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How associative thinking influences scene perception

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ABSTRACT

Perception of our external environment is not isolated from the influence of our internal thoughts, and past evidence points to a possible common associative mechanism underlying both the perception of scenes and our internal thought. Here, we investigated the nature of the interaction between an associative mindset and scene perception, hypothesizing a functional advantage to an associative thought pattern in the perception of scenes. Experiments 1 and 2 showed that associative thinking facilitates scene perception, which evolved over the course of the experiments. In contrast to scene perception, Experiment 3 showed that associative thinking hinders the perception of mundane objects, in which associative information is minimized. Nevertheless, object perception was facilitated when associative thinking was reduced. This double dissociation suggests that an associative mind is more receptive of externally perceived associative information, and that a match between the orientation of internal and external processing may be key for perception.

1. Introduction

Almost every human experience interweaves internal thought and perception of the external environment. Consider the simple example of sitting on the beach and enjoying the sunset. As we consciously appreciate the visual scene, our mind wanders in thought. How do these thoughts influence the perception of the scene in front of us? Although this question has been tackled from various directions, we still don't have a comprehensive framework for how our mindset interacts with perception.

1.1. How thought and perception interact

Some theories suggest that thoughts and perception compete for attention, such that mindsets that require more internal focus come at the expense of processing perceptual inputs, resulting, for example, in enhanced inattentional blindness (Shi & Li, 2020) or in perceptual decoupling (Schooler et al., 2011; Smallwood et al., 2011). Other lines of research contend that thought may serve as a top-down cue for perception by priming - ultimately facilitating the perception of stimuli that correspond with what is internally represented (Brunyé et al., 2012; Scorolli et al., 2009, though see Firestone & Scholl, 2016). Recent theories, however, go beyond attentional competition or content-level priming framework, to suggest that thought and perception may be interdependent based on a shared form or orientation of processing. For example, the Construal Level Theory predicts that abstract levels of thinking are linked with

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global perceptual processing (Trope & Liberman, 2010). Similarly, the Overarching States of Mind framework (Herz et al., 2020) postulates that different elements encompassing one's state of mind (i.e., perception, attention, thought, openness to experience and affect) are interdependent, and that the processing mode in one element (e.g., thought) influences processing of other elements (e.g., perception). Importantly, unlike limited-resources frameworks that highlight the competition-for-resources aspect of our multi-dimensional cognition, these theories suggest that alignment in the mode of processing across cognitive dimensions reduces cognitive demands and may in fact facilitate performance. In line with these theories, here we bring scene perception and thought-related processing together and hypothesize that 'how' we think influences 'how' we perceive, and more specifically, that an associative mode of thought would facilitate scene perception, which also relies on associative processing.

1.2. Scene perception and mindsets may share an associative foundation

Indirect evidence supports the suggestion that scene perception and mindset-related processes share a unified mechanism. As we elaborate next, both seem to rely on associative processing.

Natural scene perception requires the integration of individual elements (Kim & Biederman, 2011), as well as the extraction of global gist (Bar, 2004; Torralba et al., 2006), and it involves the processing of spatial information (Epstein & Kanwisher, 1998), textures (Park & Park, 2017) and viewpoints (Park & Chun, 2009). Most notably, scene perception relies on processing contextual associations of various kinds, learned over multiple co-occurrences. Much of the information we process in a scene relates to object-to-object associations and their relations within their spatial setting (Biederman et al., 1982). Demonstrating this effect, activity in scene-preferring brain regions was modulated by the contextual associations afforded by the visual stimulus (Bar & Aminoff, 2003; Bar et al., 2008). Moreover, in exploring an associative account for scene processing, Aminoff and colleagues demonstrated that the mere acquiring of associations, even in the absence of semantic meaning, engaged scene-selective brain regions (Aminoff et al., 2007; Aminoff & Tarr, 2015). This evidence-based account highlights the rich associative nature of scenes.

Associativity in the external processing of scenes may be compatible with associativity in the internal realm of our state of mind (Herz et al., 2020) – our fluctuating stream of thought (Christoff et al., 2016). States of mind, or mindsets, have specifically been delineated in terms of the associative processes they involve. For example, a creative state of mind is suggested to rely on processing associations in a novel yet useful way (Mednick, 1962). Abilities such as associative flexibility (i.e., diversity in associations) and associative fluency (i.e., number of associations) are found to represent a core function underlying creativity (Beaty et al., 2014; Benedek et al., 2012). Additionally, remoteness of associations is a strong indicator of divergent thinking, a primary measurement of creative thought (Acar & Runco, 2014). Spontaneous thought as well, and the state of 'mind wandering', were also recently suggested to be sustained by associative processing (Baror et al., 2021). More globally, Christoff et al., (2016) define spontaneous thought by aligning different mindsets such as creativity, mind wandering, ruminations and sleep, along an axis indicating the level of associativity and variability each of them involves.

Due to these shared associative characteristics, we hypothesized that compatibility in associative processing may be an organizing principle governing the interaction between mindset and perception. This hypothesis is indirectly supported by data showing that spontaneously evoked associations taking place during memory encoding (Peters et al., 2009), or self-referential episodic thought (Gilmore et al., 2016; Szpunar et al., 2009) activate scene-selective brain regions. Nevertheless, a direct examination of the hypothesized interaction between the two in behavior has yet to be explored. We examine this hypothesis here by testing scene perception via a 1-back scene similarity task while promoting mindset in different levels of associativity, in aim of simultaneously manipulating associative processes in internal thoughts and in external perception. Here, we define an associative mindset as one in which many related associations are brought to mind, generating a rich representation of the context they all share. In the perceptual task, perceptual performance relies on processing the unique associations each scene triggers, especially when different scenes belong to the same category.

1.3. Manipulating an associative mindset

Associative mindsets (e.g., a mind-wondering state) are often observed and measured, not actively manipulated. Here, to manipulate an associative mindset, we used word lists inspired by the lists created by Deese, Roediger and McDermott (DRM effect, Roediger & McDermott, 1995). Each list of words is structured such that all words are strongly related to a critical lure word not shown. For example, 'door', 'glass', 'pane', 'shade', 'curtain' are words that are all related to the critical lure word of 'window'. Thus, the list of words generates a rich, and detailed associative context of a window. Typically, the DRM lists are read to participants during an encoding phase, and due to the associative nature of the list, at test, participants falsely remember the critical lure word as part of the encoding list even though it was never read. Importantly, this effect has been attributed to associative processing that occurs during the encoding of the list (Dewhurst, Bould, Knott, & Thorley, 2009). We build on this literature and use DRM inspired word lists to generate an associative mindset. Using words to manipulate one's mindset has been proven successful in other realms as well, showing for example that the presentation of emotional words influences encoding of emotional faces (Fugate, Gendron, Nakashima, & Bartlett, 2017). These previous findings show the effectiveness in using words and word lists to prime the content of thought and activate related associations. Here we examine how word lists that are used to manipulate the *form* of thought (i.e., associative), rather than its *content*, influence perception.

1.4. Different timescales in thought and perception

In natural settings thought and perception take place simultaneously and in an ongoing manner. In most lab settings, however, perception and thought are manipulated in a serial manner (with thought usually priming perception, partially under the assumption that thought takes time to evolve) and assessed in different time scales (with thought probed over the order of seconds to minutes and perceptual processing in the order of milliseconds). To interrogate the parallel processing of scene perception and associative thought, we asked participants to perform a perceptual task while, rather than after, artificially inducing the associative degree of their mindset using the word lists. Such parallel processing inherently raises the interesting question of when one's mindset can affect perceptual processing. Immediately? Or after some time engaging in that mindset? The time course of a perception-thought interaction could evolve in several ways: for example, a mindset could become more influential on perception over time or it could become less influential over time from the mindset's onset. The potential interdependent influence could also remain at a fixed level throughout one's experience. To address this open question, we divided the experiments into three consecutive blocks, treating time into the

Fig. 1. Stimuli and experimental design of Exp. 1. a, Examples of scene stimuli. The image stimuli consisted of scenes from the BOLD5000 data set (Chang et al., 2019). The examples depict pairs of scene exemplars that share a category but are not identical (i.e., similar condition). b, Mindset examples. The stimuli consisted of lists of twelve words each. In the *Narrow* condition all words are associatively related to the same context. In the *Broad* condition, only consecutive words are associatively related to the same context, but the list as a whole raises multiple unrelated contexts. In the *Unrelated* condition, words do not share a context at all. c, An array example. Words were superimposed on the images, both presented for 1250 ms in each trial, and followed by a 250 ms presentation of a cross. Following twelve trials, participants were shown one word and were asked to determine whether that word appeared as part of the array or not. The example depicts a list from the *Broad* condition.

experiment as an additional independent variable. Previewing the results, in three experiments we found that an associative mindset enhanced associative scene perception, an effect that evolved over time with the maximum enhancement found on the last block of each experiment.

2. Experiment 1

Experiment 1 was aimed to examine how different mindsets influence scene perception. To that aim, scene images were presented consecutively, and participants were asked to respond to each image and judge whether it was identical or different from the preceding image. Simultaneously, words that elicited different mindsets were superimposed on the presented images, and participants were asked to remember them for a subsequent memory test. We hypothesized that if mindsets interact with perception, varying mindset conditions would lead to performance changes in the scene perception task.

2.1. Material and methods

2.1.1. Stimuli

Stimuli were scene images used for the perceptual task, and word lists used for the mindset manipulation. The scene images for the perceptual task were chosen from the BOLD 5000 dataset (Chang et al., 2019). This large dataset includes 5000 images as well as the fMRI BOLD signal results of four participants viewing these images. Images were 375 × 375 pixels and subtended approximately 9.5 degrees of visual angle. We used a sub-sample of this dataset, which includes 250 scene categories, each having four exemplar images. Of these four images, we chose the two images among the four exemplars, that showed the highest correlation in BOLD signal in the parahippocampal place area (PPA) and retrosplenial complex (RSC), the core brain regions suggested to sustain scene perception through contextual associative processing (Bar & Aminoff, 2003). While these image pairs belonged to the same category (e.g., a playground), they did not necessarily share all their comprising features, such as their viewpoint or their comprising elements. This selection process resulted in a total of 500 images (250 categories with two exemplars each) that were subsequently embedded in the task. Examples for such associative-based scene pairs are depicted in Fig. 1a.

Word lists for the mindset manipulation were adapted from Mason & Bar (2012) and comprised three levels of associativity. In the ‘narrow’ condition, words were all contextually associated to one another, all focusing on one, narrow contextual theme (e.g., dog-cat-puppy-animal). In this case there would be rich associative processing of the context. In the ‘broad’ condition, each word was associated to the word preceding it and to the word following it, but the list as a whole involved a broad rather than a narrow set of contexts, where contexts may have few associations, presumably eliciting more dispersed and shallow associative processing (e.g., tomato-red-blood-knife). Although this condition involves associations between consecutive words, it is not likely to elicit an all-encompassing associative mindset as is evident in DRM findings. In the ‘unrelated’ condition, words were completely unrelated to one another, such that associative processing was minimized (e.g., whistle-helmet-shovel-cat). Each list comprised 12 words, and each mindset condition comprised a total of 24 lists. An example list for each mindset condition is depicted in Fig. 1b.

2.1.2. Design

The experiments involved a 1-back scene similarity task. Images of scenes were presented one after the other, interleaved with fixation crosses, and participants were asked to determine as fast as possible with regards to every image whether it was identical to or different from the previously presented image. The task comprised three image conditions: images could be identical to the previous image (i.e., ‘same’ condition), completely different from the previous image (i.e., ‘different’ condition) or similar in their contextual category to the image preceding them yet different in the specific details and layout (i.e., ‘similar’ condition).

Simultaneously to the perceptual scene task, participants’ mindsets were manipulated by the presentation of the word lists. These word lists were successfully used in the past to affect one’s mindset (Mason & Bar, 2012). Words in each list were sequentially presented, superimposed on top of the scene images at screen center. Participants were asked to attend to the presented words in parallel to actively reporting their perceptual same/different decisions regarding the scene images. To verify attention to the words, participants were asked to remember these words for a following memory recognition test at the end of the array. In each thirteenth trial, a word was presented against a white background, and participants were asked to determine whether that word appeared in the previous sequence or not. In 50% of the cases the test word appeared as part of the sequence and in 50% of the cases the test word was novel yet associated with one of the words in the sequence.

To summarize the conditions in the paradigm- the perceptual task comprised three image conditions, such that images could be either the same as, similar to, or completely different from their preceding image. The memory-words task comprised three mindset conditions, which were either narrowly associated with one another, broadly associated, or unrelated.

Each trial included a presentation of a scene image, and a presentation of a word superimposed on the image at screen center. The content of the words in each list did not overlap the content of the images, in order to minimize the possible influence of binding processes between the image and the word superimposed on top of it. Every image-word pair was presented for the duration of 1250 ms and was followed by a 250 ms presentation of a fixation cross. Presentation duration was not influenced by response reaction time (RT). Trials were grouped into arrays of twelve, such that the presentation of each 12 words-list was paired with and superimposed over the presentation of 12 consecutive scene images.

Scene images were randomized across lists. Additionally, image conditions were randomized within each list, such that in each 12-trials array, 50% were images identical to their preceding image (i.e., ‘same condition’), and 50% were of images different from their preceding image. Of the different images, 50% were images completely different from the preceding image (i.e., ‘different condition’) and 50% were different from the preceding image in their details yet similar to the preceding image in their category (i.e., 'similar condition'). This division of trials was made to make sure the responses are not biased to making a 'same' or 'different' response in any of the arrays. An example of several consecutive trials is depicted in Fig. 1c.

The experiment comprised three blocks (i.e., beginning, middle, and end), and each block contained a total of 24 lists, eight consecutive lists from each mindset condition, counterbalanced in their order across blocks. This arrangement was aimed to verify that the narrow, broad and unrelated mindset conditions all appeared at the beginning (first block), middle (second block) and end (third block) of the experiment, such that possible differences between mindset conditions cannot be accounted for by practice or time into the experiment. Breaks were introduced between each 8 consecutive 12-trials arrays that belonged to the same mindset conditions. This was meant to allow rest periods throughout the experiment.

2.1.3. Procedure

Upon arriving to the experiment, participants signed informed consent forms and were administered a short practice stage that included a total of 12 lists, 4 from each mindset condition, each list counterbalancing all scene image conditions within it. Participants received feedback on their memory performance during practice regarding their memory of the test word at the end of every list. After completing the practice stage and verifying that they understood the task, the participants completed the full experiment. The entire experimental process took ~50 min, after which participants were thanked and compensated, either with money or with course credits. This experiment, as well as Experiments 2 and 3 were run in a quiet room. Participants were seated in front of the monitor, with their head positioned at ~60 cm from the center of the screen. All experiments were run on an iMac using MATLAB psychtoolbox. All three experiments reported here were approved by Fordham University's Institutional Review Board. Informed consent was obtained from all participants. All research was performed in accordance with the Declaration of Helsinki.

2.2. Results

35 participants took part in the experiment (22 females, mean age = 21.13 years). Four participants were excluded from analysis due to poor performance in the scene perception task (below 2.5 std from the mean). Two participants were excluded from analysis due to poor performance in the memory task (below 2.5 std from the mean). One participant was excluded due to not performing the task correctly (responded only to images that repeated themselves). All further analysis was performed based on the data of the remaining 28 participants.

In analyzing the results, we first looked at the memory performance to make sure that participants attended the words, and that their attention did not vary across mindset conditions. We then examined performance in the scene perception task, analyzing all three image conditions (i.e., same, similar, different) in both accuracy and in RT, under the varying mindset conditions (i.e., narrow, broad, unrelated). We hypothesized that mindset differences in associative processing will influence scene perception, operationalized as how they performed in the 1-back task. Lastly, to evaluate the time course related to the effectiveness of the mindset manipulation, we were interested in how performance varied as a function of the duration into the experiment (first, middle and end block), introducing this variable as another focus of analysis.

Memory analysis did not yield accuracy differences between the mindset conditions, thus verifying that attention to the words did not vary across mindset conditions. Memory means for the narrow, broad and unrelated mindset conditions were: 0.78, 0.76, 0.77, respectively, and were not significantly different from one another ($F(2,26) = 0.49$, $p > 0.5$, n.s.). Nonetheless, a significant interaction between mindset and order of blocks emerged ($F(4,24) = 2.79$, $p < 0.035$, observed power = 0.71, $\eta_p^2 = 0.09$). Post-hoc analysis shows that this interaction stems from accuracy decline over time in the broad mindset condition ($F(2,26) = 6.31$, $p < 0.006$, observed power = 0.86, $\eta_p^2 = 0.32$).

RT analysis of memory performance reveals a significant main effect for mindset condition, such that RT in the unrelated condition (M = 907 ms, SD = 34 ms) was slower than RT in the narrow (M = 870 ms, SD = 26 ms) and the broad (M = 871 ms, SD = 29 ms)

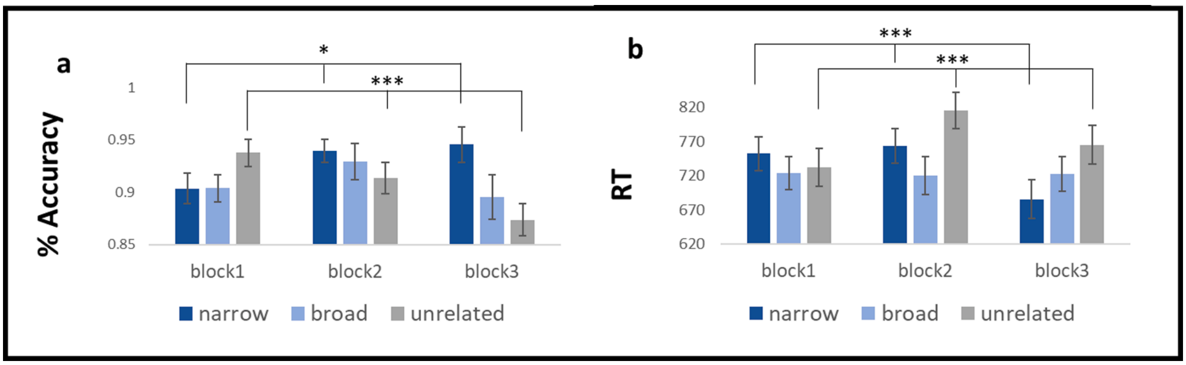

Fig. 2. Results of the 'similar' image condition in Exp. 1. a, Accuracy. b, RT. Figures depict the interaction between mindset conditions (i.e., narrow, broad and unrelated) and the order of blocks (first to last). Bars indicate standard error of the mean. Significant main effects are denoted by asterisks.

Table 1
Complete statistical descriptives for the scene task. The table shows the mean and the std (in parenthesis) in all experiments (Exp. 1, Exp. 2, Exp. 3), in both accuracy (left) and RT (in ms, right) measures, as they change as a function of image conditions (same, similar or different) and across experimental blocks (B1, B2, B3). Cells with * denote the main effect of change across the experimental blocks was statistically significant.

		Accuracy									Reaction Time								
		Same			Similar			Different			Same			Similar			Different		
		B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3
Experiment 1	Narrow	93 (0.5)	93 (0.6)	93 (0.5)	90* (0.7)	93* (0.5)	94* (0.8)	96 (0.5)	96 (0.4)	94 (0.8)	696 (108)	713 (134)	663 (109)	752* (130)	763* (131)	685* (149)	721* (127)	702* (159)	677* (136)
	Broad	93 (0.4)	93 (0.6)	94 (0.4)	90 (0.6)	92 (0.9)	89 (1.1)	95 (0.4)	96 (0.6)	97 (0.4)	672 (113)	680 (126)	689 (136)	723 (126)	719 (147)	722 (134)	676 (136)	693 (162)	687 (136)
	Unrelated	93 (0.5)	93 (0.6)	93 (0.6)	95* (0.6)	91* (0.7)	87* (0.8)	93 (0.6)	93 (0.6)	95 (0.4)	693 (130)	736 (128)	720 (138)	731* (146)	815* (140)	764* (151)	701* (160)	761* (150)	717* (157)
Experiment 2	Narrow	92 (0.7)	91 (0.9)	90 (1)	90 (0.7)	91 (0.8)	92 (0.9)	90 (1.5)	90 (1.7)	91 (1.4)	643 (91)	641 (95)	634 (107)	765* (114)	739* (118)	696* (137)	716* (121)	693* (123)	671* (119)
	Broad	90 (0.8)	88 (1)	89 (1)	90 (0.9)	92 (0.8)	89 (0.8)	93 (1.1)	91 (1.1)	94 (0.6)	646 (115)	626 (94)	652 (106)	720 (139)	714 (12)	734 (135)	692 (130)	679 (130)	694 (139)
	Unrelated	96 (1)	92 (1)	90 (0.9)	91 (0.9)	90 (1)	86 (1.1)	92 (1.1)	91 (1.7)	91 (1.2)	638 (106)	646 (84)	644 (89)	723* (125)	773* (104)	735* (111)	691 (141)	717 (106)	712 (127)
Experiment 3	Narrow	95 (0.4)	91 (0.8)	92 (0.6)	95* (0.5)	96* (0.4)	87* (0.8)	96 (0.5)	96 (0.4)	96 (0.3)	660 (117)	652 (109)	655 (81)	696* (121)	679* (85)	751* (96)	650* (123)	674* (85)	739* (115)
	Broad	94 (0.4)	88 (1)	89 (0.8)	95 (0.6)	93 (0.8)	96 (0.4)	97 (0.3)	98 (0.4)	94 (0.3)	658 (93)	665 (120)	649 (100)	709 (115)	736 (83)	664 (69)	691 (107)	693 (108)	649 (49)
	Unrelated	91 (0.8)	93 (0.7)	91 (1)	90 (0.6)	94 (0.7)	94 (0.7)	93 (0.6)	97 (0.4)	97 (0.5)	677 (111)	650 (114)	660 (85)	745* (91)	689* (127)	680* (98)	732* (104)	638* (95)	669* (89)

conditions ($F(2,26) = 5.58$, $p < 0.010$, observed power = 0.81, $\eta_p^2 = 0.30$).

Next, we turn to analyze performance of the scene perception task. This analysis includes only trials in which memory of the words was correct.

Accuracy analysis of the scene perception task, which focused on hit rate, revealed a main effect for image condition, such that accuracy in the task was the highest when images were completely different from the image preceding them ($M = 0.95$, $SD = 0.006$), followed by images that were identical to the image preceding them ($M = 0.93$, $SD = 0.007$). Lowest accuracy was found for images that were similar in their category yet different in their details from the image preceding them ($M = 0.91$, $SD = 0.009$; $F(2,26) = 26.80$, $p < 0.001$, observed power = 1, $\eta_p^2 = 0.67$).

Accuracy analysis also showed a triple interaction between the image condition, the mindset condition and the order of blocks ($F(8,20) = 5.42$, $p < 0.001$, observed power = 0.98, $\eta_p^2 = 0.68$). This interaction revealed that in the similar image condition, which involved sensitivity to the scene's associations to the greatest extent, accuracy rate increased over time under the narrow mindset, and deteriorated under the unrelated mindset (Fig. 2a). Subsequent pairwise comparison analyses revealed that under the unrelated mindset, performance in block 3 was significantly worse from performance in block 1 ($p < 0.003$; corrected for multiple comparisons using Bonferroni correction).

RT analysis of the scene perception task revealed a complementary result. First, a significant effect of image condition was found, such that RT in the similar image condition ($M = 742$ ms, $SD = 24$ ms) was significantly slower than RT in the same ($M = 696$ ms, $SD = 21$ ms) and different ($M = 704$ ms, $SD = 25$ ms) conditions ($F(2,26) = 51.51$, $p < 0.001$, observed power = 1, $\eta_p^2 = 0.79$). Second, a significant effect of mindset condition was found for the scene task, such that RT was significantly faster in the narrow ($M = 708$ ms, $SD = 22$ ms) and broad ($M = 696$ ms, $SD = 22$ ms) mindset, compared with the unrelated mindset ($M = 738$ ms, $SD = 25$ ms; $F(2,26) = 12.85$, $p < 0.001$, observed power = 0.99, $\eta_p^2 = 0.49$).

Most importantly a triple interaction emerged between the image conditions, the mindset conditions and the order of blocks ($F(8,20) = 2.22$, $p < 0.037$, observed power = 0.83, $\eta_p^2 = 0.47$). This interaction demonstrated a double dissociation. RT was significantly faster under the narrow mindset over the course of the blocks and at the same time, RT was significantly slower under the unrelated mindset over the course of the blocks. No significant over-time RT changes were observed in the broad mindset. Post-hoc analysis revealed that this interaction was significant in the similar and in the different image conditions (Fig. 2b; Graphs are presented for the similar image condition, in which the results were most evident, but see Table 1 for the complete set of statistical information from all conditions in all experiments).

Subsequent pairwise comparison analyses revealed that under the narrow mindset, in the similar image condition, performance in block 3 was significantly faster compared with block 1 ($p < 0.002$) and block 2 ($p < 0.001$). In the different image condition, faster performance was found in block 1 compared with block 3 ($p < 0.029$). Under the unrelated mindset, in the similar image condition, significant differences were found between all blocks (block1-2: $p < 0.001$, block 2–3: $p < 0.004$, block 3–1: $p < 0.014$) such that performance was slowest in block 2 and fastest in block 1. In the different image condition performance in block 2 was the slowest and was significantly different from block 1 ($p < 0.016$) and block 3 ($p < 0.017$). All analyses were corrected for multiple comparisons using Bonferroni correction.

These results demonstrate that scene processing occurs faster and more accurately when performed under a mindset in which associative processing is augmented, compared with under a mindset in which associative processing is reduced. These findings are most apparent when processing consecutive scene images that are different exemplars of the same scene category.

3. Experiment 2

Exp. 1 incorporated a memory recognition test to verify attention to the presented words simultaneously to performing the perceptual task. While this procedure was aimed to motivate attention to the words, to indeed trigger the different mindset conditions, it is possible that remembering the words was not equally demanding across conditions, and the results in Exp. 1 are confounded by variations in memory load across the mindset conditions. To tease apart mindset associativity from memory load, Exp. 2 was conducted in which words were presented but the memory task was eliminated. This allowed us to examine whether the mere exposure to concepts that vary in their encompassed associative information is enough to influence perception.

3.1. Material and methods

All stimuli in Exp. 2 were identical to the stimuli used in Exp. 1. The only difference between the experiments is that in Exp. 2, participants were not explicitly asked to attend to the presented words, as task performance was measured with regards to the scene images, but not with regards to the word lists. Here, participants were told that the words appearing superimposed on top of the images are not the focus of their task, and that they can choose to ignore them. Instead of a memory recognition test, following every 12-trials array a white screen appeared for three seconds, and participants were encouraged to let their eyes rest from the perceptual scene task during this short intermission. As there was no memory task in Exp. 2, participants did not receive feedback on their performance during practice.

3.2. Results

26 participants took part in the experiment (15 females, mean age = 19.38 years). Two participants were excluded from analysis due to poor performance in the scene perception task (below 2.5 std from the mean), therefore all further analysis was performed based

on the data of the remaining 24 participants.

Accuracy analysis of the scene perception task did not reveal a significant effect of the image conditions nor did it reveal a significant effect of the mindset conditions. Nonetheless, RT analysis revealed significant effects that resemble the results in Exp. 1. First, a significant effect of image condition was found, such that all image conditions were significantly different from one another. Slowest RT's were found in the similar image condition (M = 733 ms, SD = 23 ms), followed by the different image condition (M = 696 ms, SD = 23 ms). Fastest RT was found in the same image condition (M = 641 ms, SD = 18 ms; $F(2,22) = 67.21$, $p < 0.001$, observed power = 1.00, $\eta_p^2 = 0.85$).

Most importantly a triple interaction emerged between the image conditions, the mindset conditions and the order of blocks ($F(8,16) = 2.76$, $p < 0.040$, observed power = 0.77, $\eta_p^2 = 0.58$). This interaction shows a double dissociation similar to that found in Exp. 1. Over time, RT was significantly faster under the narrow mindset, unchanged in the broad condition, and significantly slower under the unrelated mindset. As in Exp. 1, this was most apparent in the similar image condition, in which fine sensitivity to scene's associative content is most required (Fig. 3). Subsequent pairwise comparison analyses revealed that under the narrow mindset, in the similar image condition, performance in block 3 was significantly faster compared with block 1 ($p < 0.001$) and block 2 ($p < 0.016$). In the different image conditions, the significant difference was found between block 3 and block 1 ($p < 0.038$). Under the unrelated mindset, in the similar image condition, performance in block 1 was significantly faster than performance in block 2 ($p < 0.038$). All analyses were corrected for multiple comparisons using Bonferroni correction.

Exp. 2 replicates the facilitatory effect of an associative mindset on scene processing, and is not confounded by memory load.

4. Experiment 3

Exp. 1 & 2 revealed that an associative mindset facilitates scene perception, but it is possible that an associative mindset facilitates any perceptual task, regardless of the involved associative affordance of the visual stimuli. To dissociate a general enhancement effect from an associative-related effect, we conducted Exp. 3 which involved images of mundane individual objects that are similar to scenes in their naturalness, yet minimize associative processing. If an associative mindset selectively enhances associative-based perception because of the shared associative orientation, then it will not enhance perception of objects with minimal associations. Alternatively, if an associative mindset has a global facilitatory effect on perception, then object perception will be enhanced.

4.1. Material and methods

4.1.1. Stimuli

The main goal of experiment 3 was to evaluate whether the influence of the associative mindset on perceptual processing is specific to scenes, or whether it enhances perception of any stimuli. We therefore used daily objects as stimuli, images that are of items as meaningful and natural as scenes, but that have been contrasted with scenes in the past in terms of recognition processes and associative involvement. The object images for the perceptual task were chosen from a dataset by Brady et al., (2008). This dataset includes images of various objects, each having more than one exemplar. Because this experiment was aimed to examine the influence of mindset on perceptual performance in which associative processing is minimized, we chose 265 objects that are not associated with a specific context (e.g., a t-shirt rather than a wedding tuxedo). The objects chosen were inspired by the original set of weak contextual objects defined in Bar & Aminoff (2003). For each object we chose two different exemplars. This selection resulted in a total of 530 images to be used in the experiment. Examples for these object image pairs are depicted in Fig. 4a. The word lists for the mindset manipulation were identical to the ones used in Exp. 1 and Exp. 2.

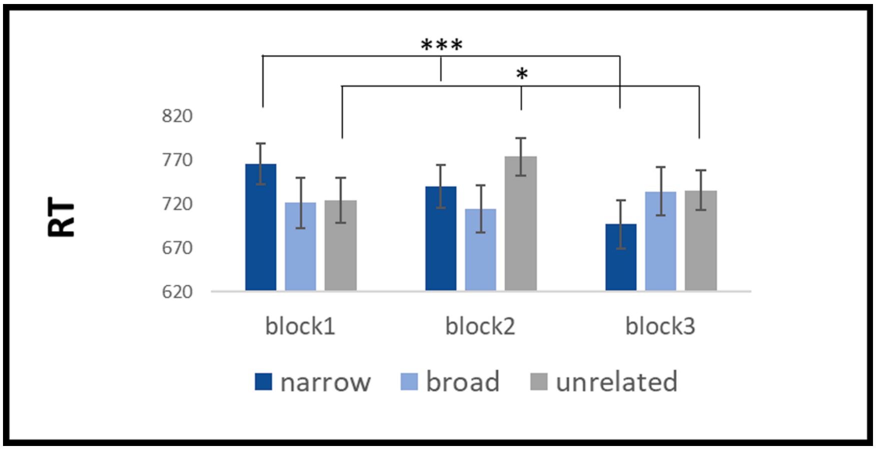

Fig. 3. RT results of 'similar' image condition in Exp. 2. Figure depicts the interaction between mindset conditions (i.e., narrow, broad and unrelated) and the order of blocks (first to last). Bars indicate standard error of the mean. Significant main effects are denoted by asterisks.

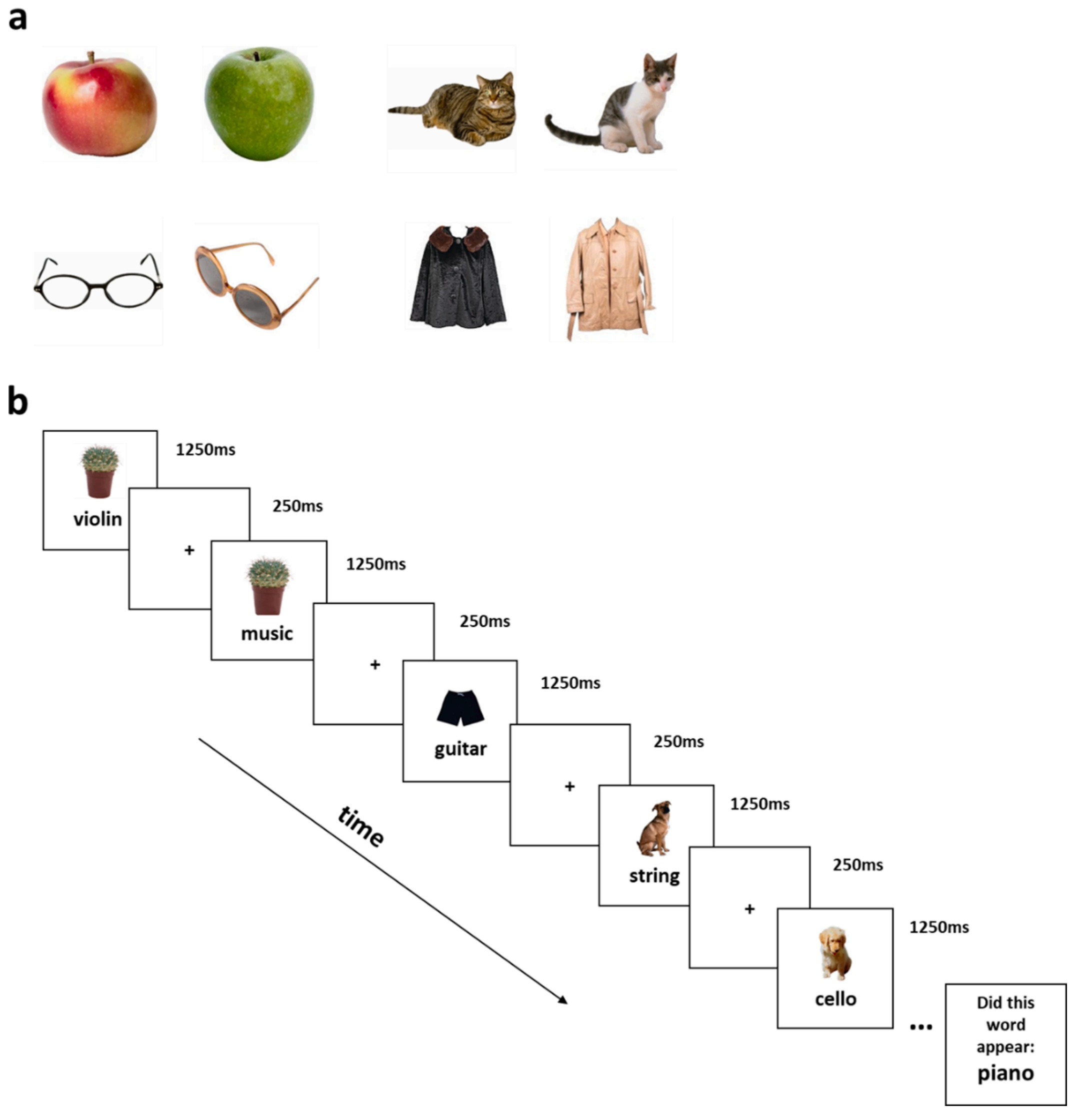

Fig. 4. Stimuli and experimental design of Exp. 3. a, Stimuli examples. The image stimuli consisted of mundane objects. The examples depict pairs of object exemplars which share a category but do not trigger a specific context. b, An array example. Words were presented below the images, and both were presented for 1250 ms in each trial, and followed by a 250 ms presentation of a cross. As in Exp. 1, following twelve trials, participants were shown one word and were asked to determine whether that word appeared as part of the array or not.

4.1.2. Design

In Exp. 3, a 1-back task was employed in which images of objects were presented one after the other (interleaved with fixation crosses) and participants were asked to determine as fast as possible with regards to every image whether it is identical to or different from the previously presented image. The task comprised three image conditions, such that images could be either identical to the previous image (i.e., same condition), completely different from the previous image (i.e., different condition) or a different exemplar of the image preceding them (i.e., similar condition). This was aimed to conduct the task in the most similar manner to the first two experiments, yet dissociate between experiments in the affordance of associative information.

In addition to the perceptual object task, participants' mindset was manipulated by the presentation of the word lists that were used in Exp. 1 and Exp. 2. Words in each list were sequentially presented, such that they appeared simultaneously and below the object images (see Fig. 4b). Participants were asked to attend the presented words in parallel to actively reporting their perceptual same/different decisions regarding the object images. As in Exp. 1, participants were asked to remember the words for a following memory recognition test. Similarly to Exp. 1, the experiment's design involved three conditions in the object perception task (i.e., same, similar and different) and three mindset conditions (i.e., associative, intermediate and unrelated). This experiment was identical to Exp. 1 in its design and procedure, with the exception that the images were objects, and the words were presented below the image.

4.2. Results

13 participants took part in the experiment (12 females, mean age = 19.46). This relatively small sample size is due to the outbreak of COVID-19 pandemic, which did not allow running further experimental sessions. One participant was excluded from analysis due to poor performance in the object perception task (below 2.5 std from the mean), therefore all further analysis was performed based on the data of the remaining 12 participants.

Memory analysis did not yield accuracy differences between the mindset conditions ($F(2,10) = 2.04$, $p > 0.09$), nor did it yield RT differences ($F(2,10) = 1.03$, $p > 0.19$).

Accuracy analysis of the object perception task revealed a main effect for images, such that accuracy in the task was the highest when images were completely different from the image preceding them (M = 0.96, SD = 0.008), compared with images in the same (M = 0.92, SD = 0.01) and similar image conditions (M = 0.93, SD = 0.01; $F(2,10) = 16.00$, $p < 0.001$, observed power = 0.99, $\eta_p^2 = 0.76$). This result replicates the result from Exp. 1.

Additionally, an interaction emerged between the mindset conditions and the order of blocks ($F(4,8) = 3.60$, $p < 0.035$, observed power = 0.66, $\eta_p^2 = 0.24$). This interaction shows the opposite of the findings in Exp. 1 and 2. Specifically, in the similar image condition accuracy increased over time under the unrelated mindset, and decreased under the narrow associative mindset (Fig. 5a). Subsequent pairwise comparison revealed that under the narrow mindset, in the similar image condition a significant difference is found between block 2 and block 3, where performance was worse in block 3 compared with block 2 ($p < 0.050$, corrected for multiple comparisons using Bonferroni correction).

RT analysis of the object perception task revealed a complementary result. First, a significant effect of image condition was found, such that RT in the similar image condition (M = 706 ms, SD = 24 ms) was significantly slower than RT in the same (M = 659 ms, SD = 26 ms) and different (M = 682 ms, SD = 23 ms) image conditions ($F(2,10) = 11.71$, $p < 0.002$, observed power = 0.96, $\eta_p^2 = 0.70$).

Additionally, an interaction emerged between the image conditions, the mindset conditions and the order of blocks ($F(4,8) = 3.36$, $p < 0.015$, observed power = 0.83, $\eta_p^2 = 0.23$). This interaction showed a double dissociation in an opposite trend from Exp. 1 and 2. Over time, RT was faster under the unrelated mindset, and slower under the associative mindset. As in Exp. 1, post-hoc analysis reveals that this interaction was significant in the different and in the similar image condition (Fig. 5b). Subsequent pairwise comparison analyses revealed that under the narrow mindset, in the similar image condition, performance was significantly slower in block 3 compared with block 2 ($p < 0.001$). In the different image conditions, performance in block 3 was significantly slower than block 1 ($p < 0.045$) and 2 ($p < 0.045$). Under the unrelated mindset however, in the similar image condition, performance in block 1 was significantly slower than performance in block 2 ($p < 0.016$) and 3 ($p < 0.008$). Similarly, in the different image conditions, performance in block 1 was significantly slower than block 2 ($p < 0.002$) and 3 ($p < 0.024$). All analyses were corrected for multiple comparisons using Bonferroni correction.

Exp. 3 shows that the positive effect of an associative mindset on perception depends on the associative affordance of the given perceptual process. Furthermore, when taking together the findings in all experiments, a double dissociation between the form of thought and the form of perception is revealed. Whereas scene perception is facilitated under an associative mindset (and hindered under an un-associative one), perception of objects with minimal associations benefit from a mindset that does not involve associative processing (and hindered by an associative one).

5. Inter-experiments follow-up analysis

All three experiments revealed an interaction between mindset and perceptual processing. To better evaluate whether these interactions are equivalent across experiments, we conducted a follow-up planned comparisons analysis which focused on RT difference in performance between the first and third block in every experiment.

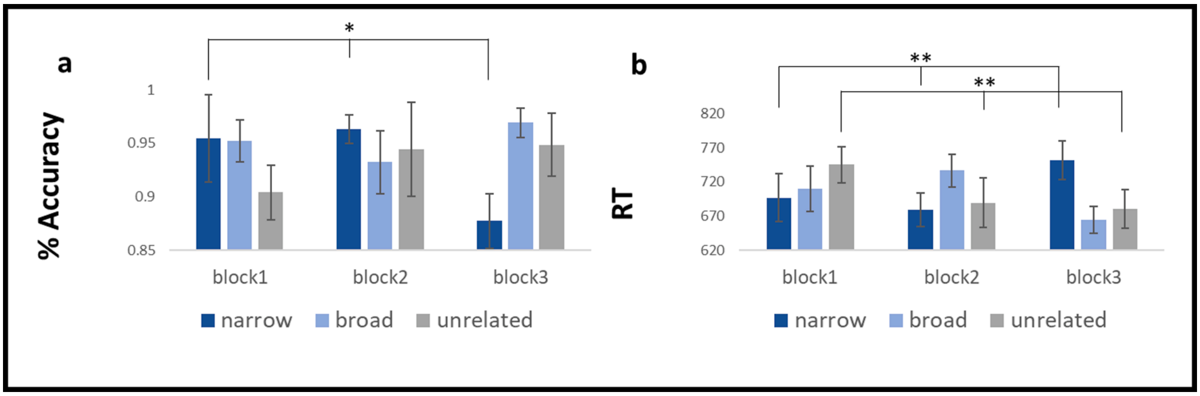

Fig. 5. Results of 'similar' image condition in Exp. 3. a, Accuracy. b, RT. Figures depict the interaction between mindset conditions (i.e., narrow, broad, and unrelated) and the order of blocks (first to last). Bars indicate standard error of the mean. Significant main effects are denoted by asterisks.

For each participant, we subtracted RT in the first block from RT in the third block for each the image and mindset conditions. A planned-comparison mixed ANOVA revealed a significant interaction between the influence of mindset on perceptual processing and the experiment ($F(4,122) = 8.43$, $p < 0.001$, observed power = 0.99, $\eta_p^2 = 0.21$), showing that while in Exp. 1 and 2 scene perception was enhanced over time under the narrow mindset and deteriorated under the unrelated mindset, in Exp. 3 object perception deteriorated under the narrow mindset and improved under the unrelated mindset (Fig. 6).

An additional triple interaction emerged, between the experiments, the mindset condition and the image condition ($F(8,116) = 4.30$, $p < 0.001$, observed power = 0.95, $\eta_p^2 = 0.12$). This interaction shows that the most significant difference between experiments stems from the narrow associative mindset and the similar image condition which involves associative processing to the greatest extent. This finding implies that the most significant difference between the experiments that involved scene perception (i.e., Exp. 1 and 2) and the experiment involving object perception (i.e., Exp. 3) was indeed the associative processing.

6. Discussion

6.1. An associative thought interacts with scene perception

Associative processes have been studied in the context of scene perception as well as in the context of different modes of thought. Nonetheless, despite being intertwined in everyday life, the possible interaction between associative processing in thought and perception has rarely been studied. Addressing this gap, we explored whether scene perception is influenced by the processing of an associative mindset occurring in parallel.

Exp. 1 showed that over time, an associative mindset facilitates scene perception. Exp. 2 replicated this result, and further excluded a memory-load based explanation. Critically, Exp. 3 showed that visual processing of isolated objects that do not elicit many contextual associations is hindered by an associative mindset, showing that an associative mindset selectively enhances associative-based scene perception.

The influence of mindset on perception has been demonstrated in the past, predominantly by means of priming, showing that the content of thoughts, memories and goals influence conscious perception (Brunyé et al., 2012; Radel & Clément-Guillotin,2012; Scorolli et al., 2009) and related perceptual decision-making (Bartholow & Heinz, 2006). These studies suggest that thought influences perception by providing a priming simulation of the content to be subsequently perceived (Hesslow,2002). Here, however, the content triggered by the mindset manipulation was not related to the content of the simultaneously presented scenes. Therefore content-related mechanisms such as priming or spreading activation cannot explain our findings. Instead, independent from priming of content, our findings suggest that the *form* of thought facilitates the *form* of perceptual processing; a cross-domain priming of the 'how' rather than the 'what'. This proposal pertains to the benefit in the match between the associative way in which thought and perception are structured. This is demonstrated in Exp. 1 & Exp. 2, in which participants were more receptive of scene-related information when thought was associatively oriented, and is further corroborated in Exp. 3, where participants were more receptive of un-associative

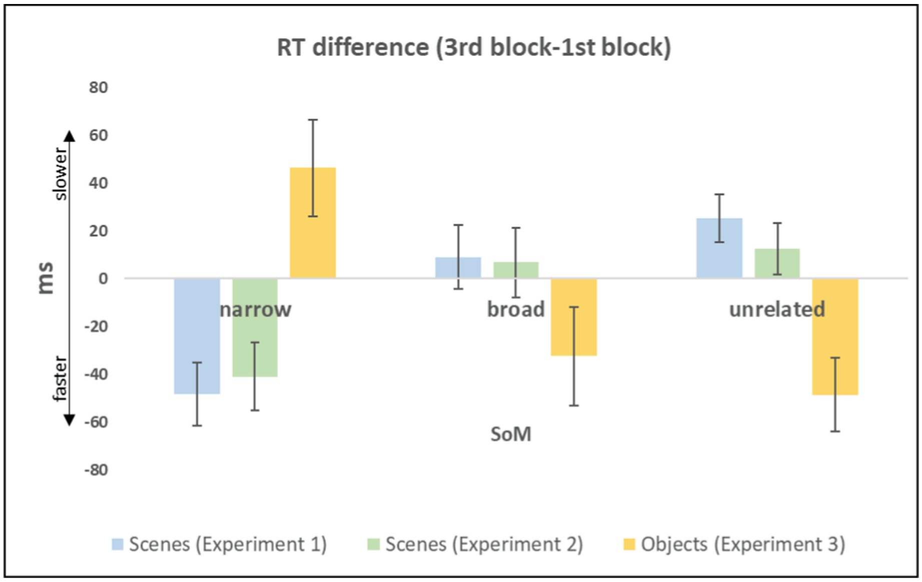

Fig. 6. Follow up analysis. Comparing Exp. 1,2,3 by the subtracting RT in the first block from RT in the third block in each experiment. A positive difference in ms depicts slower performance over time and a negative difference depict faster performance over time. An interaction is found between experiments and mindset conditions. Under the narrow mindset, Scene perception (Exp. 1 and 2) is facilitated and object perception (Exp. 3) is delayed. Complementarily, under the unrelated mindset scene perception is delayed and object perception is facilitated ($F(4,122) = 8.43$, $p < 0.001$). Bars indicate standard error of the mean. Significant differences are denoted by asterisks. The figure is collapsed across scene conditions.

perceptual information when thought was organized in an un-associative manner.

Our results relate to the Episodic Specificity Induction (ESI) line of work, which suggests that orienting one's thoughts towards recollecting episodic details from recent events, situates one to construct a following scene better and in greater detail (Madore et al., 2019). It is possible that the DRM lists manipulation employed in our studies, is akin to the ESI in orienting one's thoughts to elicit multiple associated details belonging to the same context. In turn, as ESI promotes scene processing via enhanced recollection of associated details in the scene construction task, the DRM associative mindset promotes scene perception via enhanced processing and recognition of associated details in the scene task employed here. Although using somewhat different terminologies, both manipulations seem to promote scene perception through enhancing the perception/construction of associative details in one's mindset. Such mindset-based enhancement of perceptual processing corroborates other findings in the realm of memory as well, showing that one's mental state influences recollection of learned perceptual associations (Patil and Duncan, 2018).

Our findings in all three experiments point to a time-dependent influence of the associative mindset on scene perception, gradually evolving as the experiment extends from block to block. This suggests that the benefit of similarly orientated modes of cognition, in this case mindset and perception, may be evident after a delay. Such a delayed effect resembles findings in other paradigms (e.g., implicit learning (Jiang & Chun, 2001; Chun & Jiang, 2003) or sequence learning (Tal & Vakil, 2020) in which the association between events is not explicitly instructed. In addition, the time scale of the effect is in line with the episodic specificity induction literature, in which the manipulation over one's mental state precedes the task of interest by several minutes. In our study, the delay may reflect time needed to utilize the congruent orientation across the different modes of cognition. It should also be noted that our design did not have sufficient power to systematically probe the possible interactions between scene perception and mindset within a block, and changes from list to list. Whether an associative mindset can influence associative-based perception at the scales of seconds remains an open question for future research.

Our findings contribute to understanding how mindset interacts with perceptual processing, as they are manipulated in parallel in our designs. Nevertheless, it would be of importance to further examine how our findings generalize to more ecologically valid settings, in which scene perception takes place in parallel to natural, ongoing thought such as mind-wandering, rather than an artificially-induced mindset as is done here.

In all three studies, we did not find an influence of the manipulated 'broad' condition on scene perception. This condition involved strong associative processing between consecutive pairs of words at the local level, but unlike in the narrow condition, at the global, list-level, it elicited multiple unrelated contexts instead of a rich unified context. Considering our results, it remains an open question whether and how this combination of elements – strongly associative locally (in the consecutive pairs) but globally (list-level) un-associated – influenced perception. While we did not find any observable effect, it is possible that a local-level associative facilitation was cancelled out by the lack of global associativity. Future studies that specifically probe one's attention in this complex condition may shed more light on the magnitude of associative processing involved.

6.2. Associative thought and scene perception possibly share an associative mechanism

Our findings point to the idea that scene perception and mindset may share a common associative mechanism. A good candidate for such a neural system that may sustain the brain's associative mode is activity in the Default Mode Network (DMN), a neural network that underlies associative, spontaneous cognition (Christoff et al., 2016; Mason et al., 2007; Raichle et al., 2001). The DMN overlaps with the Contextual Associations Network, which was found to uniquely underlie the processing of visual contextual associations (Diana et al., 2012; Rauchs et al., 2008), most predominantly found in conjunction with scene processing (Bar & Aminoff, 2003). This set of brain regions, which is referred to as the DMN in the thought literature, and as the Contextual Associations Network in the perception literature, has been suggested to centralize around a shared, domain-independent function, of proactively processing associative information (Aminoff, Gronau, & Bar, 2007; Stawarczyk, Bezdek, & Zacks, 2021). Our studies provide empirical evidence for such a domain-general associative mechanism. In interpreting our results, it is possible that an associative mindset, which activates the DMN, interacts with scene processing, which elicits associations of the perceptual input.

Furthermore, if this interpretation is correct, then our findings elucidate ongoing discussions regarding the relationship between the DMN and task-related processing. Some accounts have previously conceptualized the DMN's functional significance as sustaining task-unrelated thought, building upon observed DMN deactivation when engaged in demanding perceptual tasks (Smallwood and Schooler, 2006). Nevertheless, most of these visual tasks did not involve associative processing (Aminoff et al., 2007). Therefore, rather than exemplifying a tension between external and internal processes, these accounts may have been confounded by differences in associative affordance, namely, involving rich associative processes in the thought domain, and minimizing associative processes in the perceptual domain. Here we show that associative thought, possibly driven by DMN activity, facilitates rather than contradicts task-related perceptual performance when both processes are compatible in terms of their associative processing mode, supporting DMN accounts that highlight its primary role in processing associations, independent from how they are triggered (Baror et al., 2021).

6.3. Open questions

Taking our studies together, some open questions remain. First, the stimuli were presented for long durations (>1000 ms). How much was this a factor in yielding the results remains unknown. Does extensive processing of a scene need to occur to see an effect of associative thought, or is the initial rapid processing of a scene vulnerable to the effects of interdependence in mindset? Future studies (e.g., using EEG) should investigate whether the effect we found is occurring at early phases of scene processing (~200 ms, e.g., Harel et al., 2016); or affecting later processing stages of scene processing (e.g., Bastin et al., 2013). In addition, future studies should parametrically adjust stimulus presentation duration to see if extensive viewing of a scene is required for the effect to occur. Associative processing of objects was found to occur as early as 150 ms (Kveraga et al., 2011) and thus, we may predict the effect of this interdependence to modulate an initial, early – stage process of scene perception. However associative processing has shown to modulate scene processing in later stages as well (Võ & Wolfe, 2013) and the interdependence of the mindset effect may be salient at late processing as well. Secondly, with regards to the third experiment, beyond manipulating objects instead of scenes, this experiment was not identical to the first two experiments in that the words were presented below the object image rather than superimposed on it, therefore we cannot rule out the possibility that the opposite pattern of findings observed in the third experiment may have also resulted from this difference in design. While we cannot fully address these caveats in the current design, we propose that both of these points can be addressed by implementing eye-tracking and neuroimaging methods to similar designs in the future. Tracking one's eye movements during scene or object perception while their mindset is manipulated may shed light, both on the trajectory of attention to associations between elements in the scene, as well as to the attentional division between the words and the images.

Another key question that remains open is the one of differences in temporal dynamics between the thought and perception domains. While perceptual and mindset-related associative processes are suggested to engage a shared mechanism, the time-course of their engagement may nonetheless be different from one another. Scene perception relies on immediate associations that are triggered by the stimulus, at a timescale of milliseconds (Harel et al., 2016). Associative processing in thought, however, is assumed to result from the 'mental train of thought'; the representation of consecutive associated events (Dorsch, 2015), which dictates a slower temporal course of engagement unfolding over at least several seconds (Pelagatti et al., 2020). Our results exemplify this temporal distinction, as the enhancement of scene processing by an associative mindset evolved over the course of the experiments. Further research is required to understand how the gradually evolving mental associative process informs the immediate perceptual one. One method for mitigating this challenge in temporal discrepancies is using electroencephalogram (EEG) recordings which permits both the observation of rapid event related potentials (ERP) as well as measuring oscillations over longer timeframes. EEG studies show that scene perception is tied with the P200 ERP component (Harel et al., 2016) and that changes in alpha power recorded over seconds, are implicated with spontaneous thought (Dorsch, 2015) and with DMN activity (Compton et al., 2019; Knyazev et al., 2011). It is possible that changes in alpha oscillations that result from inhabiting an associative mindset, provide an internal neural state which then shapes the more local P200 scene-related ERP. Similarly, conducting fMRI studies in mixed block/event related designs (Petersen & Dubis, 2012; Visscher et al., 2003) may provide another effective tool for jointly studying transient changes in associative based scene perception and sustained activity related to associative mindset.

6.4. Concluding remarks

Almost every human experience involves both thought and perception, yet the nature of their interaction is poorly understood. Our studies show that perceptual task performance is enhanced when one's thought-related mode of processing is in accordance. In specific, we found that the associative affordance of the perceptual process at hand was facilitated with an associative mode of thought, and point in the direction of a domain-general associative mechanism, possibly sustained by DMN activity. Our work calls to study cognitive and perceptual functions under a unified framework, similarly to how they are intertwined in our undivided brain.

CRediT authorship contribution statement

Shira Baror: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **Moshe Bar:** Conceptualization, Writing - original draft. **Elissa Aminoff:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Supervision, Writing - orginal draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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