Cognition 123 (2012) 303–307

Contents lists available at SciVerse ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Brief article

Deep thinking increases task-set shielding and reduces shifting flexibility in dual-task performance

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ARTICLE INFO

Article history:
Received 10 January 2011
Revised 15 August 2011
Accepted 2 November 2011
Available online 13 February 2012

Keywords:
Cognitive control
PRP
Multi-tasking
Crosstalk
Response-category compatibility
Creativity
Convergent and divergent thinking

ABSTRACT

Performing two tasks concurrently is difficult, which has been taken to imply the existence of a structural processing bottleneck. Here we sought to assess whether and to what degree one's multitasking abilities depend on the cognitive-control style one engages in. Participants were primed with creativity tasks that either called for divergent thinking—which were suspected to induce a holistic, flexible task processing mode, or convergent thinking—which were assumed to induce a systematic, focused processing mode. Participants showed reduced cross-talk between tasks and increased task-component switching costs (dual-task costs) for the convergent-thinking group compared to both, a divergent-thinking group and a neutral control group. The results suggest that the cognitive-control style people engage in prior to the task predicts their multitasking performance.

1. Introduction

People find it difficult to perform more than one task at the same time. An often-studied demonstration of that difficulty is the so-called *psychological refractory period* (PRP, see Pashler, 1998, for an overview)—a label that refers to the robust observation that a response (R2) to a stimulus (S2) is slower the sooner this stimulus appears after the presentation of another stimulus (S1) that signals another response (R1). In other words, the greater the temporal overlap between two tasks the worse performance is. Most researchers take this observation to indicate that at least some cognitive operations involved in a task require serial processing, so that related operations of the other task have to wait until the critical operations of the first task are completed. Less agreement exists with respect to the question whether this kind of processing bottleneck is structural (Pashler, 1998) or strategic (Logan & Gordon, 2001; Meyer & Kieras, 1997), with the latter claim receiving some support from observations that the size of dual-task costs can vary with the similarity between the tasks (Koch, 2009; Wenke & Frensch, 2005), task difficulty (Fischer, Miller, & Schubert, 2007) and expectations about their temporal proximity (Miller, Ulrich, & Rolke, 2009).

If processing bottlenecks are strategic in nature, it should be possible to a priori adjust and tune executive control parameters to optimize dual-task performance according to situational demands. In the present study we aimed to selectively induce different styles of creative thinking to prime corresponding control states that determine subsequent processing modes in dual-task performance. According to the recent dual-pathway model of creativity, creative thinking is a function of cognitive flexibility and cognitive persistence (Nijstad, De Dreu, Rietzschel, & Baas, 2010)—a view that also fits with recent insights into the dynamics of neural processes underlying cognitive control (Cools & D'Esposito, 2010). The model suggests that the *flexibility pathway* employs a holistic, flexible mode of thinking that is associated with the flexible switching between categories, the flexible use of remote associations, the overcoming of "functional

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doi:10.1016/j.cognition.2011.11.015

fixedness", and with making new connections among distant ideas. The *persistence pathway*, in contrast, induces a systematic, focused mode of thinking that encompasses effortful in-depth exploration. Original ideas, insights and problem solutions will occur through persistence in systematic search (cf. Nijstad et al., 2010). Consequently, engaging in a thinking style along the flexibility pathway (e.g., divergent thinking) and along the persistence pathway (e.g., convergent thinking) will prime different cognitive control states.

The same reasoning was applied and tested in a recent study by Hommel, Akbari Chermahini, van den Wildenberg, & Colzato (Submitted for publication). They had participants perform particular cognitive tasks after having carried out a prime task that required either convergent thinking (Mednick, 1962) or divergent thinking (Guilford, 1967). Performance in conflict-inducing tasks that are likely to require strong top-down control, like the Navon global-local task, the Stroop and the Simon task, benefited more from a convergent-thinking prime than from a divergent-thinking prime. In contrast, performance in the Attentional Blink task, which is known to suffer from too much top-down control (Olivers & Nieuwenhuis, 2006; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006; see Taatgen, Juvina, Schipper, Borst, & Martens, 2009, for a computational model of the too-much-control idea), benefited more from divergent than from convergent thinking. Hommel et al. (Submitted for publication) suggested that convergent thinking mainly relies on the persistence pathway and induces a cognitive-control state that strengthens top-down support for relevant information and/or local competition between more relevant and less relevant information (Duncan, Humphreys, & Ward, 1997). Divergent thinking, associated with the flexibility pathway, induces a state in which top-down support and/or local competition are reduced. As cognitive-control states are notorious for being rather inertial (Allport, Styles, & Hsieh, 1994; Meiran, Hommel, Bibi, & Lev, 2002; Memelink & Hommel, 2006), they tend to outlive the task context they were established for and, thus, to bias subsequent control states in one or the other direction. As the "exclusive" control mode induced by convergent thinking fits nicely with the type of control needed in conflict tasks, its after-effects supported conflict resolution and reduced global-local, Stroop, and Simon effects. Analogously, the more "flexible" control mode induced by divergent thinking reduced the degree of top-down control in the following Attentional Blink task and improved performance therein.

Although these previous findings allow for specific hypotheses with respect to the dual-task context, it should be mentioned that single- and dual-task settings differ considerably in processing. Dual-task processing requires a number of control processes and their flexible adjustment that distinguishes them from control adjustments in single-task performance. Most importantly, in dual-tasks the processing of the prioritized task (T1) needs to be shielded from influences based on additional task processing. At the same time, however, a rigid control state of effectively shielding the prioritized task goal needs to be replaced eventually when component processing of the additional task (T2) requires the allocation of attention. Therefore, the effective regulation between T1 goal shielding and the switching between T1 and T2 component processing represents a critical adaptation of complementary cognitive control processes, the success of which determines the quality of multiple task performance.

The present study investigated whether the logic underlying Nijstad et al.'s (2010) dual-pathway model and the control-mode approach of Hommel et al. (Submitted for publication) can be extended to assess and bias individual strategies and associated processing dynamics under dual-task conditions. Two measures were of particular importance. The effectiveness of T1 goal shielding is reflected in the amount of between-task interactions, measured as the impact of the crosstalk between the two tasks on RT1. It is known that RT1 is sensitive to the compatibility between activated semantic categories or response codes in both tasks (Hommel, 1998; Logan & Schulkind, 2000). This effect suggests that R2 selection (traditionally considered a bottleneck process: Pashler, 1994) did not wait for the completion of R1 selection; it thus indicates the presence and the degree of parallel processing (Lien & Proctor, 2002; Logan & Gordon, 2001). The second measure is the PRP effect, which denotes the flexible task component switch at the bottleneck and is assessed by the increase in reaction time (RT) for R2 (RT2) as the two tasks overlap in time, that is, with short (S1–S2) Stimulus Onset Asynchrony (SOA).

According to our logic, a holistic-flexible mode of thinking (i.e., divergent thinking) should induce a cognitive-control state that facilitates parallel processing, at least to some degree. If so, it should be possible to reduce dual-task costs (e.g., smaller PRP) by using a divergent-thinking task as a prime. Engaging in divergent thinking, so the rationale, should establish a processing mode that encompasses processing of both tasks, thus, reducing T1 shielding and allowing for more multitasking (e.g., more parallel simultaneous processing). Inducing a more systematic-focused type of thinking (i.e., convergent thinking), on the other hand, should prime a control state with more in-depth processing, thus, biasing the balance between flexibility and stability towards persistent, focused and thus, more serial processing and increased Task 1 shielding. Serial processing would reduce between-task interactions and increase the PRP effect.

We investigated this possibility by having one group of participants perform a dual-task (modeled after Logan & Schulkind, 2000) that was intermixed with a divergent-thinking task and another group perform the same dual-task intermixed with a convergent-thinking task.

2. Method

Forty-eight students (8 male, mean age: 23.4 years) participated for €5 or course credits, 24 in the convergent-thinking group and 24 in the divergent-thinking group.

Convergent thinking was induced by means of the *Remote Association Task* (RAT), in which participants were presented with three unrelated words (e.g., large, leave, and shade) and asked to find a common associate (tree).

Table 1
Response times for Task 1 (RT1) and Task 2 (RT2) for each creative thinking group as a function of Stimulus Onset Asynchrony (SOA) and response-category compatibility (R1–R2 compatibility), respectively. Standard error of the means are presented in parenthesis.

Task	Group	R1–R2 compatibility	SOA			
			40	130	300	900
RT1	Convergent	Compatible	642 (27)	634 (26)	664 (38)	694 (50)
		Incompatible	677 (32)	671 (35)	662 (41)	666 (51)
		Δ	35	37	−2	−28
	Divergent	Compatible	564 (15)	570 (18)	572 (29)	692 (68)
		Incompatible	610 (21)	613 (22)	599 (29)	729 (70)
		Δ	46	43	27	37
	Neutral	Compatible	632 (25)	644 (28)	639 (41)	764 (81)
		Incompatible	744 (51)	702 (44)	679 (54)	765 (84)
		Δ	112	58	40	1
RT2	Convergent	Compatible	799 (32)	707 (24)	624 (32)	525 (16)
		Incompatible	906 (37)	821 (42)	676 (34)	545 (23)
		Δ	107	114	52	20
	Divergent	Compatible	718 (29)	656 (28)	579 (27)	528 (23)
		Incompatible	846 (32)	760 (35)	631 (33)	539 (28)
		Δ	128	104	52	11
	Neutral	Compatible	739 (30)	681 (31)	601 (34)	559 (33)
		Incompatible	933 (53)	822 (49)	700 (49)	580 (39)
		Δ	194	141	99	21

Our version (based on Mednick (1962), and taken from Bolte & Goschke (2005)) consisted of two runs (each 3 min) including 17 items each.

Divergent thinking was induced by means of the *Alternative Uses Task* (AUT), in which participants were to write down as many possible uses for four common household items (foam upholstery, newspaper, yarn, and paper clip) as they could within 3 min per two items (based on Guilford (1967), and translated into German).

In order to ensure large crosstalk effects onto the primary T1 we adopted the dual-task paradigm from Fischer et al. (2007; see also Logan & Schulkind, 2000), in which both tasks required participants to categorize the stimuli as being smaller vs. larger than 5. To avoid identical stimuli in both tasks (e.g., perceptual match) and to maintain numerical distance to 5, the digits 3 and 7 and digits 2, 4, 6, and 8, presented in white on black background, served as stimuli for Task 1 (S1) and Task 2 (S2), respectively (Fischer et al., 2007). Participants had to press one of two keys; the "," and "." key of the QUERTZ keyboard to S1, by using their right index and middle finger, and the "*Y*" and the "*X*" key to S2, by using their left middle and index finger. The stimulus-response mappings were counterbalanced across participants. Each trial began with a 500-ms fixation display, next to which S1 appeared above the screen center. Following an SOA of 40, 130, 300, or 900 ms, S2 appeared below screen center for 1000 ms. Both stimuli were replaced by a 2-s blank screen, followed by the 300 ms feedback "correct" or, in case of an incorrect response in either task, a missing response, or incorrect response order, the feedback "error". Participants were told not to group responses and to respond as fast and as accurately as possible, first to S1 and only second to S2 (Task 1 priority).

Participants performed 64 practice trials, followed by the first part of either the RAT or the AUT, 64 multi-tasking trials, the second part of the RAT or the AUT, and another 64 multi-tasking trials. All participants also completed the MDBF mood questionnaire (Steyer, Schwenkmezger, Notz, & Eid, 1997) prior to the first creativity task and after the second multi-tasking part to control for subjective mental states on three dimensions (i.e., good mood vs. bad mood, calmness vs. restlessness, and alertness vs. fatigue).

3. Results

The two groups did not differ in their mean scores on subjective mental state, i.e., good vs. bad mood, fatigue vs. alertness, or arousal vs. calmness, all F's < 1, nor in their performance in the practice block, all group-related p's > .26. For the experiment, incorrect T1 (1.8%) and T2 responses (3.8%) were excluded. Greenhouse–Geisser adjustments were applied wherever appropriate. Results are presented in Table 1 and Fig. 1.

3.1. Rt1

A repeated-measures ANOVA of median RTs was run with SOA and response-category compatibility (R1 and R2 both indicating "smaller than 5" or both "larger than 5" stimuli vs. one indicating a "smaller than 5" and the other a "larger than 5" stimulus) as repeated factors and creativity (divergent vs. convergent) as between-subject factor. The groups did not differ in their overall RT level, $F < 1$, but main effects were obtained for SOA, $F(3, 138) = 4.32$, $p < .05$, $\eta_p^2 = .09$, and response-category compatibility, $F(1, 46) = 13.35$, $p < .01$, $\eta_p^2 = .23$. Participants categorized S1 faster when S1 and S2 fell into the same response category. This effect was more pronounced for short than for long SOAs (40, 40, 12, and 4 ms, respectively), as confirmed by a significant SOA X response-category compatibility interaction, $F(3, 138) = 2.87$, $p < .05$, $\eta_p^2 = .06$. Most importantly for our purposes, the size of the response-category compatibility effect was significantly smaller in the convergent-thinking group (10 ms), $F(1, 46) = 4.42$, $p < .05$, $\eta_p^2 = .09$, than in the

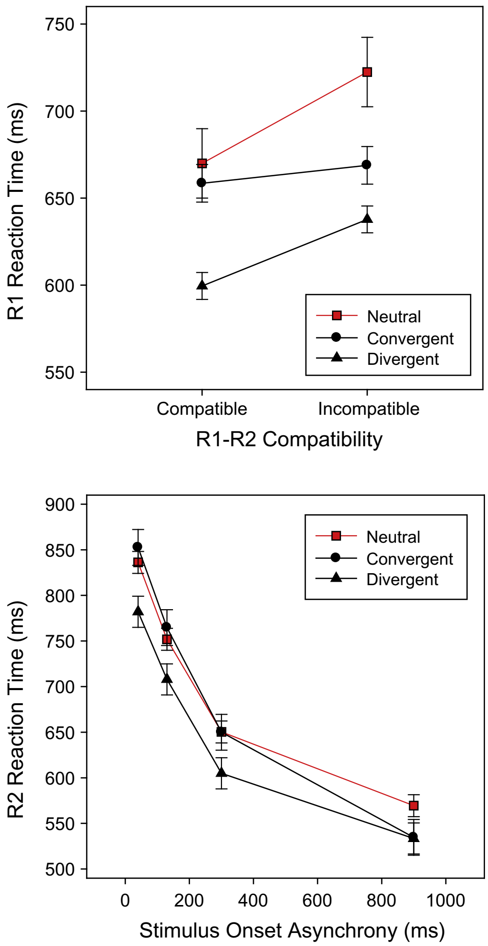

Fig. 1. Response-category compatibility effect in Task 1 for each creative thinking group (top panel). Response times for Task 2 (RT2) for each creative thinking group as a function of stimulus onset asynchrony (bottom panel). R1–R2 compatibility–compatibility between response-category in Task 1 and response-category in Task 2. Error bars represent standard errors of the response-category compatibility effect (Task 1) and of the PRP effect (Task 2).

divergent-thinking group (38 ms) (see Fig. 1 top panel). These effects were not modulated by SOA, $F(3, 138) = 1.51$, $p = .217$, $\eta_p^2 = .03$. The connection between the response-category compatibility effect and the creative-thinking manipulation was also visible in a trend towards a positive correlation between divergent thinking (the number of different item categories used: see Akbari Chermahini & Hommel, 2010) and the size of the response-category compatibility effect, $r = .3$, $p = .077$ (one-sided). In contrast, the effect was negatively correlated with the number of correct responses in the convergent-thinking task, $r = -.372$, $p < .05$ (one-sided).

3.2. Rt2

As expected, RT2 increased steeply with shorter SOA, reflecting a standard PRP effect, $F(3, 138) = 225.30$, $p < .001$, $\eta_p^2 = .83$. Importantly, this effect was more pronounced for the convergent- than for the divergent-thinking group, yielding a creativity X SOA interaction, $F(3, 69) = 3.30$, $p < .05$, $\eta_p^2 = .08$ (see Fig. 1 bottom panel). Furthermore, there was a significant response-category compatibility effect, $F(1, 46) = 65.59$, $p < .001$, $\eta_p^2 = .59$, which also varied with SOA, $F(3, 138) = 17.49$, $p < .001$, $\eta_p^2 = .28$, showing that the RT1 effect propagated to Task 2 the more the closer the two tasks overlapped in time. No other effects were significant.

3.3. Control analyses

Visual inspection may suggest an at least numerical difference in RT1 between both groups. To test whether this difference might compromise our findings, we re-ran the ANOVAs and included median RT1 as covariate in the analyses. Importantly, the response-category compatibility effect in T1 was still smaller, $F(1, 45) = 6.40$, $p < .05$, $\eta_p^2 = .13$, and the PRP effect in T2 still larger $F(1, 45) = 5.31$, $p < .05$, $\eta_p^2 = .11$ (linear contrasts), for the convergent-thinking as compared to the divergent-thinking group.

A possible account of effect differences in terms of systematic processing strategies, such as delaying T1 processing (response grouping), was not substantiated: the proportion of trials in which both responses were emitted within a brief inter-response-interval (IRI < 150 ms and <250 ms) did not differ between groups, both p's > .507. On the contrary, excluding two "heavy groupers" (grouping in >65% of trials) further increased the differences in the response-category compatibility effect between divergent (45 ms) and convergent (0 ms) groups.

In order to further elucidate which thinking style can be held responsible for the differences in findings between convergent- and divergent-thinking group, we collected additional data of a neutral group in which participants ($N = 24$, 12 male, mean age 22.0 years) did not engage in a prime task. They performed the identical dual-task but were asked to relax in the time periods usually taken by the prime task. The response-category match effect in T1 and the PRP slope in T2 of the neutral group mirrored the effects of the divergent-thinking group, both F's < 1 (see also Fig. 1). A general trend of faster responses (77 ms) in the divergent group failed to reach significance, $F(1, 46) = 1.85$, $p = .181$, $\eta_p^2 = .04$. In contrast, the response-category match effect in the neutral group (52 ms) appeared larger compared to the convergent-thinking group (10 ms) which, however, only approached significance, $F(1, 46) = 3.46$, $p = .069$, $\eta_p^2 = .07$. In Task 2, however, the PRP slope was steeper, thus reflecting a larger PRP effect, for the convergent-thinking as compared to the neutral group (103 ms vs. 79 ms), $F(1, 46) = 4.43$, $p < .05$, $\eta_p^2 = .09$ (linear contrast).

4. Conclusion

The outcome is straightforward in demonstrating that the prior engagement in different creative thinking styles forms global meta-control states that determine local control adjustments in subsequent dual-task performance.

More specifically, participants who engaged in convergent thinking displayed increased task-set shielding of the primary task which came at the cost of reduced shifting flexibility at the bottleneck (i.e., increased PRP effect) compared to participants in the divergent-thinking group who showed a higher degree of parallel processing and reduced costs at the processing bottleneck (i.e., reduced PRP effects). An additional neutral thinking group revealed that the dual-task performance differences between convergent and divergent thinking styles were primarily driven by the converging thinking group.

We conclude, therefore, that systematic-focused and effortful in-depth processing as displayed by a convergent thinking style reduces multitasking abilities by increasing dual-task costs at the bottleneck (i.e., PRP effect). On speculative terms and along the lines of Hommel et al. (Submitted for publication), it is conceivable that the PRP effect does not result from too little but from too much top-down control or, to use the term of Olivers and Nieuwenhuis (2006), from an "overinvestment" of attentional resources (see also Taatgen et al., 2009). From this perspective, attempts to "train away" dual-task costs through practice (e.g., Ruthruff, Johnston, Van Selst, Whitsell, & Remington, 2003) may not be optimal because they, in the sense, emphasize the need for efficient control. Better suited may be a psychological task context that discourages active control by distracting participants or by creating a relaxed atmosphere.

Taken together, our findings provide evidence that at least some substantial portion of the dual-task processing bottleneck depends on the cognitive-control style people engage in and, thus, speaks in favor of the possibility that the bottleneck is strategic in nature (Meyer & Kieras, 1997).

In general, predicting the "quality" of dual-task performance by the previously engaged style of thinking provides an important mean of strategic control regulation to optimize dual-task performance whenever a situation calls either for flexibility or persistence in dual-task behavior.

Acknowledgements

We thank Julia Kleindienst, Vivien Suchert, and Juliane Wetzel for assistance in data collection.

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