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The Relevance of the Irrelevant: Attentional Distractor-Response Binding Predicts Performance in the Remote Associates Task

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Psychologists have long thought that an inability to suppress irrelevant information hinders our ability to solve problems. However, most studies have investigated *analytical* rather than *creative* problem solving. Here, we examine whether the way in which the brain processes task-irrelevant information affects its ability to solve complex and creative problems. Using well-established paradigms from the attentional-perceptual literature (the event-file binding task) and problem-solving literature (the Remote Associates Test and Raven's Advanced Progressive Matrices), we found that greater attentional leakage, as manifest by strong perceptual distractor-response binding, might be beneficial for solving insight-based creative problems but not necessarily for problems that require pattern finding and logic. These results suggest a specific advantage for spreading attention more equally between relevant and irrelevant information in order to creatively 'think outside of the box'. This delineates a beautiful mapping between the way our sensory systems interact with the external world and our brain's formation of internal semantic networks that underlie our creative capacities.

Keywords: creativity, remote associations, problem solving, stimulus-response integration, distractor-response binding

Since the early pioneering work of William James (1890) in the psychology of attention, there has been a widely held agreement in the psychological literature that in order for the brain to respond adaptively to the environment and solve problems effectively, information that is irrelevant to the task at hand should be ignored or inhibited, while relevant information should be processed and attended to (Marzocchi, Lucangeli, De Meo, Fini, & Cornoldi, 2002; Passolunghi, Cornoldi, & De Liberto, 1999; Passolunghi & Siegel, 2001; Ridderinkhof & van der Molen, 1995; Ridderinkhof, van der Molen, Band, & Bashore, 1997). Indeed, research into atypical populations has demonstrated that a failure to ignore irrelevant information is related to poor problem-solving ability, as seen in children with attention-deficit hyperactivity disorder (Passolunghi, Marzocchi, & Fiorillo, 2005; Passolunghi & Siegel, 2001) and high-psychotic-prone adults (de la Casa, Ruiz, & Lubow, 1993). Moreover, developmental studies have shown a link between the ability to ignore or suppress irrelevant information and the capacity to efficiently solve problems—both of these are enhanced during development (Ridderinkhof & van der Molen, 1995; Ridderinkhof et al., 1997; Tipper, Bourque, Anderson, & Brehaut, 1989) and decline during aging (Hoyer, Rebok, & Sved, 1979; Kausler & Kleim, 1978). Hence, the ability to suppress irrelevant information seems to be a good predictor of high mental functioning, and it has indeed been granted a key role in cognitive control (Miyake et al., 2000).

And yet there are reasons to assume that the tendency to spread attention more equally between relevant and irrelevant information may sometimes be a good thing. Although extreme forms of focusing on relevant information may be beneficial in artificial laboratory tasks, outside the lab, it is much less clear what counts as relevant and what as irrelevant. Accordingly, truly adaptive behavior needs to find some sort of balance between beneficial attentional leakage to less relevant information and a goal-directed focus on what is relevant to the task at hand (Goschke, 2003). This is particularly obvious in tasks that require some sort of creativity. One example is divergent thinking, as, for instance, assessed by the alternate uses task (Guilford, 1967). But even more constrained problem solving is likely to benefit from *attentional leakage* to less relevant information, that is, from the availability of irrelevant information because of a failure of attentional selectivity. This has

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been pointed out by Ashby and colleagues (Ashby, Isen, & Turken, 1999; Ashby, Valentin, & Turken, 2002) with respect to the Remote Association Task (RAT; Mednick, 1962)—a more convergent version of a creativity task.

In the RAT, participants are presented with three unrelated words and asked to generate a fourth word, which serves as a compound word with each of the given words. For example, prime words such as *boot*, *summer*, and *ground* are unrelated to one another but may be related to a fourth word (*camp*) via the formation of a semantic associate. The difficulty of this task stems from the fact that finding and identifying the associations between both the three prime words and between the prime words and the response word requires attention to less frequent, less familiar, and often less relevant meanings or associations of the words. As Ashby and colleagues (1999, 2002) point out, processing a word will commonly activate only the core (i.e., the most frequent) associations of this word, which will not allow for good performance in the RAT. What good performance requires is the broadening of attention to more uncommon associations, which, for instance, can be achieved by inducing positive mood (Ashby et al., 1999, 2002). Interestingly, for our purposes, this suggests that some sorts of creative problem solving may actually *benefit* from paying attention to other things than the task requires, as this may facilitate the activation of remote associations and thinking out of the box. In particular, this implies that individuals that are less selectively attending to, or retrieving, relevant information—that is, people with greater attentional leakage—would be expected to perform better in creative problem solving such as tested by the RAT. In the present study, we tested this prediction by studying whether people who demonstrate stronger attentional leakage in a simple laboratory task that is sensitive to individual differences in information integration do indeed show better performance in the RAT.

Studies on perceptual information integration have consistently demonstrated that when individuals respond to a presented stimulus, the representation of the response to the task-relevant stimulus becomes automatically integrated with both the task-relevant features of the stimulus (i.e., stimulus-response binding) and with task-irrelevant features (i.e., distractor-response binding; Frings, 2011; Frings & Rothermund, 2011; Frings, Rothermund, & Wentura, 2007; Hommel, 1998, 2004, 2005; Mayr & Buchner, 2006; Rothermund, Wentura, & De Houwer, 2005; Wesslein, Spence, & Frings, 2014). For example, sequentially responding to the color of two different shapes would produce binding effects between the task-relevant feature (color) and the response (stimulus-response binding) but also between the irrelevant information (shape) and the response (distractor-response binding). These stimulus-response and distractor-response integration effects have been illustrated when all the features of the stimulus originate from the same sensory modality, for instance, in vision (Frings et al., 2007; Hommel, 1998, 2004; Kahneman, Treisman, & Gibbs, 1992; Rothermund et al., 2005), audition (Dyson & Quinlan, 2003; Hall, Pastore, Acker, & Huang, 2000; Mayr & Buchner, 2006; Mayr, Buchner, & Dentale, 2009; Moeller, Rothermund, & Frings, 2012; Takegata et al., 2005; Zmigrod & Hommel, 2009), or tactition (Moeller & Frings, 2011), as well as in cases when the stimulus is composed of features originating from different sensory modalities (Evans & Treisman, 2010; Jordan, Clark, & Mitroff, 2010; Zmigrod, Spapé, & Hommel, 2009). The likelihood of irrelevant features becoming bound to the other perceptual and response features increases with factors such as spatiotemporal proximity (Gao & Scholl, 2010; Mitroff & Alvarez, 2007; Spapé & Hommel, 2010), salience (Dutzi & Hommel, 2009), or if the relevant feature originates from the same modality (Zmigrod & Hommel, 2010; for review see Zmigrod & Hommel, 2013).

In order to examine the binding effects between different perceptual features (including the relevant and the irrelevant features of an event) and the response feature, Hommel (1998) developed the event-file paradigm. In this sequential prime-probe paradigm, two stimulus features (one which is relevant and the other irrelevant to the task) and one response feature are varied independently. Participants sequentially respond to the two stimuli. The first response is cued in advance and carried out in response to the first stimulus (with one relevant and one irrelevant feature), so that it is independent from the features of that stimulus but merely triggered by it. The second response is a binary-choice response to the relevant feature of the second stimulus (see Figure 1). This design allows assessing the performance in terms of reaction time (RT) and accuracy of all the combinations of repetition and alternation of the stimulus features and the response feature. A typical finding reveals interaction effects with better performance when all the features are repeated or all the features are alternated compared with when some but not all features are repeated. These findings were replicated in multiple studies with different features and sensory modalities (Hommel, 1998, 2004; Hommel & Colzato, 2004; Zmigrod & Hommel, 2009, 2010, 2011; Zmigrod et al., 2009). Thus, it is possible to calculate the cost associated with repeating only some, but not all, features, for each combination of stimulus feature and response feature, by subtracting the mean RT of the trials with total repetition and total alternation of the features from the trials with partially repeated features. These partial repetition costs (PRCs) represent the temporal delay caused by the automatic retrieval of the previous event representation, triggered by the repetition of at least one feature. As the cost implies that not only the code of the repeated feature is reactivated but, in fact, the entire previous stimulus event (Kühn, Keizer, Colzato, Rombouts, & Hommel, 2011), the PRC can be taken as a marker for feature binding (Hommel, 1998, 2004; Zmigrod & Hommel, 2010; for review: Zmigrod & Hommel, 2013). Of particular importance for the present study is the PRC obtained from partial repetition of irrelevant stimulus information, as this indicates that the distractor and the response were bound together and retrieved as a unit.

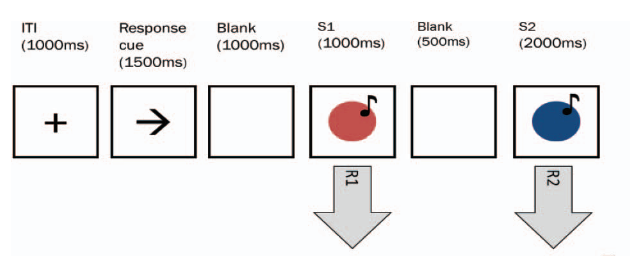

Figure 1. Sequence of events in the event file task. A visual response cue signals a left or right response (R1) that should be delayed until presentation of the first stimulus S1 (S1 is used as a detection signal for R1). The second stimulus S2 appears 500 ms after responding to S1. S2 signals R2, a speeded left or right response according to the value of the pitch of S2 (low vs. high). See the online article for the color version of this figure.

An accumulating body of research is showing that stimulus-response bindings are not solely coded in terms of low-level perceptual representations or motoric codes but also at multiple representational levels, which can be abstract, flexible, and can operate with or without awareness and attention (Denkinger & Koutstaal, 2009; Dennis & Perfect, 2013; Horner & Henson, 2009; for review, see Henson, Eckstein, Waszak, Frings, & Horner, 2014; Moeller, Hommel, & Frings, 2015). Notably, Frings, Moeller, and Rothermund (2013) showed that distractor-response bindings can occur even when the modality of the repeated distractor was alternated between the prime and the probe, indicating that conceptual features, and not just the perceptual features, of the distractors were encoded and integrated with the response in the stimulus-response episodes. This suggests that the distractor-based retrieval effect can be conceptually or semantically mediated. Furthermore, using an approach-avoidance task, Giesen and Rothermund (2016) reported findings that distractor-based retrieval leads to the retrieval of both motor codes and more abstract semantic codes. This suggests that binding is not restricted to low-level stimulus and response codes but also comprises of more abstract representations.

Interestingly for our purposes, binding effects and PRCs show considerable variability both within and between participants. Among other things, PRCs have been shown to vary with IQ (Colzato, van Wouwe, Lavender, & Hommel, 2006), affective state (Colzato, van Wouwe, & Hommel, 2007b) and stress (Colzato, Kool, & Hommel, 2008), biomarkers of the striatal dopamine level (Colzato, van Wouwe, & Hommel, 2007a), drug use (Colzato & Hommel, 2008), and autism (Zmigrod, de Sonneville, Colzato, Swaab, & Hommel, 2013). In the present study, we were particularly interested in interindividual variability related to distractor-response binding (Frings et al., 2007; Hommel, 1998), that is, to the binding of irrelevant stimulus information to the response. Given that neither the irrelevant stimulus feature nor the relationship between this feature and the response were relevant or informative to the task in any way, PRCs related to this relationship could be taken to indicate the individual tendency to consider irrelevant information—with more pronounced PRCs reflecting greater attentional leakage. Our hypothesis was that greater attentional leakage might be advantageous when retrieving semantic associations between remote conceptual representations, such as in the RAT. We therefore predicted that individuals with larger PRCs related to the irrelevant stimulus feature and the response show better performance in the RAT. To test whether a possible effect is indeed specific to remote associations, we also included the Raven Advanced Progressive Matrices (APM) task (Raven, 1965), which also requires problem solving but does not rely on particular word or other associations.

Method

Participants

In total, 112 native Dutch Leiden University students (56 men; mean age = 20 years, *SD* = 2.1; age range = 17–27 years) took part in the study for course credits or a financial reward. All participants were right-handed with normal or corrected-to-normal vision. Exclusion criteria included a history of psychiatric disorders, drug abuse, and active medication. Participants gave their written informed consent to participate in the study.

Stimuli and Procedure

Multisensory event-file task. A multisensory event-file task was adapted from Zmigrod and Hommel (2010). This task has been validated and tested within and between sensory modalities and action in dozens of experiments, and reliably produces binding effects (Hommel, 1998, 2004, 2005; Hommel & Colzato, 2004; Zmigrod & Hommel, 2009, 2010, 2011, 2013). The bimodal stimuli S1 and S2 were composed of two pure tones of 1,000Hz and 3,000Hz (duration 50 ms) presented at approximately 70dB SPL, accompanied by a colored circle which was presented in either red or blue. Responses to S1 and S2 were made by clicking the right or left mouse button with the same hand. Response cues for S1 were left- and right-pointing arrowheads in the middle of the screen indicating a left or right mouse click, respectively. Response cues for S2 was a binary-choice reaction to the pitch (high vs. low) of S2.

The experiment was composed of a practice block with 15 trials and an experimental block with 128 trials. The order of the trials was randomized. The sequence of events in each trial is shown in Figure 1. A response cue with a right or left arrow was presented for 1,500 ms, signaling response (R1), which was to be carried out after S1 was presented. S2 appeared 500 ms after the onset of R1 (i.e., the response to S1). In case of an incorrect or absent response, an error message was presented. Half of the participants responded to the high and low pitch of the sound by pressing on the left or right mouse button, respectively; the other half of the participants received the opposite mapping. The participants were instructed to respond as quickly and accurately as possible.

Remote Associates Task (RAT). A computerized version of the RAT was adapted from Chermahini, Hickendorff, and Hommel (2012), and comprised of 30 problems (Cronbach's alpha = .85). In this task, each item included three unrelated words, and participants were asked to write a common associate as an answer (e.g., *hair*, *stretch*, *time* → *long*). The participants had to find the answer within 30 s.

Raven's Advanced Progressive Matrices (APM) task. The Raven's APM task (Raven, 1965) was used to assess problem solving ability. This task is often used to estimate fluid intelligence and Spearman's *g*. The task was composed of visual patterns with one element missing, whereby participants were instructed to choose the correct solution out of six possible answers. In this task, we used 30 items, which progressively increased in difficulty over the 20 min during which the APM was administered.

Procedure

The participants read and signed the informed consent form before the beginning of the experiment. All participants completed the multisensory event-file task, the RAT, and Raven's APM task. The order of the tasks was counterbalanced between participants. The study conformed to the ethical standards of the Declaration of Helsinki (World Medical Association, 2001) and was approved by the Ethical Committee of Leiden University.

Results

Multisensory Event-File Effects

After excluding trials with incorrect responses, as well as missing (RT $>$1,500 ms) or anticipatory response (RT $<$100 ms), mean RTs and accuracy of the second response (R2) were analyzed as function of three variables: the relationship between R1 and R2 (repetition vs. alternation), the relationship between S1 and S2 with regards to the task-relevant auditory feature pitch (repetition vs. alternation), and the relationship between the task-irrelevant visual feature color (repetition vs. alternation). Three-way ANOVAs for repeated measures was performed on these variables with RTs and accuracy as independent measures (see Table 1 for descriptive statistics).

The well-established findings were replicated (Zmigrod & Hommel, 2010, 2011; Zmigrod et al., 2009). Main effects of response were observed in RTs, $F(1, 111) = 5.341$, $p = .023$, $\eta_p^2 = .046$, and accuracy $F(1, 111) = 9.366$, $p = .003$, $\eta_p^2 = .078$. Also, a main effect of pitch repetition was obtained in RTs, $F(1, 111) = 10.397$, $p = .002$, $\eta_p^2 = .086$. In terms of stimulus-response integration, the standard crossover interactions between pitch and response repetition were observed in RTs, $F(1, 111) = 257.453$, $p < .0001$, $\eta_p^2 = .699$, and accuracy $F(1, 111) = 245.717$, $p < .0001$, $\eta_p^2 = .689$. A significant interaction in accuracy between color and response was obtained, $F(1, 111) = 6.789$, $p = .01$, $\eta_p^2 = .058$, indicating better performance when both the stimulus and the response repeated or alternated than when only one feature was repeated. Furthermore, multisensory integration effect was obtain between pitch and color in RTs, $F(1, 111) = 18.658$, $p < .0001$. The effect followed the typical crossover pattern, with better performance for color repetition when pitch was also repeated than when it was alternated, but worse performance for color alternation when pitch was repeated than when it was alternated, as was observed previously (Zmigrod & Hommel, 2010, 2011; Zmigrod et al., 2009). In addition, individual sizes of the PRCs were calculated for each combination of stimulus and response features by subtracting the mean RTs from complete repetitions and alternations from the means of partial repetitions. Replicating previous findings, we found a substantial task-relevant feature-response PRC (55.92), a medium size multisensory stimulus features PRC (11.65), and a small distractor/task-irrelevant feature-response PRC (4.48; Zmigrod & Hommel, 2010, 2011). There were no significant differences between males ($n = 56$) and females ($n = 56$) in any of the PRCs ($p > .1$).

Complex Problem-Solving Ability

The RAT and Raven's APM scores were measured in terms of the number of correct items. There was no gender difference in the performance of both problem-solving tasks ($p > .1$). Furthermore, replicating previous findings (Chermahini & Hommel, 2010), there was a positive correlation between the performances in the RAT and the performances in Raven's APM, $r(110) = .216$, $p < .05$.

Relationship Between PRC and Complex Problem Solving

Most interesting for the current study was whether paying attention to the irrelevant features of a stimulus as reflected by binding costs of the irrelevant feature and response, that is, distractor-response binding, is linked to remote associates' performance. As shown in Table 2, RAT scores were positively correlated with partial repetition of the irrelevant feature and the response (see Figure 2). That is, larger PRCs (paying attention to the irrelevant feature) are associated with higher scores in the RAT (finding remote associate solution). No other significant correlations were found with RAT scores.

Furthermore, we found a strong tendency toward a relationship between fluid intelligence and relevant stimulus-response binding: People with higher fluid intelligence are quicker in responding to stimulus-response binding, $r(112) = -.172$, $p = .069$. This replicates Colzato and colleagues' (2006) finding of such a relationship. The fact that the relationship did not achieve statistical significance in this sample may be related to the homogeneity of the population in our study in terms of fluid intelligence.

Moreover, a linear regression analyses revealed that PRCs of the irrelevant feature and response can significantly predict the performance in the remote associate task (see Table 3).

In order to further investigate these relationships, the participants were split along the performances median into high performers and low performers for the RAT ($n_{\text{low}} = 69$, $n_{\text{high}} = 43$) and Raven's APM ($n_{\text{low}} = 51$, $n_{\text{high}} = 61$). As is demonstrated in Figure 3, t-test analyses revealed significant differences between the groups in PRCs of the distractor feature and response for the

Table 1
Descriptive Statistics of Mean Reaction Time (RT in Ms) and Percentage of Accuracy for R2 as a Function of the Relationship Between the Response (R1 and R2) and the Relationship Between the Stimulus (S1 and S2) for Both the Task-Relevant Feature (Pitch) and the Distractor/Task-Irrelevant Feature (Color)

The relationships (repetition vs. alternation) between first stimulus (S1) and the second stimulus (S2) for each stimulus' feature	Response for R2 as a function of the relationships (repetition vs. alternation) between the first response (R1) and the second response (R2)			
	Repetition Mean RTs (*SE*)	Alternation Mean RTs (*SE*)	Repetition Mean accuracy (*SE*)	Alternation Mean accuracy (*SE*)
Task-relevant feature pitch				
Repetition	402.17 (8.04)	450.53 (8.93)	93.9% (.7%)	83.0% (1.1%)
Alternation	469.39 (8.99)	405.10 (7.03)	79.9% (1.0%)	95.4% (.6%)
Task-irrelevant feature color				
Repetition	431.98 (8.49)	427.15 (7.86)	87.4% (1.1%)	88.1% (1.0%)
Alternation	439.59 (8.29)	428.48 (8.02)	86.4% (1.1%)	90.3% (.7%)

Table 2
Correlation Between Partial Repetition Cost (PRC) and Problem Solving in Relation to Both the Remote Associates Task (RAT) Score and Raven's APM Score

	PRC irrelevant feature-response	PRC relevant feature-response	PRC stimulus features
RAT	.280**	–.172	–.088
Raven's APM	.004	–.161	.021

Note. $N = 112$.
** $p < .005$.

Table 3
Regression Analysis with Remote Associates Task (RAT) Scores as the Dependent Variable

Partial repetition costs	*t*	ß	*p*
Irrelevant feature – response	2.748**	.260	.007
Relevant feature – response	–1.798	–.166	.075
Stimulus features	–.492	–.047	.624

Note. $N = 112$. $R^2 = .106$; $F(3, 111) = 4.25$, $p = .007$.
** $p < .01$.

RAT, $t(110) = -2.39$, $p = .018$, but not for the Raven's APM, $p > .9$.

Discussion

For years, the field of the psychology of attention has suggested that an inability to suppress irrelevant information hinders our ability to deal with problems efficiently (Marzocchi et al., 2002; Passolunghi et al., 1999; Passolunghi & Siegel, 2001; Ridderinkhof & van der Molen, 1995; Ridderinkhof et al., 1997). However, most studies have examined analytical problem solving rather than how people deal with less structured problem-solving tasks and situations. The current study addresses this gap and indeed provides evidence that irrelevant information may, in fact, *assist* problem solving in certain types of complex and creative problem-solving situations, especially in problems that require the processing of remote associations. The results indicate that the propensity to bind irrelevant or distractive information, as manifested with large PRCs between the irrelevant feature and the response, that is, distractor-response binding, was highly correlated with and predicted the performance on the RAT but not the Raven's APM (see Tables 2 and 3, Figures 2 and 3). This suggests that people who tend to process irrelevant information are better at solving remote associative problems, such as in the RAT, but are not better at solving more analytical pattern-finding problems as in Raven's APM task.

These results complement the existing research on the link between "leaky" attention and creativity (Carson, Peterson, & Higgins, 2003; Zabelina, O'Leary, Pornpattananangkul, Nusslock, & Beeman, 2015). "Leaky" attention can be conceptualized as a decrease in latent inhibition, that is, a reduced ability to suppress and inhibit irrelevant information (Zabelina, Saporta, & Beeman, 2016). Zabelina and colleagues (2016) noted that Carson and colleagues' (2003) finding of a relationship between reduced latent inhibition and creative achievement, and Zabelina and colleagues' (2015) finding that "leaky" sensory gating is linked to creative achievement lead to the hypothesis that "leaky attention may facilitate access to remote associations, and lead to a creative thought" (p. 496). Nevertheless, because these studies assess creative achievement, rather than creative problem solving directly, the authors provided no direct evidence for this claim. The present study empirically corroborates their hypothesis by demonstrating that attentional leakage in the form of multisensory distractor-response binding is directly linked to the capacity to flexibly generate remote associations.

Our findings are in line with studies on individuals with synaesthesia, which have demonstrated the relationship between cross-modal associations and an ability to solve remote associative problems. For example, Dailey, Martindale, and Borkum (1997) found that people with high scores in the RAT exhibit stronger associations of cross-modal synaesthesia-type judgment, such as color tone and color vowel, than people with lower RAT scores, indicating that a tendency to form stronger cross-sensory associations is related to a capacity to form remote conceptual associations. Likewise, Ward, Thompson-Lake, Ely, and Kaminski (2008) observed a significant correlation between RAT performance and the number of types of synaesthesia that a synesthete experienced. Additionally, Zmigrod and Zmigrod (2016) explored the relation-

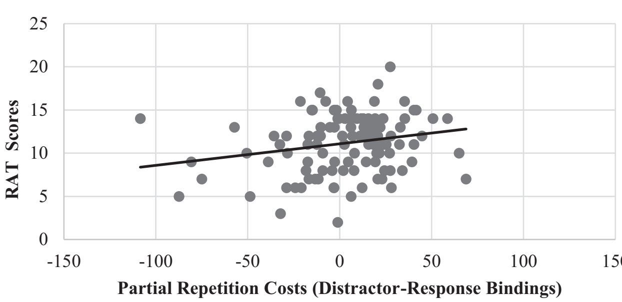

Figure 2. Correlation between Distractor-Response Bindings and RAT scores.

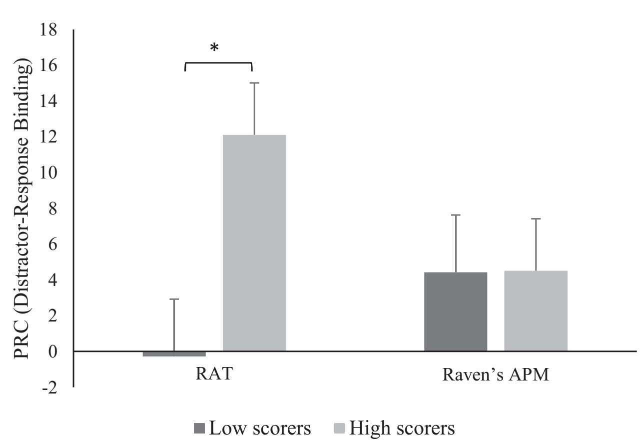

Figure 3. Partial Repetition Costs (PRC) between irrelevant feature and response, i.e. Distractor-Response Binding (with standard errors), as a function of high scorers and low scorers for Remote Associates Test (RAT) and Raven's APM, * $p < .05$.

ships between problem-solving ability and the audio-visual temporal binding window, which reflects the interval during which two asynchronous sensory inputs are perceived as a single synchronous event. The results revealed a relationship between the individual's width of the multisensory temporal binding window and their ability to solve RAT and Raven's APM problems, whereby a narrower multisensory temporal binding window (i.e., one that is more precise and can sensitively detect multisensory asynchrony) predicted better performance in both tasks. This suggests the existence of a link between individual differences in perceptual processes and conceptual problem-solving capacities.

The results of the present study indicate that lack of suppression of irrelevant perceptual features, as was measured by the event-file task, is linked to more flexible retrieval of conceptual connections, as was measured by the RAT. This brings to light an important and interesting question: Do the processes of encoding and retrieving perceptual feature associations yield advantages in encoding and retrieving conceptual semantic associations? And if so, is this because perceptual associative ability underlies or shares a common mechanism with conceptual associative ability? It is possible to begin tackling these questions by building on previous research into the links between perceptual distractor-response binding and higher level cognition, which investigated decision making under uncertainty (Nett, Bröder, & Frings, 2015) and the occurrence of distractor-response binding on a conceptual level and not merely on a sensory perceptual level (Frings et al., 2013; Giesen & Rothermund, 2016). For example, it would be interesting to apply Frings and colleagues' (2013) cross-modal methodology in order to examine whether individual differences in conceptual distractor-response binding are linked to conceptual remote association capacity. Moreover, in the current study, we have demonstrated that lack of suppression of irrelevant or distractor features within the same event or stimulus is linked to remote associative ability. Frings and Rothermund (2011) extended the concept of distractor-response bindings to instances when the distractor originates from a different stimulus or object, and so future research should examine whether individual differences in remote associative and problem-solving ability is also related to distractor-responses bindings of different irrelevant objects. Interestingly, studies in creativity and attention have suggested that creative individuals demonstrate more defocused attention (Mendelsohn, 1976)—but only in certain situations and task demands—through flexible adjustment of their focus of attention (Martindale, 1999; Vartanian, Martindale, & Kwiatkowski, 2007). Combining these ideas, it would be interesting to examine how the origin of the distracting information (i.e., from within the same stimulus or from different irrelevant coinciding events) mediates the adjustment of attention in creative individuals. Additionally, given the evidence that a common mechanism might underlie distractor-response binding and bindings between responses and the effects they cause (Hommel, 2005; Moeller, Pfister, Kunde, & Frings, 2016), it will be interesting to extend the present investigation to response-effect bindings.

The present findings signify that the way one processes irrelevant or distracting information is linked to one's ability to solve high-level creative problems, and consequently affects one's cognition. Future research will need to explore the causal mechanisms of how low-level perception shapes high-level problem-solving ability. One promising technique is through noninvasive neurostimulation, which allows researchers to temporarily enhance or interfere with perceptual or cognitive functions. Recent studies have illustrated that transcranial DC stimulation (tDCS) can affect the way individuals perceive and integrate perceptual and response events (Bolognini, Olgiati, Rossetti, & Maravita, 2010, Bolognini, Rossetti, Casati, Mancini, & Vallar, 2011; Zmigrod, 2014; Zmigrod, Colzato, & Hommel, 2014; Zmigrod & Zmigrod, 2015). Consequently, one way to test the causal relationships between low-level perception and high-level creative problem solving is to use neurostimulation to interfere with perceptual processes and examine whether there are associated disruptions in creative associative performance. This approach may shed light on the roots of our ability to solve creative problems and demonstrate ways to enhance and promote solving-problem ability and creative thinking.

Mednick's (1962) associative theory of creative thinking proposed that individual differences in associative hierarchies and in the flexibility of their semantic associations underlies differences in creative idea generation. In the present study, we provide an additional angle to this framework by demonstrating that individual differences in formation of perceptual associations are related to differences in the formation of semantic associations. In fact, a remarkably similar pattern of results to the present study was found when studying problem solving ability in relation to hierarchical perception using Navon's (1977) global-local task (Zmigrod, Zmigrod, & Hommel, 2015). In the task, participants are presented with large letters composed of smaller letters (e.g., an "H" made of small "S"s) and are instructed to attend to either the large letter (global level) or the smaller constituent letters (local level), while ignoring the other level. It therefore measures the extent to which irrelevant, distractive information is processed in perception. When participants attended to the local level, the individuals who were more distracted by the irrelevant global perceptual level (i.e., experienced a large global interference effect) performed better in solving remote associative problems in the RAT, but performed equally in the analytical pattern-finding problems of Raven's APM, compared with individuals who did not experience the distraction by the irrelevant information. It is striking that the results of this study and the present investigation found a specific link between the inability to ignore irrelevant information and the ability to solve remote associative problems but not analytical problems. This suggests that individuals with a weaker tendency to suppress information that is not immediately relevant to the task, which may facilitate formation of broader and stronger perceptual associations between environmental stimuli, have an advantage when they generate internal semantic associations between remote conceptual representations. This is a beautiful example of the close mapping between the way in which an individual's sensory systems interact with the external world and the way in which their internal semantic networks are formed.

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