contrast between Saturation Repetition and the switch-versus-repeat contrast that was nearly significant,  $F(1, 15) = 3.36$ ,  $p = .09$ ,  $\eta_p^2 = .18$ . Thus, there was some indication that participants processed saturation information when they executed the shape task, but only in mixed tasks conditions, in line with the shared central resources hypothesis.

**Experiment 4.** The mean number of trials per condition was 82–91 (minimal number 58–82).

**RT.** All the three main effects were significant including Task,  $F(1, 31) = 43.14$ ,  $MSE = 11,498.93$ ,  $p < .0001$ ,  $\eta_p^2 = .58$ ; Transition,  $F(2, 62) = 291.78$ ,  $MSE = 30,914.99$ ,  $p < .0001$ ,  $\eta_p^2 = .90$ ; and Filtering,  $F(1, 31) = 78.06$ ,  $MSE = 3,912.53$ ,  $p < .0001$ ,  $\eta_p^2 = .72$ . In addition, there were three significant interactions including the interaction between Task and Filtering,  $F(1, 31) = 48.75$ ,  $MSE = 2,507.63$ ,  $p < .0001$ ,  $\eta_p^2 = .61$ , Task and Transition,  $F(1, 31) = 4.96$ ,  $MSE = 4,998.26$ ,  $p < .05$ ,  $\eta_p^2 = .14$ , and the triple interaction  $F(1, 31) = 9.18$ ,  $MSE = 1,801.91$ ,  $p < .005$ ,  $\eta_p^2 = .23$  (see Figure 2). Responses were quickest in the

single-task condition (513 ms) followed by repeat (769 ms) and slowest in switch (1,044 ms), indicating overall mixing cost of 256 ms and overall switching cost of 275 ms. The interaction between Task and Filtering indicates the fact that GI was much larger in the brightness task (92 ms) than in the shape task (21 ms) although simple effects analysis indicates that it was significant in both,  $F(1, 31) = 85.69$ ,  $12.34$ ,  $p < .005$ ,  $.0001$ , respectively. The interaction between task and transition was underadditive, indicating larger mixing cost (273 vs. 237 ms) and switching cost (284 vs. 286 ms) in the easier (shape) task, reflecting switch asymmetry (e.g., Allport et al., 1994; Yeung & Monsell, 2003).

To explore the significant triple interaction, we computed the simple interaction between Transition and Filtering, separately for the two tasks. In the brightness task, this interaction was highly significant,  $F(2, 62) = 11.12$ , but it did not reach significance in the shape task,  $F(2, 62) = 1.52$ . We then probed the simple interaction by examining GI separately for each task and transition condition. In the brightness task, GI was 129, 85, and 62 ms in single-task, repeat and switch, respectively,  $F(1, 31) = 151.32$ ,  $48.04$ , and  $15.66$ , respectively,  $p < .0005$ . Although the simple interaction between Filtering and Transition was nonsignificant in the shape task, we decided to explore it. GI was 6 ms,  $F(1, 31) = 0.33$ , *ns*, 36 ms,  $F(1, 31) = 8.77$ ,  $p < .01$ , and 20 ms,  $F(1, 31) = 2.47$ ,  $p = .12$ , in single-task, repeat, and switch, respectively. Thus, the nonsignificant trend was somewhat in line with the shared central resources hypothesis.

**PE.** There were significant main effects for Transition,  $F(2, 62) = 14.41$ ,  $MSE = .0010$ ,  $p < .0001$ ,  $\eta_p^2 = .32$ ; and Filtering,  $F(1, 31) = 16.83$ ,  $MSE = .0007$ ,  $p < .0005$ ,  $\eta_p^2 = .35$ . In addition, all the two-way interactions were significant including Task  $\times$  Filtering,  $F(1, 31) = 10.28$ ,  $MSE = .0009$ ,  $p < .005$ ,  $\eta_p^2 = .25$ ; Task  $\times$  Transition,  $F(2, 62) = 4.13$ ,  $MSE = .0006$ ,  $p < .05$ ,  $\eta_p^2 = .12$ ; and Filtering  $\times$  Transition,  $F(1, 31) = 4.46$ ,  $MSE = .0004$ ,  $p < .05$ ,  $\eta_p^2 = .12$ . Finally, the triple interaction was also significant,  $F(2, 62) = 10.65$ ,  $MSE = .0005$ ,  $p < .0005$ ,  $\eta_p^2 = .26$ . Of theoretical interest is the two-way interaction between Task and Filtering. The trend of this interaction indicates a GI of .02 in the brightness task and no GI in the shape task. The triple interaction reflects the fact that, in the brightness task, GI (in errors) decreased

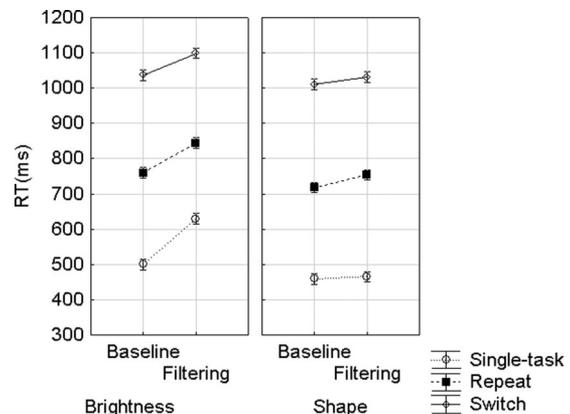


Figure 2. RT as a function of Task, Transition, and Filtering, Experiment 4 (error bars represent 95% confidence intervals, based on the MSE of the triple interaction and Hollands and Jarmasz, 2010, formulae).

moving from single-task (.04), through repeat (.02) to switch (.00). In the brightness task, the trend was different, indicating  $GI = .00$ ,  $.005$ , and  $-.01$ , respectively.

### Discussion of Experiments 3 and 4

The main results of Experiments 3 and 4 can be summarized as follows. First, in both experiments, there was a robust interaction between Task and Filtering, indicating the expected GI in the brightness task and absence (Experiment 3) or much smaller GI (Experiment 4) in the shape task. This result indicates that participants were generally able to treat the shape and the brightness dimensions analytically in the sense that when they responded to shape, they effectively ignored saturation. This was less true when the CTI was short (Experiment 4), however.

### The Role of CTI: An Across Experiment Analysis

In this section, we examine the shape task results in which the dimensions were hypothesized to be separable (shape and texture, Experiments 1 and 2; shape and saturation, Experiments 3 and 4). The preceding analyses indicate lack of GI when the CTI was long (thus confirming our assumptions concerning separability of dimensions). However, when the CTI was short, GI was significant. To demonstrate the statistical significance of this finding we included the shape task results from all the experiments in a single ANOVA with Transition and Filtering as within-participants independent variables and with CTI and Interfering Dimension (texture vs. saturation) as between-participants independent variables. Of greatest interest is the marginal two-way interaction between CTI and Filtering,  $F(1, 92) = 3.50$ ,  $MSE = 2,119.37$ ,  $p = .064$ ,  $\eta_p^2 = .04$ . GI was 0 ms when the CTI was long but it was 16 ms (732 vs. 716 ms,  $p < .005$ ) when it was short. This interaction was not modulated by significant higher order interactions,  $\eta_p^2 < .03$ ,  $p > .11$ . Also interesting is the lack of significant Transition by Filtering interaction,  $F(2, 184) = 1.34$ ,  $\eta_p^2 = .01$ , *ns*.

Unsurprisingly, there was a significant main effect of CTI,  $F(1, 92) = 22.25$ ,  $MSE = 99,914.43$ ,  $p < .0001$ ,  $\eta_p^2 = .19$ , and a significant interaction between CTI and Transition,  $F(2, 184) = 21.30$ ,  $MSE = 19,545.22$ ,  $p < .0001$ ,  $\eta_p^2 = .19$ . These results show that a short CTI was associated with significantly slower responses and enlarged task transition costs.

### Task Rule Congruency

In the task switching literature, the ability to ignore information that is sometimes relevant and sometimes irrelevant is often indexed by the task rule congruency effect (TRCE; e.g., see Meiran & Kessler, 2008, for review). The TRCE is observed by comparing trials in which the two dimensions between which participants switch indicate the same response (congruent) or conflicting responses (incongruent). To examine whether incongruence (that is known to impair performance) influences GI we ran a series of ANOVAs on the RT results of the four experiments. All the ANOVAs had the same design with the independent variables Task, Transition, Filtering, and Congruence. For brevity sake, we discuss only results related to Congruence.

**Experiment 1.** There was a significant main effect of Congruence,  $F(1, 15) = 17.80$ ,  $MSE = 10,525.79$ ,  $p < .001$ ,  $\eta_p^2 = .54$ ,

reflecting a TRCE of 45 ms (633 vs. 588 ms) as well as a significant interaction between Congruence and Transition,  $F(2, 30) = 15.33$ ,  $MSE = 2,270.73$ ,  $p < .0001$ ,  $\eta_p^2 = .50$ , showing that (as usual) congruence effects increased when moving from single-task to repeat to switch (11, 44, and 77 ms, respectively). Nonetheless, Congruence and Filtering were never both involved in a significant interaction,  $F_s < 1.35$ ,  $\eta_p^2 < .08$ .

**Experiment 2.** There was a significant main effect of Congruence,  $F(1, 31) = 20.04$ ,  $MSE = 13,638.62$ ,  $p < .0001$ ,  $\eta_p^2 = .39$ , reflecting a TRCE of 38 ms (712 vs. 674 ms). Additionally, there was a significant interaction between Transition and Congruence,  $F(2, 62) = 22.65$ ,  $MSE = 4,359.35$ ,  $p < .0001$ ,  $\eta_p^2 = .42$ , showing that congruence effects increased when moving from single-task to repeat to switch (−1, 37, and 78 ms, respectively). Importantly, Congruency and Filtering were never both involved in a significant interaction,  $F_s < 1.76$ ,  $\eta_p^2 < .05$ .

**Experiment 3.** There was a significant main effect of Congruence,  $F(1, 15) = 15.16$ ,  $MSE = 3,026.87$ ,  $p < .005$ ,  $\eta_p^2 = .50$ , reflecting a TRCE of 22 ms (614 vs. 592 ms) and a significant two-way interaction between Congruence and Transition,  $F(1, 15) = 7.49$ ,  $MSE = 1,947.68$ ,  $p < .005$ ,  $\eta_p^2 = .33$ , showing that congruence effects increased when moving from single-task to repeat to switch (−1, 26, and 41 ms, respectively). Finally, the four-way interaction approached significance,  $F(2, 30) = 2.77$ ,  $MSE = 2,672.53$ ,  $p = .08$ ,  $\eta_p^2 = .16$ . The remaining interactions involving both Congruence and Filtering were nonsignificant,  $F_s < 1.28$ ,  $\eta_p^2 < .08$ .

**Experiment 4.** There was a significant main effect of Congruence,  $F(1, 31) = 18.44$ ,  $MSE = 4,283.68$ ,  $p < .0005$ ,  $\eta_p^2 = .37$ , reflecting a TRCE of 21 ms (786 vs. 765 ms). Additionally, there was a marginally significant interaction between Transition and Congruence,  $F(2, 62) = 2.78$ ,  $MSE = 4,116.26$ ,  $p = .07$ ,  $\eta_p^2 = .08$ , showing that congruence effects increased when moving from single-task to repeat to switch (6, 22, and 33 ms, respectively). Importantly, Congruency and Filtering were never both involved in a significant interaction,  $F_s < 0.80$ ,  $\eta_p^2 < .03$ .

The results of these analyses indicate that Congruence generally did not modulate Filtering ability. Importantly, incongruence is a condition that challenges switching ability (as seen in the aforementioned interactions between Congruence and Transition, see also Fagot, 1994; Meiran, 2000, among others). Therefore, the present results further substantiate the general conclusion from this paper that switching ability and filtering ability do not draw on a common general limited capacity resource.

## General Discussion

In the present experiments, we addressed the question concerning the interrelationship between the ability to focus on a given perceptual dimension as studied in the Garner paradigm and the ability to switch attention between perceptual dimensions as studied with task switching. To this end, we ran experiments in which participants switched between two tasks, each defined in terms of a perceptual dimension. These two dimensions were chosen to be separable. Three Transition conditions were realized in our design including single-task, repeat, and switch, so that mixing cost (repeat vs. single-task) and switching cost (switch vs. repeat) could be assessed. So far, what is being described is a rather standard task switching paradigm. The novel aspect was that, in addition,

the value along a third, never-relevant dimension was either fixed (baseline condition) or varied orthogonally (filtering condition) thus incorporating selective attention to dimensions into our design. In Experiments 1 and 2, the relevant dimensions were shape and color and the third, never-relevant dimension, texture, was chosen to be separable from both of them. In Experiments 3 and 4, the relevant dimensions were shape and brightness that were separable. The never-relevant third dimension was saturation that was chosen to be separable from shape and integral with brightness.

The main novel results can be summarized as follows: (A) When the CTI was long (Experiments 1 and 3), switching did not cause formerly separable dimensions to become integral although there were some trends (in Experiment 3) showing that the irrelevant dimension of saturation was processed in the shape task in blocks in which participants switched between shape and brightness; (B) When the CTI was short, GI was significant even when the dimensions were formerly separable but it was considerably smaller (11 and 21 ms) than the GI seen in the brightness task (92 and 114 ms), which was formerly known to be integral with saturation. (C) participants were able to treat the task dimensions of shape and brightness analytically, especially when the CTI was long. This was seen in the fact that GI was present in the brightness task but was absent (Experiment 3) or was much smaller (Experiment 4) in the shape task. Below we discuss the theoretical implications of these results.

### Do Filtering Ability and Switching Ability Draw On a Common Limited Capacity Central Resource?

The answer to this question is generally negative. The only place in which formerly separable dimensions became (slightly) integral was when the CTI was short. These results contrast with the developmental findings cited in the introduction but accord with the available results from adults (especially Meiran et al., 2002). One advantage of the present paradigm is that the dimension used to manipulate Filtering was never relevant and therefore GI was not caused by the fact that the to-be ignored information was relevant beforehand or could have become relevant soon (e.g., Biederman, 1972; Rubin & Meiran, 2005; Shedden et al., 2003; Waszak, Hommel, & Allport, 2003).

Interestingly, studies using dual-task methodology show that GI (Kunde et al., 2007) and task switching (Oriet & Jolicoeur, 2003) occupy bottleneck stages, suggesting that both of these abilities involve central resources. This conclusion seems to contrast with the present conclusion. However, dual task paradigms involve presenting the stimuli of two tasks in rapid succession, so that the responses are given only after the stimuli were presented. Thus, the dual task paradigm could be conceived of as being similar to a task switching paradigm with an extremely short CTI. Result B indicates some capacity limitations when the CTI was short. The role of a short CTI is perhaps unrelated to switching because in Experiment 2, GI was significant also in single task conditions, and in fact, this is the only condition in which it reached statistical significance in that experiment.

Future research should clarify why switching ability and filtering ability are relatively strongly dependent among preschoolers and much more independent among adults. We tentatively suggest that dedicated (and noncentral) processes for switching, filtering or

both evolve during childhood and that before this change takes place, children must rely heavily on limited capacity central resources.

### Does Task Cuing Direct Attention to the Relevant Target-Stimulus Dimension?

Previous work suggests that participants process separable dimensions analytically when requested to do so (Melara, Marks, & Lesko, 1992). However, it is less obvious that they do so in contexts of frequent task switches. In fact, Logan and Bundesen's (2003) "compound cue" hypothesis suggests that they do not. Instead, the hypothesis is that participants treat the target stimulus holistically (in the sense that, e.g., a bright circle and a dark circle would be treated as two different stimuli in the shape task, despite the fact that brightness is irrelevant). Result C shows that (at least in Experiment 3) participants considered just the relevant dimension (either shape or brightness) and effectively ignored the other dimension (brightness or shape). At minimum, these findings suggest that the compound cue hypothesis is limited in its applicability.

In conclusion, the present study provides an initial attempt to bridge across two formerly separate literatures. In that sense, it joins a series of similar studies bridging across attention literatures (e.g., M. Hübner, Dreisbach, Haider, & Kluge, 2003; Jolicoeur, Dell'Acqua, & Crebolder, 2000; Luria & Meiran, 2003, 2005; Melara & Algom, 2003; Pashler, 1991; Shalev & Algom, 2000). The study shows that, unlike with preschoolers, in adults switching attention between dimensions and focusing on a dimension (filtering) do not draw on the same pool of limited capacity central resources unless, perhaps, under conditions involving a short CTI that implies little advance task preparation, little decay of the preceding task set, or both. The results also show that participants (can) treat separable perceptual dimensions in an analytic fashion even when they frequently switch between these dimensions.

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