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Running Head: PERCEPTION & REFLECTION

Some Thoughts on the Interaction between Perception and Reflection

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Over its history, experimental research on human cognition has exhibited an interesting tension between realism and constructivism (Johnson, 1983). Realism focuses on memories (traces) of events as we perceive them. Trace strength is a function of frequency and recency of experience, and connections (associations) reflect a relatively automatic sensitivity to temporal and spatial contiguity between events. Constructivism assumes that initial perceptual products decay rapidly and emphasizes recoded representations of events (e.g., images, ideas, propositions) that are informed, and sometimes tainted, by our knowledge, beliefs, and desires. These ideas, classically instantiated in the work of Ebbinghaus (1885/1964) on the one hand and Bartlett (1932) on the other, have often been depicted as being in direct opposition. However, they can be reconciled by assuming a cognitive architecture composed of multiple, interacting, memory systems consisting of processes that serve different functions.

For example, within the multiple-entry, modular (MEM) framework (Johnson, 1983; Johnson & Hirst, 1993), cognition is carried out by subsystems of perceptual and reflective processes (see Figure 1). Perceptual processes occur in direct response to external stimuli; reflective processes can occur in the absence of external stimuli. The different component processes of these subsystems are recruited in different combinations depending on the current cognitive agenda. Both perceptual and reflective processes result in changes (i.e., "records") in their respective systems—long-term changes that constitute memory. From this perspective, we would not necessarily expect the observed content of memory to be constant across different tasks used to assess memory because different tasks represent the operation of different combinations of component processes. For example, we might see evidence of highly veridical memory for perceptual information under some circumstances (e.g., Craik & Kirsner, 1974; Hintzman & Summers, 1973), and evidence of memory distortions (e.g., intrusions of associated or inferred information) under others (e.g., Deese, 1959; Johnson, Bransford & Solomon, 1973; Loftus & Palmer, 1974). Of course, perception itself can be constructive in that what we see can be affected by expectations (Hochberg, 1978; Neisser, 1967). Reflection, though it can lead to memory errors, can produce accurate memory as well, as when organizational and comprehension processes dramatically increase recall (e.g., Bower, 1972; Bransford & Johnson, 1973; Mandler, 1967; Tulving, 1968). Thus, accuracy and errors alone do not reveal the processes engaged in establishing (and later reviving) memory records (Johnson, 2006).

Here we first briefly review some of the evidence about the characteristics of perceptual representations, highlighting Musen and Treisman's (1990) important study demonstrating long-term perceptual memory. We then consider recent studies from our lab that focus on the interaction of perceptual and reflective processes. We examine how reflective processing of a representation influences later perceptual processing, and how perceptual memory influences later reflective processing.

Although the correspondence is not perfect by any means, the contributions of perceptual processes to memory largely have been explored using implicit tests (e.g., priming, transfer, Hamann & Squire, 1997; Schacter, 1992), and the contributions of reflective processes to memory largely have been explored using explicit tests (e.g., recall, recognition, Hunt & McDaniel, 1993; source memory, reality monitoring, Johnson, 2006; Lindsay, 2008; Mitchell & Johnson, 2009). Investigators have often emphasized the independence of the memory systems associated with implicit and explicit memory, although it is questionable whether implicit and explicit *tasks* directly correspond to different subsystems of memory, and strict criteria of independence are rarely satisfied (Roediger, Rajaram, & Srinivas, 1990; Sherry & Schacter, 1987). Rather, it is more likely that implicit and explicit tasks differentially call upon specific component processes that may be organized (at least conceptually) into subsystems of memory (e.g., Johnson, 1983; Johnson & Hirst, 1993; Moscovitch, 1992; Roediger, Buckner, & McDermott, 1999). Furthermore, from the perspective of a component process approach, mechanisms of interaction between subsystems are as interesting as potential dissociations between subsystems (e.g., Johnson & Reeder, 1997).

Exploring the nature of perceptual representations

Implicit tests do not require participants to explicitly attribute particular events to the past; they assess whether prior exposure to a stimulus in the experimental setting influences later processing of the same or a related stimulus (e.g., during a perceptual identification or lexical decision task). When there is a positive effect for the same stimulus (i.e., faster or more accurate performance) the phenomenon is known as "repetition priming" (e.g., Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993; Tulving & Schacter, 1990; Wiggs & Martin, 1998). Studies of implicit memory have generated a great deal of information about the nature of perceptual representations. For example, Jacoby and Dallas (1981) showed that a brief (1 sec) exposure to a word during study resulted in more accurate perceptual identification of the word when it was briefly flashed later during the test phase. Repetition priming has resulted in superior performance across various tasks (word identification, Alexander & Reinitz, 2000; Jacoby & Dallas, 1981; Murrell & Morton, 1974; lexical decision, Forback, Stanners, &

Hochhaus, 1974; Grant & Logan, 1993; Scarborough, Gerard, & Cortese, 1979; word stem completion, Bassili, Smith, & MacLeod, 1989; Roediger, Weldon, Stadler, & Riegler, 1992; word fragment completion, Challis & Brodbeck, 1992; Roediger et al., 1992; Sloman, Hayman, Ohta, Law, & Tulving, 1988; Tulving, Schacter, & Stark, 1982; picture naming, Durso & Johnson, 1979; picture identification, Warren & Morton, 1982; picture fragment identification, Mitchell, 2006; sound identification, Chiu, 2000; visual search, Maljkovic, & Nakayama, 1994), and repetition priming occurs for various types of stimuli including visually presented words (Alexander & Reinitz, 2000; Jacoby & Dallas, 1981; Murrell & Morton, 1974), word-pairs (Goshen-Gottstein & Moscovitch, 1995), non-words (Butler, Berry, & Helman, 2004; Kirsner & Smith, 1974; Scarborough, Cortese, & Scarborough, 1977), faces (Bruce, Carson, Burton, & Kelly, 1998; Bruce & Valentine, 1985; Ellis, Young, Flude, & Hay, 1987), scenes (Yi, Turk-Browne, Chun, & Johnson, 2008), pictures of familiar objects (Bartram, 1974; Cave, 1997; Durso & Johnson, 1979), novel objects or patterns (DeSchepper & Treisman, 1996; Gabrieli, Milberg, Keane, & Corkin, 1990; Musen & Treisman, 1990; Schacter, Cooper, & Delaney, 1990), and for auditory words (Bassili et al., 1989; Jackson & Morton, 1984) and sounds (Chiu, 2000). One of the most striking features of repetition priming is that, despite relatively brief study exposure, effects can last days (Roediger et al., 1992), weeks (DeSchepper & Treisman, 1996; Musen & Treisman, 1990), months (Cave, 1997; Grant & Logan, 1993; Sloman et al., 1988), and even years (Mitchell, 2006) from the original encounter and across multiple intervening items (DeSchepper & Treisman, 1996; Musen & Treisman, 1990; Yi et al., 2008).

An early, systematic, and influential investigation of the characteristics of perceptual memory was a study by Musen and Treisman (1990). It came at a time when interest in implicit memory had received a boost not only from studies of healthy young adults (e.g., Jacoby & Dallas, 1981), but also from demonstrations of implicit memory in individuals with profound amnesia on explicit tests (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Graf, Squire, & Mandler, 1984; Warrington & Weiskrantz, 1982). Most of this previous work used stimuli such as words for which there would likely be pre-existing representations (e.g., Jacoby & Dallas, 1981) or unfamiliar pictures of objects that could easily be named (e.g., Durso & Johnson, 1979). Musen and Treisman used novel line patterns. Participants studied visual patterns (either once or multiple times) constructed from 5 connecting lines joining dots in a 3 x 3 matrix (see Figure 2). On an implicit memory test, studied and new patterns were briefly flashed one at a time and then masked and participants were asked to draw each pattern. Drawing accuracy was better for previously seen than new patterns (perceptual priming), and the advantage for previously seen items was at almost the same level for patterns seen once during the study session as for those seen multiple times. This perceptual priming effect showed little or no decrease across a range of delays up to as long as one month. In contrast, on a test of explicit memory (4-alternative forced-choice recognition), recognition for studied patterns benefited from repeated study exposures, and decreased significantly across the various delays. Finally, for any particular item, implicit and explicit memory showed stochastic independence. In short, Musen and Treisman demonstrated a case of rapid and long-lasting implicit memory for novel visual patterns that was independent of whether participants showed explicit recognition of having seen the visual patterns before. Such findings, implying that long-term memory records are a general consequence of perception, fit well with the idea of multiple memory systems, especially models positing perceptual subsystems (e.g., Johnson, 1983; Tulving & Schacter, 1990).

Given how rapidly such representations can be formed, one might expect them to lack detail. In fact, perceptual representations of briefly presented stimuli can be highly specific (for reviews, see Ochsner, Chiu, & Schacter, 1994; Wiggs & Martin, 1998), as evidenced by greater priming for a repeated item that is more similar perceptually to the original. Greater priming is observed when study and test items are presented in the same modality (i.e., both perceptually and semantically similar) versus in a different modality (i.e., semantically but not perceptually similar). For example, greater priming has been observed for visually presented test items that were previously experienced visually compared to auditorially (e.g., Bassili et al., 1989; Blaxton, 1989; Challis et al., 1993; Challis & Sidhu, 1993) and vice verse for auditory test items (Bassili et al., 1989; Jackson & Morton, 1984). Within modality, priming tends to be greater when the study and test items are in the same format. For example, Roediger et al. (1992) found greater priming on a word completion task for items previously presented as seen words than as pictures. Similarly, greater priming occurs for picture fragment naming (Srinivas, 1993; Weldon & Roediger, 1987) and picture naming (Durso & Johnson, 1979; Warren & Morton, 1982) when the items have previously been presented as pictures than as words (but see Brown, Neblett, Jones, & Mitchell, 1991).

Within the same format, priming is greater when participants are tested on the same exemplar than a different exemplar from the same category (e.g., for objects, Cave, Bost, & Cobb, 1996; for sounds, Chiu, 2000, but see Stuart & Jones, 1995). Even when the same exemplar is presented at test, priming can be sensitive to physical changes in the stimulus. For visually presented words, changes in typography (Graf & Ryan, 1990; Jacoby & Hayman, 1987; Kinoshita & Wayland, 1993; Wiggs & Martin, 1994) can reduce priming. Whether representations are specific to letter case is unclear; some studies have shown no effect of letter case on the magnitude of priming for words (Bowers, 1996), while others have shown that, under certain conditions, changes in letter-case reduce the amount of priming observed (e.g., words tested in lower case letters, Jacoby & Hayman, 1987, or words presented to the right hemisphere, Burgund & Marsolek, 1997; Marsolek, 2004). For familiar objects, changes in surface contours (Srinivas, 1993) and viewpoint orientation (Burgund & Marsolek, 2000; Murray, Jolicoeur, McMullen, & Ingleton, 1993; Srinivas, 1993) reduce priming. Repetition priming for faces has also been shown to be sensitive to viewpoint (Bruce et al., 1998).

Neuroimaging studies have demonstrated that certain brain areas generally show a decrease in neural signal for repeated compared to novel stimuli (e.g., Desimone, 1996; Grill-Spector et al., 1999; Squire et al., 1992). This decrease is known as “repetition attenuation” (also called “repetition suppression” or “neural adaptation”) and is thought to be the neural correlate of repetition priming (for reviews, see Grill-Spector, Henson, & Martin, 2006; Henson, 2003; Wiggs & Martin, 1998). The cause of this attenuation of neural activity is still a matter of some debate. One possibility is that repeated exposure to the same stimulus results in a pruning or sharpening of that stimulus' representation in cortex (Desimone, 1996; Wiggs & Martin, 1998). Neurons not essential to the coding of the stimulus drop out (are “pruned”), resulting in fewer neurons firing in response to the stimulus when it is presented again. Hence, while the selectivity of the neural response increases, its overall level of activation decreases.

In any case, repetition attenuation can be taken as an index of the type of information represented in a brain area (e.g., Grill-Spector et al., 1999; James, Humphrey, Gati, Menon, & Goodale, 2002; Park & Chun, 2009; Park, Chun & Johnson, in press; Vuilleumier, Henson, Driver, & Dolan, 2002; for reviews, see Grill-Spector et al., 2006; Schacter, Dobbins, & Schnyer, 2004). For example, while the magnitude of behavioral repetition priming is often preserved across changes in stimulus size (e.g., Biederman & Cooper, 1992), Grill-Spector et al. (1999) found that repetition attenuation in posterior lateral occipital cortex, an area associated with perceptual processing of objects, was sensitive to changes in object size. Different regions show sensitivity to various object features including object viewpoint (anterior and posterior lateral occipital cortex, Grill-Spector et al., 1999; caudal intraparietal sulcus, James et al., 2002; regions in right fusiform, parietal, and occipital cortex, Vuilleumier et al., 2002), and object illumination (anterior and posterior lateral occipital cortex, Grill-Spector et al., 1999). Studies have also shown neural sensitivity to changes in object exemplar (in fusiform cortex, Koutstaal et al., 2001; Vuilleumier et al., 2002) and to the boundary of a scene layout (parahippocampal place area and retrosplenial cortex, Park, Intraub, Yi, Widders, & Chun, 2007). Similar effects have been found in a posterior region associated with face processing (fusiform face area, Kanwisher, McDermott, Chun, 1997; McCarthy, Puce, Gore & Allison, 1997). Activity in this region is sensitive to viewpoint changes of familiar (Davis-Thompson, Gouws, & Andrews, 2009) and unfamiliar (Davies-Thompson et al., 2009; Ewbank & Andrews, 2008) faces. Similar to the behavioral phenomenon of repetition priming, repetition attenuation can be long-lasting (e.g., evident at three days, van Turennout, Ellmore, & Martin, 2000).

To summarize, representations of the perceptual details of even a brief stimulus can be rapidly formed, long-lasting, robust to interference from intervening stimuli, and demonstrate high specificity on both the neural and behavioral level.

Exploring the interaction of perceptual and reflective processes

Although a great deal of emphasis has been given to dissociations between memory subsystems subserving explicit memories arising from reflective processes and implicit memories arising from perceptual processes, recent studies in our lab show interactions of reflective and perceptual processing as would be expected according to the MEM model (Johnson, 1983; Johnson & Hirst, 1993). We start by describing the basic reflective component process of *refreshing,* which involves briefly thinking of (i.e., directing reflective attention to) the still active representation of a just-experienced event. We show how this simple process acts to provide top-down modulation of posterior brain areas and influences subsequent perceptual processing. Then we discuss how perceptual memory can influence the outcome of reflective processing, in this case, episodic memory attributions.

Refreshing acts to select a mental representation of a recent thought or percept from among multiple recent thoughts or percepts—it is a type of reflective attention analogous to perceptual selection of an external target stimulus from among perceptually present distractors. Refreshing a representation foregrounds or privileges it relative to other representations that are also currently active (Johnson et al., 2005; Raye, Johnson, Mitchell, Greene, & Johnson, 2007). Although a relatively simple process, refreshing has been shown to have long-term memory benefits. For example, refreshing a just-seen word results in better long-term memory than perceiving the word a second time (Johnson, Reeder, Raye, & Mitchell, 2002). In addition, refreshing functions as a top-down process that modulates neural activity in areas associated with perceptual processing of visual stimuli (M. R. Johnson, Mitchell, Raye, D'Esposito, & M. K. Johnson, 2007). For example, M. R. Johnson et al. presented participants with two pictures, a picture of a scene and a picture of a face, shown simultaneously, side by side (see Figure 3a). Next participants were shown one of the pictures a second time or they were cued by a dot on the left or right to think of (i.e., *refresh*) the picture that had just been in that location. In addition to prefrontal activation associated with refreshing (Raye, Johnson, Mitchell, Reeder, & Greene, 2002), as shown in Figure 3b (see also M.R. Johnson & M.K. Johnson, 2009) refreshing a scene resulted in modulation of a posterior, category-sensitive brain area associated with perceptually processing scenes (parahippocampal place area, Epstein & Kanwisher, 1998).

Refreshing can influence later perceptual processing of the refreshed stimulus. Yi et al. (2008) showed that refreshing a visual scene affects subsequent perception of the scene. Immediately after viewing a scene, participants thought of the scene (refresh), then saw the scene a second time (repeat), or were presented with a new scene. Later in the session, Yi et al. measured neural activity when participants saw the original scene again. They found repetition attenuation (i.e., reduced activity for previously viewed vs. novel scenes) for refreshed as well as repeated scenes in the parahippocampal place area. Additionally, the magnitude of repetition attenuation was similar for refreshed and repeated scenes.

Given that refreshing foregrounds or privileges one representation over others that are also active, what effect, if any, does reflective attention have on subsequent perception of nonselected items? Higgins and Johnson (2009) showed that refreshing a target item reduces the accessibility of distractors that were present at the time of refreshing. Participants saw a set of three words, and then either saw and read aloud one of the words again, or were given a location cue to think of and say aloud (i.e., refresh) the word that had just appeared in that location (Task 1). During Task 2, participants saw the set of words a second time, and then either saw and read aloud one of the nonselected items from Task 1 or saw and read aloud a new word. Hence, we examined the accessibility of a Task 1 distractor (as reflected in response times on Task 2) as a function of whether the Task 1 target was processed perceptually or reflectively (see Figure 4a). Response times to read one of the Task 1 distractors were slower if the Task 1 target had been refreshed than if the Task 1 target had been read a second time (see Figure 4b). In contrast, response times to read a new word on Task 2 were not influenced by the type of processing that occurred on Task 1. Hence, a brief act of reflective attention reduced the accessibility of the nonselected items during subsequent perceptual processing of these items.

Taken together, our studies suggest that refreshing, a basic reflective process, is one mechanism by which the perceptual and reflective systems interact. Refreshing a stimulus can positively (Yi et al., 2008) and negatively (Higgins and Johnson, 2009) influence subsequent perceptual processing of selected and nonselected stimuli, respectively. The neural substrate of this interaction likely involves top-down modulation of some of the brain areas recruited during perception of the stimulus (M. R.

Johnson et al., 2007; M. R. Johnson & M. K. Johnson, 2009). An important open question is whether the performance of a selective reflective act during processing is necessary for such facilitation or impairment to occur? For example, would other reflective processes such as noting differences among multiple items have similar effects as reflectively selecting an item over others for further processing?

Finally, we consider how perceptual representations may influence not only implicit but also explicit measures of memory. Musen and Treisman (1990) demonstrated that despite the robustness of perceptual memory, we may not have conscious access to these representations. That is, they found perceptual representations can influence performance implicitly even when we fail to explicitly recognize the same information. Studies in our lab have shown that a perceptual representation of one event can implicitly influence memory for another event that is accessed explicitly (Lyle & Johnson, 2006, 2007). For example, perceptual representations that are inadvertently activated can contribute to false memories (Lyle & Johnson, 2006). Participants viewed drawings of some objects and imagined drawings of other objects in response to a label (see Figure 5). Perceived objects were presented on screen in different locations (or colors in another experiment). Labels for imagined objects were always presented in the center of the screen in black and white. During a later memory test which included labels only, participants reported whether they had perceived or imagined the object and, if they had reported perceiving it, in which location/color they had seen it. Participants were more likely to falsely remember an imagined item as having been perceived if it was perceptually similar to a perceived item (e.g., a *lollipop* was imagined and a *magnifying glass* was perceived) than when they were not (e.g., a *feather* was imagined and a *belt* was perceived). This suggests that when retrieving information about an imagined event (i.e., imagining the *lollipop*), perceptual information (e.g., shape) from a similar event (perceiving the *magnifying glass*) can become inadvertently activated (see also Henkel & Franklin, 1998; Henkel, Johnson, & De Leonardis, 1998). Because real events are associated with having more perceptual detail than imagined ones (Johnson, 2006; Johnson & Raye, 1981), inadvertently activated perceptual detail makes imagined events more likely to be judged as having been perceived. Additionally, participants were more confident in their false memories for similar items compared to control items, and were more likely to attribute the associated contextual detail (i.e., location or color) of the similar perceived object to the imagined item. Presumably, perceptual details (i.e., shape, location, color, etc.) about the perceived event are bound together and when retrieval of the imagined event activates shared perceptual detail (e.g., shape) other information bound to shape information is also activated and attributed to the imagined event. This array of perceptual detail that is misattributed to the imagined item increases one's confidence that the item was in fact perceived. Hence, stored perceptual representations of a non-target event that become implicitly activated during cognitive processing can contribute to phenomenal experience of a target event, influencing the outcome of explicit memory attributions.

Summary

Musen and Treisman’s (1990) study was influential in beginning to characterize a perceptual memory system that can rapidly learn novel stimuli and that contains robust representations that are long-lasting, surviving up to several weeks and across many intervening items. Subsequent studies have shown that perceptual memory can facilitate both the speed and accuracy of later processing involving the original stimulus and is reflected in reductions in the amount of neural activity required when the original stimulus is perceived again. Perceptual representations can be highly specific, having their greatest effect when the exact stimulus is encountered again.

While perceptual memory may be phylogenetically primitive, relatively automatic, and functionally dissociable from more reflectively-generated memory (e.g., Johnson & Hirst, 1993; Sherry & Schacter, 1987), a crucial feature of human cognition is that perceptual and reflective processes interact (Johnson, 1983). Recent findings from our lab show that even a brief act of reflective attention to a currently active perceptual representation results in activation of brain areas associated with perception of the original stimulus (M. R. Johnson et al., 2007) and has a facilitatory effect on subsequent processing that can be similar to having perceived the item a second time (Yi et al., 2008). At the same time, when multiple perceptual representations are currently active, reflective attention towards one item impairs subsequent perceptual processing of the other items (Higgins & Johnson, 2009). When perceptual representations become active inadvertently, they can implicitly influence episodic (source) attributions resulting in false memories and enhanced confidence in those false memories (Lyle & Johnson, 2006).

Although there is much evidence for both realism and constructivism in human cognition, our understanding of exactly how they are instantiated in the human cognitive system is incomplete. The idea of interactions between bottom-up and top-down process is not new (e.g., Bruner & Postman, 1949; Neisser, 1967), but there is still much to learn about specific mechanisms of, constraints on, and memorial consequences of, interactions between perception and reflection.

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Figure Captions

Figure 1. A multiple-entry, modular memory (MEM) system that includes two reflective subsystems (R-1 and R-2) and two perceptual subsystems (P-1 and P-2), each composed of component processes of cognition (e.g., *refreshing*, *rehearsing,* and *retrieving* are reflective processes and *locating, tracking,* and *identifying* are perceptual processes) and representations (records) they act upon. Interactions between perceptual and reflective levels occur when processes and representations are recruited by active *agendas* (virtual "executives" or "supervisors") as represented by the cones intersecting the subsystems. Figure adapted from Johnson and Hirst (1993).

Figure 2. Sample of novel line pattern stimuli used in Musen and Treisman (1990). Participants were more accurate at drawing patterns that were briefly flashed and then masked if the patterns had been previously seen, indicating perceptual priming.

Figure 3. (a) Sample repeat and refresh trials from M.R. Johnson et al. (2007). (b[i]) Parahippocampal place area (PPA) shown for a representative participant. (b[ii]) Activation estimates are plotted for the two Refresh conditions. Error bars represent standard error of the mean. After identical perceptual (bottom-up) stimulation, activity in bilateral PPA was greater for refreshing a scene than for refreshing a face.

Figure 4. (a) Sample trials from Higgins and Johnson (2009) Experiment 2. Participants read aloud three words and then either saw and read aloud one of the items presented again (Task 1 Repeat), or were cued with a dot to refresh one of the items (Task 1 Refresh). Then participants saw and read aloud the word set a second time, after which they either read another item from the set (Task 2 Repeat) or read a new word (Task 2

Read). [*Note*. To equate target items across the tasks, a filler word was substituted for one word in the three-word set for trials in which Task 2 was a Read.] (b) Response times on Task 2 (Diff = mean increase in RTs on Task 2 having refreshed vs. repeated on Task 1). Refreshing a target item reduced accessibility of the non-selected items when they later became the targets of perceptual processing (i.e., Task 2 Repeat trials).

Figure 5. Sample study stimuli from Lyle and Johnson (2006). On Perceive trials, participants saw a line drawing of an object with its associated label. Perceived objects could appear in one of four locations on the screen (Experiment 1A), or in one of four colors (Experiment 2). On Imagine trials, participants saw an object label in the center of the screen and imagined a line drawing of the object. Imagined items were either perceptually similar or dissimilar to an item perceived during the study session. For example, for perceptually similar items, participants saw a magnifying glass (above left), and imagined a lollipop, while for perceptually dissimilar items, participants saw a belt (above right), and imagined a feather. On a subsequent memory test, participants were more likely to misremember an imagined item as having been perceived if it was perceptually similar to a perceived item, and more likely to attribute features (location, color) of the similar perceived item to the imagined item.

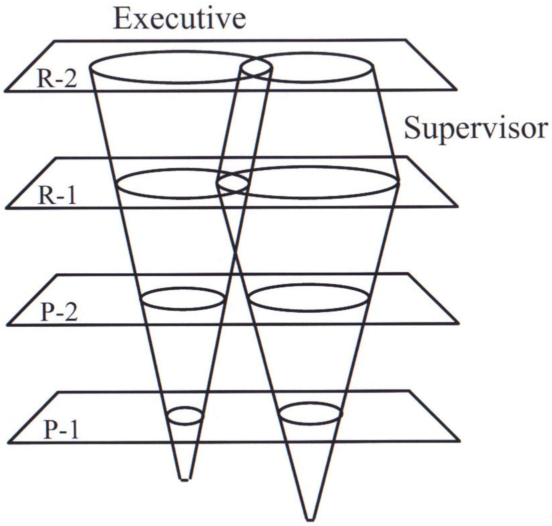


Figure 1.

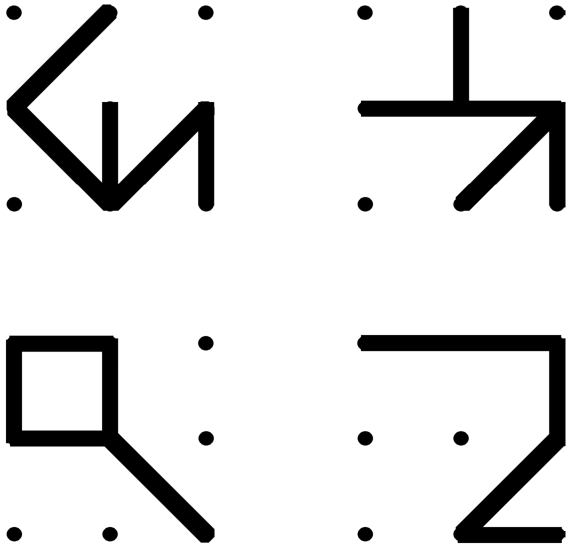


Figure 2.

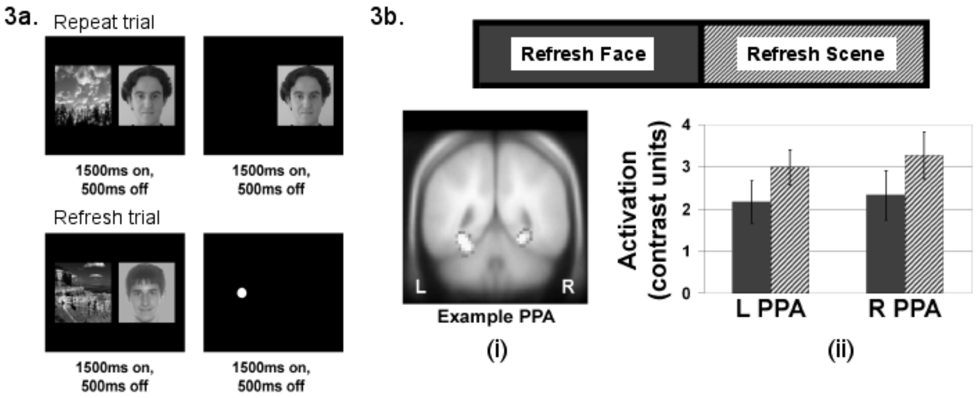
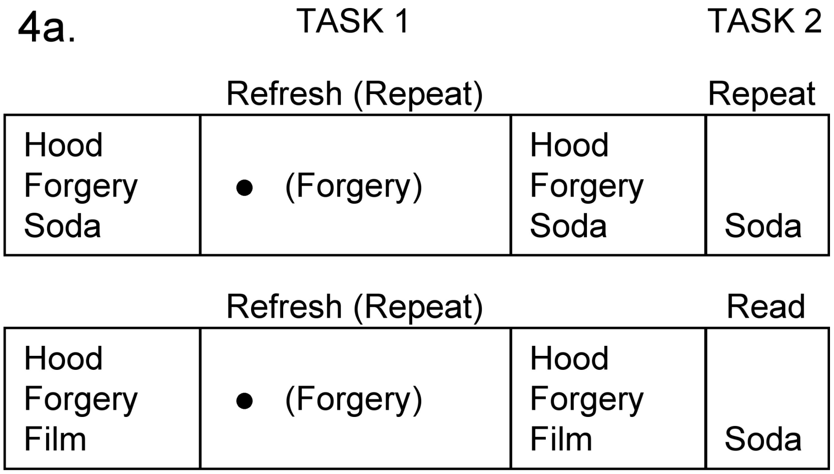

3a.
Repeat trial
1500ms on,
500ms off
1500ms on,
500ms off
Refresh trial
1500ms on,
500ms off
1500ms on,
500ms off
3b.
Refresh Face
Refresh Scene
L
R
Example PPA
(i)
Activation
(contrast units)
0
1
2
3
4
L PPA
R PPA
(ii)

Figure 3.

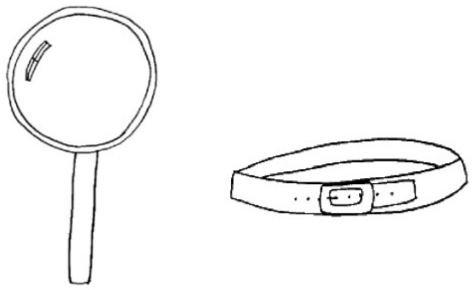
4a.



4b.

		TASK 1		
		Refresh	Repeat	Diff
TASK 2	Repeat	599	584	15
	Read	677	674	3

Figure 4.



MAGNIFYING GLASS

BELT

Figure 5.