

BEHAVIORAL AND BRAIN FUNCTIONAL CORRELATES OF THE
PROCEDURALIZATION OF EVALUATION

By

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To my parents Yingchao Li and Jian Yang, without whose sacrifices and unconditional love
none of this would be possible

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Our study concerned the effects of practice with evaluative judgments at both the behavioral and the brain functional levels. We hypothesized that evaluative practice increases the likelihood and efficiency of evaluative judgments. As predicted, Experiment 1 showed that participants who practiced evaluating visual stimuli became faster with time and were more likely to make evaluative judgments spontaneously at a later time. To explore the brain functional correlates of evaluation proceduralization, in Experiment 2 we used functional magnetic resonance imaging (fMRI) to compare the activity before and after participants practiced performing evaluative judgments of pictures. We found that practice in evaluation had effects on brain activation in various regions. Specifically, when evaluative judgments were proceduralized, brain activation increased at regions associated with automatic evaluative processing, including the amygdala, the insula, and the orbito-frontal cortex, and regions associated with controlled evaluative processing (e.g., the temporal pole, the anterior cingulate cortex, the frontal operculum), as well as late visual regions (e.g., the posterior fusiform, the superior occipital lobe, and the parietal occipital lobe). Moreover, evaluation proceduralization was reflected by increased activity in areas associated with procedural learning (e.g., the striatal

regions, the lateral cerebellum, the precuneus, and the inferior frontal cortices), and decreased activity in areas associated with declarative learning (e.g., the medial temporal lobe, the ventromedial prefrontal cortex, the dorsolateral prefrontal cortex).

CHAPTER 1 INTRODUCTION

Evaluation, which is believed to be a fundamental dimension of meaning in all languages (Osgood, Suci, & Tannenbaum, 1957), entails momentary responses of favor or disfavor engendered by an object (Breckler & Wiggins, 1989; Schimmack & Crites, 2005). The ability to evaluate one's environment is learned at an early age, and children's abilities to distinguish good from bad are critical in personality development (Rhine, Hill, & Wandruff, 1967). Moreover, explicitly evaluating external stimuli is an important component of learning from experience and adapting to a changing environment (Greenberg & Safran, 1987). For example, when a new set of behaviors results in unsatisfactory outcomes, people often evaluate and adjust their behavior in an explicit way.

Extensive research has shown that evaluations are retrieved and made automatically in the presence of objects. Murphy and Zajonc (1993) supported the affective primacy hypothesis (Zajonc, 1980), which indicates that affective reactions can be elicited with minimal stimulus input and virtually no cognitive processing. Less extremely, Bargh and colleagues (1992) suggested a cognitive mediation framework, and demonstrated that most evaluations are stored in memory and become active automatically with the mere presence of the object. That is, evaluation can proceed without the intervention of conscious acts of will or guidance of the process (Bargh & Ferguson, 2000). Although this important past research suggests that evaluations are retrieved and made automatically, there is surprisingly little evidence on how evaluations become more efficient and faster. Our purpose was to advance our understanding of this problem.

Proceduralization of Evaluation

Proceduralization is the acquisition of generalized implicit knowledge about a skill that permits executing the skill without requiring representation of declarative information (i.e., description of relevant facts, methods, and procedures) in working memory (Anderson, 1982; Neves & Anderson, 1981). Proceduralization has been confirmed for a variety of non-social skills. For example, one of the most common paradigms used to study motor-skill learning is the serial response time task (Robertson, 2007), during which participants are trained to select appropriate responses whenever a visual cue appears. With practice, perceptual-motor skills can become proceduralized, indicated by a gradual reduction in the amount of time required to execute a task. Judgments of whether words contain a certain target sound can also be proceduralized with practice (Smith, 1989). Moreover, practicing judgments using formal logic rules speeds up this type of decision-making process (Carlson, Sullivan, & Schneider, 1989). Overall, this evidence suggests that various motor and cognitive skills can proceduralize.

Judgment proceduralization has also been confirmed for various social domains. For instance, Smith, Branscombe, and Bormann (1988) indicated that trait inferences can be strengthened by practice, and that the effects of practice need not be content-specific. Smith and colleagues (1992) further demonstrated that repeatedly determining whether a behavior implies a trait speeds up this judgment in a later time, even when there is no conscious awareness of practice. Smith, Fazio and Cejka (1996) extended this work to the area of social categorization, supporting the idea that judgments of a person become more accessible after practice in determining whether a person belongs to a certain social category. Also related to the speeding up effects of social judgment practice, Bassili (1993) found that practice with judgments of whether a behavior implies a trait also rendered more spontaneous trait inferences later, in the absence of an explicit request.

Despite the value of previous work on effects of practice on judgments, no prior research has directly investigated whether *evaluative judgments* can be proceduralized during learning/practice. Before discussing the possibilities of evaluation proceduralization, we describe how procedural knowledge is produced, and how it influences our learning process.

Based on Fitts' (1964) three-stage model of learning (i.e., cognitive, associative and autonomous learning), Anderson (1982) proposed that skill acquisition comprises declarative, knowledge compilation, and procedural stages. In addition, the defining features of proceduralization through practice are increased efficiency (i.e., speeding up of the performance) and removal of deliberative efforts at executing responses.

Specifically, as procedures are initially learned and enacted in a deliberative fashion (Kolers & Roediger, 1984; Wyer & Srull, 1989), they are often inferred from declarative knowledge with frequent errors and verbal mediation (Anderson, 1982). For example, when one learns a certain task for the first time (e.g., riding a bicycle), one must mentally rehearse the order of the movements to perform the task. Over time, however, reliance on declarative knowledge decreases and reliance on procedural knowledge increases, allowing the procedural knowledge to be applied to identical as well as different targets (Anderson, 1982; Smith, 1989, 1994; Smith & Lerner, 1986). That is, during the associative stage, the single steps involved in a task are converted into a collection of inter-related procedures, and this collection of knowledge can be activated to guide behavior automatically whenever necessary conditions are met. Proceduralization, the process of establishing direct condition-action associations, is used to explain performance improvements (e.g., speedup in execution) during practice of a procedural skill¹.

¹ These features therefore distinguish proceduralization from habituation, which is an extremely simple form of non-associative learning. Habituation is often characterized by a progressive diminution of behavioral or attentional

Thus, although initially an evaluative procedure may be cognitively demanding, practice reduces the load of working memory by integrating declarative descriptions of the procedure, thus making the execution of the procedure effortless. Learning to evaluate stimuli (e.g., good vs. bad) may be similar to the acquisition of other skills. Extant evidence supporting the notion of evaluation proceduralization comes largely from work on automatic evaluations. For example, using evaluative priming paradigms, Fazio and colleagues (1986) demonstrated that the automatic activation of evaluations is obtained primarily for attitude objects toward which people have highly accessible attitudes. Similarly, Devine (1989) has shown that the activation of automatic evaluations (e.g., prejudice) occurs despite a person's willingness to control or ignore them. In addition, a study by Castelli and colleagues (2004) supported that, once a person is categorized as a member of a given group, evaluations of the category are activated automatically. Thus, the greater the practice with certain evaluations, the more automatic or spontaneous these evaluations become.

Briefly, past research has established that a specific positive or negative evaluation is often automatic. However, the empirical question addressed in this research is whether the process of evaluation proceduralizes with practice. Specifically, although the activation of evaluative or affective responses to external stimuli may be automatic, making explicit evaluations (e.g., ratings on Likert scales) is a voluntary act. For example, the activation of negative evaluative responses when seeing a snake may be automatic, but quantifying the *extent* to which this is unpleasant may be deliberate. In addition, previous research indicated that there are individual differences in chronic evaluative tendencies (Jarvis & Petty, 1996). For example, people who are

responses with repetition of the same stimulus. For instance, after a period of exposure to continuously presented stimuli (e.g., strong odors, bright light, and noise), our sensory systems (e.g., the nose, the eyes, and the ears) stop responding.

high in need to evaluate tend to make extreme fast evaluations, whereas people who are low in need to evaluate often make moderate or slow evaluations. Therefore, making evaluative judgments is more automatic for some people, but more deliberate for others.

A range of research has supported the idea that explicit evaluative judgments are not as efficient as the evaluations measured with implicit measures, such as the implicit association test (IAT; Greenwald, McGhee, & Schwartz, 1998). Hence, studies of *explicit* evaluative judgments may offer ideal opportunities to observe evaluation proceduralization. People who practice applying an evaluative rating scale may speed up their judgments as time goes by. In fact, practice may speed up evaluative judgments to both repeated and novel stimuli. That is, response times to repeated targets may decrease faster than those to novel targets, because earlier judgments of a target increase the accessibility of the earlier evaluation when a judgment is conducted again (Smith, 1989). In addition, evaluation proceduralization may influence the way in which people judge new targets by, for example, increasing the chances of making other explicit evaluative judgments (Fergusson, Bargh, & Nayak, 2005; see also, Bassili, 1993). For instance, applying a scale to evaluate images may lead to more evaluations of new images if one is later asked to write comments about images without any further instruction.

Another important question underlying this research concerns which aspects of explicit evaluative judgments change during proceduralization. In particular, we want to investigate what specific processes contribute to the behavioral outcome (i.e., faster response time and better performance) usually present in proceduralization studies. The evaluative-skill learning itself requires several stages of cognitive and evaluative operations, such as interpreting the situation depicted in stimuli, evaluating visceral responses triggered by the target stimuli, comparing the experience of the presented stimulus with other stimuli, recalling appropriate anchors from the

scale, and behaviorally assigning a value to the stimuli. Thus, practicing evaluative judgments may proceduralize the skills involved in expressing judgments and the evaluations themselves. These aspects among other processes were addressed by investigating changes in brain activity during evaluation proceduralization.

Possible Brain Functional Correlates of Proceduralized Evaluations

To detect which aspects of evaluation proceduralize with practice, we examined the effects of evaluation practice on brain regions associated with (a) procedural learning, (b) declarative learning, (c) automatic evaluation, and controlled evaluation, and (d) early and late visual processing, and primary motor processing..

Brain Functional Correlates of Proceduralization

We predicted that practice with explicit evaluations could trigger changes in several separate sets of regions. Specifically, before practice, evaluative skills are in the form of declarative learning. Therefore, we should observe activation in brain regions associated with declarative learning at the early stage of practice. In contrast, when evaluative skills are transformed to procedural knowledge, activations in regions associated declarative learning should decrease while activations in regions associated with procedural learning should increase.

1. Brain regions associated with procedural learning. Based on prior research, several regions are involved in the process of procedural learning. First, *basal ganglia* are the largest subcortical structures in the human forebrain, and the system influences multiple aspects of motor, affective, and cognitive behavior (Graybiel, 2000). The basal ganglia system operates in close relation with the cerebella cortex, and is part of the extensive basal ganglia-thalamocortical circuits modulating the activity of the frontal cortex. According to previous research, the basal ganglia function as a system that helps the cortex to group learning into habits and routines in a way that facilitates accessing stored information (Graybiel, 2005). Important for our analysis, the

basal ganglia are involved in the regulation of non-motor as well as motor sequence learning (Vakil et al., 2000).

The basal ganglia consist of a set of interconnected subcortical nuclei. The major input nucleus is the *striatum*, which consists of the *caudate nucleus*, the *putamen*, and the *nucleus accumbens*. The striatum is located close to the output station of the basal ganglia - the globus pallidus, which projects to most cortical areas of the frontal lobe (Alexander et al., 1990). During learning, the striatum interacts with the sensorimotor and frontal cortices by recognizing known behavioral contexts and modulating cortical activity to produce a response (Seger, 2006). Importantly, the striatum plays an essential role in *non-declarative/procedural* cognitive-skill learning (Poldrack et al., 1999; Seger & Cincotta, 2006) and implicit sequence learning (Peigneux et al., 2000). For example, the caudate nucleus has been shown to be more active during the procedural learning phase of a probabilistic classification task than during a perceptual-motor control task (Poldrack et al., 1999). Moreover, using a complex serial reaction time task, Peigneux et al. (2000) found that the striatum plays a critical role in implicit sequence learning. Specifically, the striatum (e.g., the caudate nucleus, the putamen) was significantly more active when stimuli were predictable and thus facilitated faster responses than when they were not. In addition, Destrebecqz and colleagues (2005) investigated the cerebral correlates of explicit and implicit knowledge in a serial reaction time task. They showed that activity in the striatum is associated with the implicit component of performing a learned task, whereas activity in the anterior cingulate and medial prefrontal cortex are associated with the explicit component.

Other research suggests that different parts of the striatum have different functions. For example, during motor sequence learning, the putamen is involved in the execution of well-learned movements by projecting to premotor and supplementary motor areas of the cortex. In

contrast, the caudate nucleus is one of the main loci for the reward-processing aspect of behavioral learning (Doya, 2000; Haruno et al., 2004; Packard & Knowlton, 2002) and is involved while an individual is receiving feedback. Furthermore, Lehericy and colleagues (2005) suggested that distinct basal ganglia regions are involved in early and advanced stages of motor sequence learning. Specifically, during motor sequence learning, the rostromedial areas of the putamen decrease in activity with practice, whereas the activity of the caudoventral areas of the putamen increases. Furthermore, the nucleus accumbens plays a role in regulating emotions (Phan et al., 2004), and in processing rewards (Schoenbaum & Setlow, 2003) and personal relevance information (Lieberman et al., 2004; Phan et al., 2004). For instance, Lieberman and colleagues (2004) found that the nucleus accumbens participates in intuition-based self-knowledge judgments. That is, consistent with an implicit learning interpretation, the nucleus accumbens was more active when people judged themselves on traits related to behaviors practiced frequently than when they judged themselves on traits related to behaviors they practiced infrequently (Lieberman et al., 2004). Similarly, other research found that activity in the nucleus accumbens increased with both increased emotional intensity and increased self-relatedness of the stimulus targets (Phan et al., 2004). Hence, the nucleus accumbens apparently participates in both intrinsic evaluative processing and self-relatedness processing. In sum, we expected to find increased involvement of the striatal system in evaluations when they are proceduralized with practice.

In addition to the basal ganglia, the *cerebellum* is also involved in a wide range of motor and cognitive tasks, including motor skill learning, mental imagery, sensory processing, planning, attention, and language (Doya, 2000; Doyon et al., 2003; Hikosaka, 2002; Torriero et al., 2004; Willingham et al., 2002). Despite these functional similarities, empirical evidence

(Doya, 1999, 2000; Exner, Koschack, & Irle, 2002) suggested that the basal ganglia are associated with reward-based and reinforcement learning, whereas the cerebellum is associated with error-based and supervised learning. Specifically, the cerebellum plays a role in learning specific task associations and in monitoring the internal models of the body and the environment. In contrast, the basal ganglia are more responsible for evaluating the general requirements of a task and selecting appropriate responses by predicting reward and feedback. Furthermore, prior research suggested that the cerebellum interacts with the basal ganglia. The output stage of cerebellar processing (i.e., the dentate nucleus) has a direct influence over the input stage of the basal ganglia processing (i.e., the striatum) (Hoshi et al., 2005). Thus, the cerebellum may contribute to procedural learning (Torriero et al., 2004) by adaptively adjusting the basal ganglia activity on the basis of internal information and error signals (Doya, 2000).

Areas within the parietal lobe have also been proposed to play these active roles. Extensive neuroimaging and neuropsychology evidence suggests that the posterior *parietal lobe* plays a vital role in working memory retrieval (Berryhill & Olson, 2008). There are two separate regions within the posterior parietal lobe, namely the superior parietal lobe (BA 7 and precuneus) and the inferior parietal lobe (BA 39 and 40). Although various studies have been conducted to distinguish the functions of these two regions in learning and memory, the findings are not congruent. According to some studies, the inferior parietal cortex is more active during implicit-skill learning (Mallol et al., 2007; Willingham et al., 2002), whereas the superior parietal lobe is more active during declarative-skill learning (Willingham et al., 2002). However, other studies have suggested that the superior parietal lobe is more involved in procedural learning, whereas the inferior parietal lobe is more active in declarative learning. For example, Nadel and colleagues (2007) detected increased activity at the superior parietal lobe (BA7 and precuneus)

with repeated memory retrievals. In addition, Poldrack and his colleagues (1999) found that, although the bilateral inferior parietal lobe (BA 40) was more active during procedural learning (vs. control tasks), its activation increased when the task relied on declarative memory. Another piece of evidence suggests that the inferior parietal lobe may be sensitive to the level of task difficulty, being more active for difficult (vs. easy) tasks (Klingberg et al., 1997). Therefore, the activation at the inferior parietal lobe might decrease when task difficulty decreases with practice. Nonetheless, the current study would provide further evidence of the specific roles of the superior and inferior parietal lobe in different learning stages.

Besides the above regions that were proposed to be related to learning, we were also interested in the effects of evaluative proceduralization at the inferior part of the frontal lobe. Previous research suggests that the *inferior frontal gyri* are commonly recruited across various tasks, including learning (Seger & Cincotta, 2006; Willingham et al., 2002). For instance, the inferior frontal gyrus exhibited greater activity during implicit (vs. random) learning condition in the serial response time task (Willingham et al., 2002) and during rule learning compared to the rule application process (Seger & Cincotta, 2006). Similarly, the inferior frontal cortex was involved in the rehearsal stage but not the storage stage of the phonological learning task (Baldo & Dronkers, 2006). Therefore, the inferior frontal cortex is related to procedural learning. Thus, we expected an increase in the activation of the inferior frontal region when evaluations proceduralize.

2. Brain regions associated with declarative learning. In contrast to the striatum, the cerebellum, the parietal lobe, and the inferior frontal lobe, the *medial temporal lobe* system, which is composed of the hippocampus and the parahippocampal region, is believed to be the center of declarative learning (Gabrieli et al., 1997; Poldrack et al., 1999; Squire et al., 2004).

For example, in an explicit rule-learning task, the striatum is recruited while the medial temporal lobe is suppressed (Seger & Cincotta, 2006). Similarly, Poldrack and his colleagues (2001) found that, when the task is proceduralized, the striatum shows increased activation whereas the medial temporal lobe shows decreased activation. Conversely, when the task is declarative, the striatum is less active whereas the medial temporal lobe is more active. Thus, similar patterns may be observed when practice renders individuals more efficient at evaluating stimuli. That is, as the process of making evaluative judgments of new stimuli is being proceduralized (i.e., faster evaluations), the activation in the hippocampus and related medial temporal regions decrease. Hence, in the current study, a decrease in the activation of the medial temporal lobe is expected when evaluations proceduralize.

Moreover, skill development is typically conceptualized as a decrease in need for explicit control over performance as time goes by. In neuroimaging studies, *the prefrontal cortex* has been regarded as the center of high-level information processing because of its relation to working memory, action planning, action inhibition, and decision making. For example, the *dorsolateral prefrontal cortex* (dlPFC) is active during a wide range of cognitive tasks, such as a number of problem-solving, probabilistic-learning, and reasoning tasks, as well as working-memory tasks (Poldrack et al., 1999). For instance, the activation of dlPFC decreases in people who learn skills faster (Willingham et al., 2002). Along with the hippocampus and the posterior parietal cortex, the dlPFC also appears to be involved in controlled/demanding (vs. intuitive/automatic) trait judgments (Lieberman et al., 2004). Similarly, dlPFC activation seems to be directly associated with task difficulty, as judged by its higher activation during complex tasks than during simple tasks (Klingberg et al., 1997). In addition to the dlPFC region, the *ventromedial prefrontal cortex* (vmPFC) is involved in higher level decision making (Bechara et

al., 1999), particularly by integrating all somatic state information triggered by brain regions associated with evaluation (e.g., the amygdala and the anterior cingulate cortex) and then deciding on the appropriate action. Furthermore, successful activation of the vmPFC region when surrounding stimuli are potentially aversive seems to contribute to psychological well-being, presumably because of its influence on good decision-making (Reekum et al., 2007). Based on the findings in prior research, we expected lower activation in both the dorsolateral prefrontal cortex and the ventromedial prefrontal cortex when evaluations are proceduralized than when they are not.

Brain Functional Correlates of Evaluation

We also expected that practice would influence the activation of regions associated with evaluative processing. Previous neuroscience research has demonstrated that some regions are involved in automatic evaluations and others are involved in explicit evaluations. Therefore, we hypothesized that practice with evaluations would change brain activities in automatic evaluation regions regardless of whether explicit evaluations are required. However, practice with evaluations would change brain activities in regions associated with controlled evaluation only when explicit evaluations are required.

1. Brain regions associated with automatic evaluation. A great deal of research strongly supports that the *amygdala*, an almond-shaped group of neurons located deep in the medial temporal lobes of the brain, plays an important role in evaluation learning (Hamann, Ely, Hoffman, & Kilts, 2002; Irwin et al., 1996). For example, several studies correlated the neural responses in the amygdala with affective judgments of emotional pictures (Phan et al., 2004) and words (Cunningham, Raye, & Johnson, 2004), as well as pleasant and aversive odors (Royet et al., 2003). Moreover, previous research suggested that the amygdala was more responsive to negative than positive images (Morris et al., 1996; Reekum et al., 2007) and to names of bad

people than to names of good people (Cunningham et al., 2003). Furthermore, the amygdala plays a critical role in advanced decision making by generating emotional states and attaching affective attributes to stimuli (Bechara et al., 1999). Evidence from both lesion (Adolphs, Tranel, & Damasio, 1998) and functional neuroimaging studies (Winston, Strange, O'Doherty, & Dolan, 2002) suggests that the amygdala plays a critical role in automatic processes of evaluation. For example, explicit requests of evaluations are not necessary to produce amygdala activation (Cunningham et al., 2003; Lane et al., 1997; Wright et al., 2008). Moreover, the left and right amygdala have dissociable functions in different stages of memory for emotional material (Sergierie, Lepage, & Armony, 2006). Specifically, the right amygdala is involved in the formation of emotional memories, whereas the left amygdala is involved in the retrieval of those memories.

Making emotional evaluations also modulates brain responses to affective stimuli in other areas, such as the *insula*. Functional imaging experiments have revealed that the insula plays an important role in the experience of pain and basic emotions such as anger, fear, disgust, happiness, and sadness. The insula has extensive connections with the amygdala, and these connections enable these two structures to operate as a functional unit in emotion induction (Taylor et al., 2003). For example, previous research demonstrated that evaluating responses to pleasant or aversive odors elicited activation in the amygdala, the anterior cingulate cortex, and orbito-frontal cortex, as well as the insula (Royet et al., 2003). More specifically, like the amygdala, the insula is involved in automatic evaluation, as it responds to the valence (i.e., pleasantness vs. unpleasantness) of target stimuli regardless of intention (Cunningham et al., 2004).

Finally, previous research has indicated that the *orbitofrontal cortex* (OFC) participates in automatic emotional functioning (Cunningham et al., 2004). Specifically, the OFC receives extensive sensory input and sends output to areas that are important for emotional processing and expression, such as the amygdala (Cunningham & Zelazo, 2007; Rempel-Clower, 2007). Moreover, in prior research, activity in the lateral OFC correlated with the degree to which participants tried to control their evaluative judgments of social concepts (e.g., happiness, murder) (Cunningham et al., 2004). In addition to its contribution to evaluative processing, the OFC is active during decision-making, expectation formation, reward-based learning, and representation of the affective value of reinforcers (e.g., food). In particular, the human OFC is thought to regulate planning behavior associated with sensitivity to reward and punishment (Bechara et al., 1994). A large meta-analysis of the existing neuroimaging evidence demonstrated that activity in medial parts of the OFC is related to the monitoring, learning, and memory of the reward value of reinforcers (Kringelbach & Rolls, 2004). The same meta-analysis showed that the activity in lateral or posteromedial OFC is related to the evaluation of punishment and subsequent change in ongoing behavior (see also Petrides, 2007). For example, the orbito-frontal cortex interacts extensively with the hippocampal memory system in the long-term declarative memory storing process (Ramus et al., 2007). By participating in both automatic affective and cognitive processing, the OFC plays an important role in behavioral regulation and cognition in general.

2. Brain regions associated with controlled evaluation. Contrary to the amygdala and the insula, the *anterior cingulate cortex* (ACC) is believed to be involved in controlled processes of evaluation (Cunningham et al., 2003; Cunningham et al., 2004; Taylor et al., 2003; Critchley, 2005). Activations of the anterior cingulate cortex, involving both the ventral ACC (BA 24) and

the dorsal ACC (BA 32), have been observed in functional neuroimaging studies that span a wide range of cognitive contexts including selective attention and memory (Cabeza & Nyberg, 1997). Prior research implicates ACC in supporting conscious experience including emotional feeling states (Egan et al., 2003; Hariri et al., 2003; Lane, Chua, & Dolan, 1999; Papez, 1937). Reportedly, for example, the anterior cingulate cortex engages in conscious evaluation and appraisal, together with the prefrontal cortex, by regulating amygdala activity (Hariri et al., 2003). Specifically, the anterior cingulate cortex was more active during cognitive evaluation (e.g., evaluating whether content of a target picture is natural or artificial) than during perceptual processing (e.g., matching identical targets) of the same target. Moreover, Lane and his colleagues (1997) examined neural activity associated with selective attention to subjective emotional responses in a study in which participants viewed emotional pictures. They found that when evaluative (vs. non-evaluative) judgments of visual stimuli were requested, activation increased in the ACC (as well as the *temporal pole*, the *frontal operculum*). In other words, the ACC is involved in controlled evaluation as its activation is higher when there is conscious awareness of evaluative tasks (see also Cunningham et al., 2003). Therefore, we expected to find similar patterns of change in the ACC, the temporal pole, and the frontal operculum when evaluations proceduralize.

Hypothetical Brain Functional Changes in Evaluation Proceduralization

According to the above reviewed research evidence on memory and learning, we predicted that memory/knowledge of how to express explicit evaluations to stimuli is expected to become more proceduralized with practice. Therefore, brain regions in the basal ganglia system, the cerebellum, the inferior frontal cortex, and related posterior parietal lobe may become more active after practice. Moreover, practice with explicit evaluative tasks decreases activity in brain

regions associated with declarative learning, including the medial temporal lobe, and prefrontal cortices (Figure 1-1A).

Evaluative skill learning should also alter the level of control and monitoring exhibited in various frontal cortices (Figure 1-1A). For instance, regions involved in controlled processing of motor and cognitive skills (e.g., the dorsolateral and the ventromedial prefrontal cortices) may be less active for evaluative judgment tasks when evaluation is proceduralized. However, activation in the inferior frontal gyri during evaluative judgments should increase due to its association with implicit skill learning.

Although even a simple cognitive task performed on emotionally salient stimuli can affect neural activation in emotion-associated brain regions, a more important question is whether and how training in evaluation changes neural responses in evaluation-related regions. On the one hand, repeated exposure to identical stimuli decreases neural responses in corresponding brain regions (Buchel, Coull, & Friston, 1999). This repetition suppression is thought to reflect a progressive optimization of neuronal responses elicited by the stimuli when behavioral learning performance, as well as the effective connectivity between corresponding areas, increase. However, in past research on repetition suppression, the task stimuli used for participants practice were identical. Therefore, it is unclear whether brain activity may also decrease when the stimuli content changes during learning. On the other hand, practicing a certain task can magnify the specific brain correlates of this task (Grossman, Blake, & Kim, 2004). For example, signals in the critical regions involved in a motion detection task have been shown to be more active after extensive practice, and the magnitude of the increase was positively correlated with the degree of improvement in behavioral performance. Consistently, the left amygdala has been shown to be more active when making self-descriptiveness judgments of frequent vs. infrequent

behaviors (Lieberman et al., 2004). Hence, in the current study, the activation of evaluation-related brain regions (e.g., the amygdala, the anterior cingulate cortex, the insula, the temporal pole, the frontal operculum, and the orbito-frontal cortex; Figure 1-1B) could either decrease or increase when evaluative judgments are proceduralized. In addition, we hypothesized that the pattern of activity change in regions associated with automatic evaluations and regions associated with controlled evaluations would be different. Specifically, evaluation proceduralization should have effects on automatic evaluation regions regardless of task requirement, whereas on controlled evaluation regions only during evaluations. Moreover, with evaluation practice, the magnitude of change in activities in evaluative regions should be positively associated with the improvement in response times to evaluative judgments.

Because evaluative judgments also require visual and motor systems, we are also interested in whether practice with evaluations influences brain activity in visual and motor regions (Figure 1-1C). Several studies have suggested that practice with certain tasks does not influence the activation at early visual regions (e.g., a word classification task, Maccotta & Buckner, 2004; a picture priming task, Eddy et al., 2007) or primary motor regions (Maccotta & Buckner, 2004). In contrast, late visual regions are sensitive to practice with responses to visual targets (Eddy et al., 2007; Maccotta & Buckner, 2004). Therefore, in the current study, we predicted that practice with evaluative judgments may not influence the activation in the early visual area (i.e., the calcarine) and the primary motor area (e.g., BA 4). In contrast, practice with evaluative judgments of visual stimuli should increase the activation of later visual areas such as the posterior fusiform and regions in the occipital lobe (e.g., the superior occipital gyrus, and the parietal occipital gyrus) (Grossman, Blake, & Kim, 2004).

The Present Research

Two studies were conducted to investigate the influence and brain functional correlates of practice with evaluative judgments. In Experiment 1, we examined whether practice in evaluating pictures on a scale increases the speed of evaluative judgments and the likelihood of making evaluative judgments of other visual stimuli. First, participants completed a practice task that entailed making either evaluative or non-evaluative responses to a set of pictures. After a series of filler tasks, participants were instructed to list their spontaneous thoughts about a new set of pictures. Hypothetically, evaluative-skill learning should speed up evaluative judgments to visual images. In addition, practice in evaluative judgments should increase the likelihood of making spontaneous evaluative judgments at a later time.

To test the brain functional correlates of practice in evaluative judgments, participants in Experiment 2 completed procedures similar to those used in Experiment 1 while in an MRI scanner. Specifically, participants' brain activity was recorded both *before and after* they practiced making evaluative judgments (vs. non-evaluative judgments) to non-repeated visual images. Thus, by collecting brain images both before and after the practice, changes in brain activities may reveal the neural consequences of evaluation proceduralization.

During evaluative skill learning, we expected increased activation in the striatum (e.g., the caudate nucleus, the putamen, and the nucleus accumbens), the cerebellum, the inferior frontal gyri and the occipital cortex, but decreased activation in the medial temporal lobe, and certain prefrontal cortices (i.e., the ventromedial prefrontal cortex and the dorsolateral prefrontal cortex). In addition, if activation of the inferior parietal lobe increases with evaluation proceduralization, that of the superior parietal lobe should decrease, and vice versa. Furthermore, the activation in evaluation-related regions (e.g., the amygdala, the ACC, the insula, the temporal pole, the frontal operculum, and the OFC) may change (increase or decrease) due to practice in evaluation. In

addition, activation change in regions related to automatic evaluation should occur regardless of whether explicit evaluations are required. In contrast, activation change in regions related to controlled evaluation should present only when explicit evaluations are requested. The hypothesized evaluation proceduralization-induced changes in each brain region would be tested in clusters of interrelated regions. Moreover, correlational analyses would be conducted to examine the relations between regional changes in each cluster and behavioral performance.

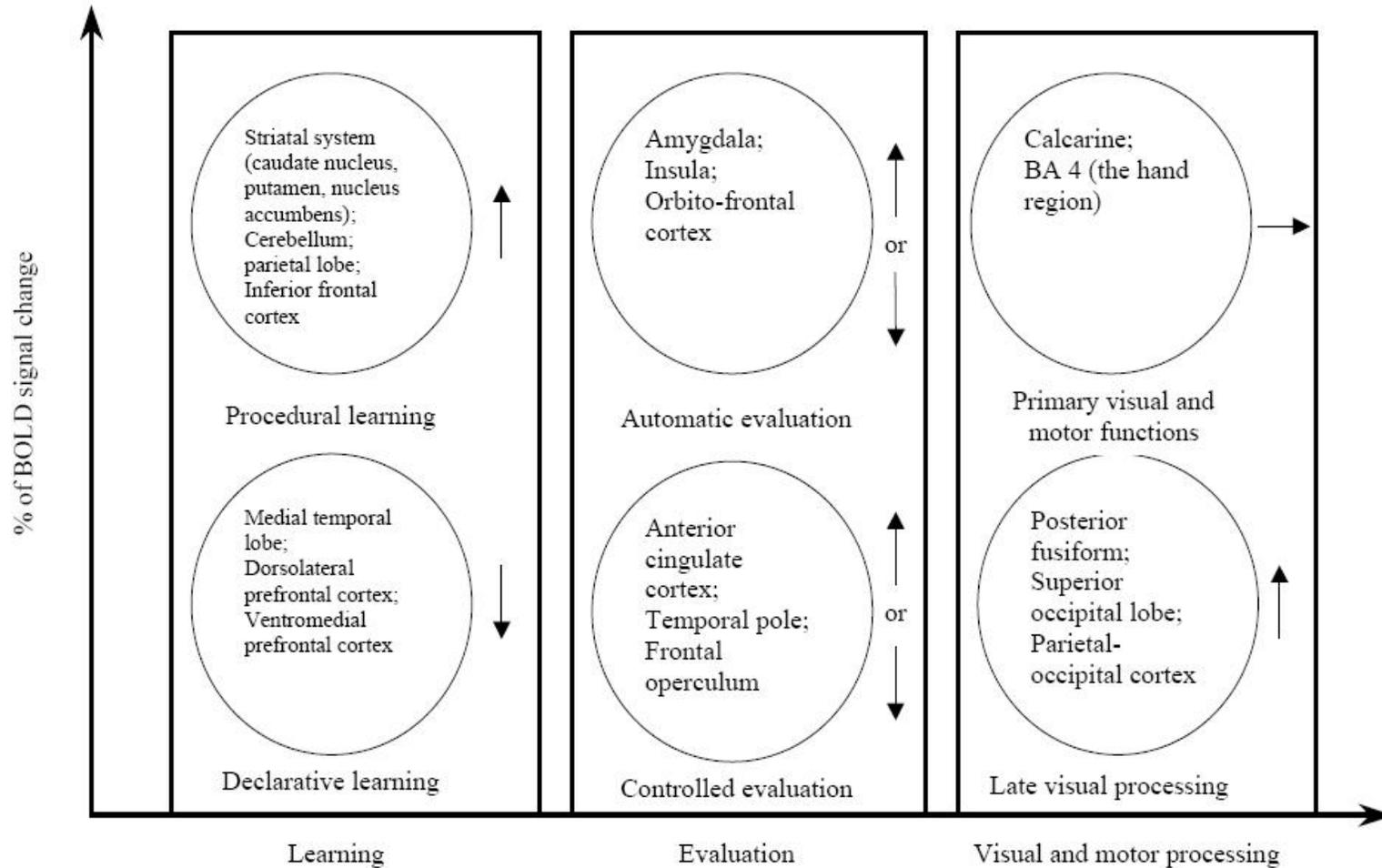


Figure 1-1. Brain regions associated with evaluation proceduralization and predicted effects. Arrows indicate predicted directions of BOLD signal changes in each group of regions when evaluation proceduralization occurs. Up arrows indicate increases, down arrows indicate decreases, and right arrows indicate no change in BOLD signals of the group of regions on the right.

CHAPTER 2 EXPERIMENT 1

Method

Overview

During Experiment 1, participants were seated at individual stations in front of a video monitor with stimulus presentation and instructions being controlled by a computer. They were told that they were participating in a study to explore the automaticity of social information processing, and that the procedure would involve a series of short computerized tasks. Based on random assignment, participants completed either evaluative or non-evaluative judgments of the same set of images selected from the International Affective Picture System (IAPS; NIMH Center for the Study of Emotion and Attention, Lang et al., 2001), presented in 4 blocks of trials. Specifically, participants in the evaluative-practice condition evaluated the pleasantness of the content of stimulus images using a scale provided for that purpose, whereas participants in the non-evaluative-practice condition estimated the frequency with which images with content similar to the target image appear on television, using a scale provided for that purpose. Next, participants completed a series of filler tasks designed to reduce potential demand characteristics and to allow 30 minutes to elapse. Then, all participants completed a thought listing task in which they were asked to list their initial reactions to each of four new stimulus images.

Participants and Design

A total of 48 undergraduate students (24 females, 24 males) at the University of Florida participated in this study in exchange for partial fulfillment of requirements for course credit. The experimental design was a 2 (task: evaluative- vs. non-evaluative practice) X 4 (block: first, second, third, or fourth) repeated-measures factorial, with task being a between-subjects factor.

Procedures

After being welcomed by the experimenter, each participant was seated in front of a computer. Then, the experimenter informed the participants that the purpose of the current research was to study social information processing. After participants submitted signed informed consents, they were randomly assigned to either an evaluative- or a non-evaluative practice condition. In both of the conditions, participants were presented with a total of 168 images displayed on the computer screen, in four blocks of 42 images each. In the evaluation-practice condition, participants were asked to report their evaluations of the pleasantness of each image. In contrast, participants in the non-evaluation practice condition were asked to report how frequently they thought that similar images appear on television. After completing the practice task, all participants completed a series of filler tasks for 30 minutes to reduce potential demand characteristics. Towards the end of the experiment, all participants completed a thought listing task in which they were asked to report their spontaneous reactions to each image of a new set in an open-ended response format. Finally, all participants were debriefed, thanked, and dismissed.

Materials and Measures

Computer setting and stimulus images. The study was administered by IBM-compatible desktop computers using MediaLab software (Empirisoft Corporation, New York, USA). Computer display screens were set to 800 × 600 pixel resolution. The same stimulus set was used for the evaluative- and non-evaluative-practice conditions. The practice contained 4 blocks, each comprised of 21 moderately pleasant and 21 moderately unpleasant color images, pre-selected from the International Affective Picture System (IAPS; NIMH Center for the Study of Emotion and Attention, 2001)¹ (see Table 2-1 for IAPS codes and image descriptions). Across the blocks,

¹ There was no difference in the ratings of the IAPS pictures between each of the four blocks, pairwise comparison, $ps > .10$.

4 (2 positively- and 2 negatively-valenced) images were repeated to differentiate the proceduralization of evaluation on familiar and novel targets. Finally, the stimulus set used to measure spontaneous thoughts after the practice consisted of 2 moderately pleasant and 2 moderately unpleasant color images, also pre-selected from the IAPS (see Table 2-2 for IAPS codes). All images were resized to 410 × 307 pixels and digitized in 24-Bit RGB color.

Evaluation practice. Participants randomly assigned to the evaluative-judgment-practice condition were instructed as follows:

This task involves evaluating the content of images. Please rate how pleasant (i.e., positive, good, pleasing, etc.) you find the content of each image using the scale provided. We are interested in both your evaluation and the speed with which you make it. Therefore, try to respond as quickly and as accurately as you can.

The task consisted of four blocks of 42 trials. Each trial presented the question, “How pleasant do you find the content of this image?” which was centered at the top of the display screen with an image presented in the center of the display screen and a 7-point scale, ranging from 1 (*extremely unpleasant*) to 7 (*extremely pleasant*), presented vertically on the left side of the screen. Participants responded by clicking the left-mouse button on the appropriate point on the scale. Stimulus images were presented in a random order during each block of 42 trials.

Non-evaluation practice. Participants randomly assigned to the non-evaluative practice condition were instructed as follows:

This task involves estimating the frequency with which images of similar content appear on television. Please estimate the frequency using the scale provided. We are interested in both your estimate and the speed with which you make it. Therefore, try to respond as quickly and as accurately as you can.

The task involved four blocks of 42 trials. Each trial presented the instruction, “Please estimate the frequency with which images of similar content appear on television,” which was centered at the top of the display screen with an image presented in the center of the display screen and a 7-point scale, ranging from *weekly* to *by the minute*, presented vertically on the left side of the

screen. As in the evaluation practice condition, participants responded by clicking the left-mouse button on the appropriate point on the scale.

Thought listing task. After the practice in evaluative or non-evaluative judgments, all participants were presented with a set of four new images. During the thought listing task, participants were asked to list their spontaneous thoughts of the content of each stimulus image. These stimulus images were presented in a random order. To quantify the extent to which participants exhibited evaluative and frequency-related judgments, each comment participants listed was coded as either evaluative or frequency-related by two independent coders, $r = 0.81$, $p < .001$. Specifically, comments such as “it is disgusting that people would live in such an environment” were coded as evaluative, whereas comments such as “it is common to see this on TV” were coded as frequency-related, and comments such as “it is a dog” were coded as neither evaluative nor frequency-related.

Results

Response Time

Because participants could spend as much time as they needed to respond to each stimulus, to correct for anticipatory responses and momentary inattention, the response time data from each participant were examined to eliminate outliers in the distribution of response times. Specifically, response times below 300 ms and above 3,000 ms were excluded. Thus, 1288 response times were regarded as missing data (16% of all responses). Then, the means and standard deviations of each participant’s response times were calculated. Then, for each participant, the response times beyond the range of $[M - 2.5SD, M + 2.5SD]$ were also excluded (for similar data cleaning process, see Greenwald et al., 1998). Overall, 10 response times were regarded as outliers (0.15% of all valid responses).

If the judgment practice was successful, participants should have made quicker evaluative or non-evaluative judgments as the task progressed. Mean response times for each participant were computed for the four task blocks and entered into a 2 (practice: evaluation vs. frequency) \times 4 (Task block: first, second, third, and fourth) repeated-measures ANOVA, with practice being a between-subjects factor. The mean response times corresponding to this analysis appear in Figure 2-1. As expected, a significant main effect of block revealed that, with practice, participants became quicker at making judgments, $F(3, 138) = 68.50, p < .001$. No other main effect or interaction was detected. Moreover, there was a linear trend in the decrease of response time over the four blocks, $F(1, 46) = 148.70, p < .001$. From the above results, we can infer that both evaluative and non-evaluative judgments of images proceduralized through practice.

Moreover, the pattern of practice effects on repeated vs. new judgment targets was examined by a 4 (Task block: first, second, third, and fourth) \times 2 (Target: repeated vs. new) two-way repeated-measures ANOVA. Means of response times corresponding to this analysis appear in Table 2-3. As expected, participants made quicker ratings of images that they had rated previously ($M = 1412.90$ ms) compared to new ones ($M = 1609.88$ ms) across blocks, $F(1, 47) = 55.34, p < .001$. Further analysis revealed that in Block 1, there was no difference between response times to the images repeated in the following blocks compared to images used only once ($M = 1810.22$ ms vs. 1786.92 ms, *ns*). However, the response times participants spent to rate previously-seen images decreased more with practice than the response times to new images across the practice blocks (block 2, 3, and 4), $F(3, 141) = 17.56, p < .001$. More importantly, as predicted, the response times to new images in the evaluative-practice condition also decreased significantly across the practice blocks, $F(3, 75) = 31.09, p < .001$, as well as those in the non-evaluative-practice condition, $F(3, 63) = 21.81, p < .001$. These findings suggest that response

times of both previously seen and new images were influenced by the practice manipulation. No effects of practice condition (evaluative vs. non-evaluative tasks) were found on response times or ratings to pictures.

Responses to Tasks

To examine the effects of practice on participants' responses, a 4 (block: one, two, three, vs. four) X 2 (valence: pleasant vs. unpleasant images) repeated measures ANOVA was performed on task ratings² in both evaluative and non-evaluative judgments practice conditions. Mean pleasantness and frequency ratings in each block appear in Table 2-4. During evaluation practice conditions, pictures selected as pleasant did receive higher pleasantness ($M = 5.48$) ratings than pictures selected as unpleasant ($M = 2.10$), $F(1, 25) = 100.11, p < .001$. Moreover, there was a significant main effect of block on pleasantness ratings, $F(3, 75) = 3.52, p < .05$. That is, the pleasantness ratings decreased over the blocks. In contrast, there was no between-block difference in frequency ratings, $F < 1$. In addition, pleasant images ($M = 3.38$) were rated as more frequently seen than unpleasant images ($M = 2.63$), $F(1, 21) = 6.15, p < .05$. There was no interaction between block and valence in either the evaluative or the non-evaluative practice condition.

Spontaneous Thought Listing

To confirm that the evaluation practice task promotes greater spontaneous evaluative responding, the proportion of evaluative (frequency-related) judgments from each participant in the spontaneous thought listing task was computed as the percentage of number of evaluative (frequency-related) comments in the total number of comments of the corresponding participant. Then, we analyzed the proportion of coded evaluative thoughts during the thought listing task as

² Only responses with valid response times were remained in the analysis.

a function of the type of practice participants previously had. Specifically, a one-way ANOVA with judgment condition (evaluative vs. non-evaluative judgments) as the between-subjects factor was conducted on the coded responses. Results indicated that participants who completed the evaluative practice generated a greater proportion of evaluative comments ($M = 0.51$) than participants who completed the non-evaluative practice ($M = 0.42$), $F(1, 46) = 3.90, p = .05$. However, participants who completed the practice condition of frequency-related judgments (vs. evaluative judgments) did not generate a greater proportion of frequency-related thoughts towards new images, $M = 0.004$ vs. 0.003 , $F < 1$. Thus, the evaluative practice appeared to elicit more spontaneous evaluations in response to new images, whereas practice in making non-evaluative judgments (e.g., frequency) did not increase the likelihood of making similar judgments. No effects of valence of images were found, $F < 1$.

Discussion

The present findings suggest that, although evaluative responses are often automatic, there is still room for evaluative judgments to get faster. Specifically, in the current study, participants' evaluative judgments of visual images became quicker with practice, and this effect was not content specific. Moreover, comparable to Bassili's (1993) findings that practice with general trait judgment increases the likelihood of subsequent spontaneous trait inferences, we found that practicing evaluative judgments (vs. frequency-related judgments) makes people more likely to make spontaneous evaluations at a later time. However, the proceduralization effects on frequency-related judgments did not carry over to spontaneous responses to further targets. That is, although frequency-related judgments also speeded up with practice, practice did not make people more likely to make such responses spontaneously. This discrepancy in spontaneous responses might indicate that evaluations are more automatic than frequency-related judgments in the first place. Therefore, practice with frequency-related judgments did not lead to

spontaneously thinking about something as specific as whether a picture is likely to appear on television. . More research should be conducted to further examine the differences between evaluative and other responses to novel targets.

Based on the findings in Experiment 1 that evaluative judgments speeded up over practice (see also Smith, 1989), Experiment 2 was conducted to further explore what aspects of evaluation were proceduralized during practice. Specifically, in Experiment 2, we used an fMRI approach to investigate the brain activity underlying evaluation proceduralization.

Table 2-1. IAPS picture codes for training tasks (Experiment 1)

Block	Positive pictures		Negative pictures	
	Code	Description	Code	Description
1	5390	Boat	1300	Pit Bull
	5875	Bicyclist	3230	Dying Man
	1600	Horse	1301	Dog
	1721	Lion	2299	Boy
	1811	Monkeys	2688	Police
	2095	Clowns	2692	Bomb
	2165	Father	2715	Drug addict
	2550	Couple	3160	Eye Disease
	4255	Attractive Female	1200	Spider
	5030	Flower	5971	Tornado
	1463	Kittens	6212	Soldier
	5600	Mountains	6213	Terrorist
	5611	Mountains	6313	Attack
	5731	Flowers	6570	Suicide
	5760	Nature	6821	Gang
	5780	Nature	6930	Missiles
	1500	Dog	8231	Boxer
	5994	Skyline	9090	Exhaust
	7325	Watermelon	9230	Oil fire
	2	7502	Castle	9390
8500		Gold	9520	Kids
5390		Boat	1300	Pit Bull
5875		Bicyclist	3230	Dying Man
5811		Flowers	9530	Boys
4510		Attractive Man	9561	Sick kitty
4624		Couple	9280	Smoke
7286		Pancakes	9181	Dead cows
2311		Mother	9594	Injection
8502		Money	6350	Attack
7350		Pizza	2800	SadChild
8420		Tubing	3530	Attack
1590		Horse	9560	Duck in oil
7481		Food	9301	Toilet
8496		Water slide	6315	Beaten Female
5001		Sunflower	2722	Jail
1460		Kitten	3280	Dental Exam
5849		Flowers	9220	Cemetery
2071		Baby	1110	Snake
1603		Butterfly	9102	Heroin
1340	Women	2730	Native Boy	
5594	Sky	9330	Garbage	
8490	Roller coaster	9911	Car accident	
3	5390	Boat	1300	Pit Bull

Table 2-1. Continued

Block	Positive pictures		Negative pictures	
	Code	Description	Code	Description
3	5875	Bicyclist	3230	Dying Man
	2510	ElderlyWoman	9452	Gun
	1942	Turtles	6230	Aimed Gun
	1750	Bunnies	1932	Shark
	7291	Chicken	3500	Attack
	2209	Bride	2683	War
	7340	Ice cream	2205	Hospital
	4538	EroticMale	9584	Dental Exam
	7470	Pancakes	9800	Skinhead
	7270	IceCream	9042	Stick thru lip
	2660	Baby	5970	Tornado
	2655	Child	1201	Spider
	7400	Candy	2751	Drunk driving
	1731	Lion	2691	Riot
	2092	Clowns	9342	Pollution
	5990	Sky	1019	Snake
	7289	Food	7359	PieW/bug
	5626	HangGlider	2720	Urinating
	8497	CarnivalRide	2710	Drug addict
	4	1920	Porpoise	9417
5390		Boat	1300	Pit Bull
5875		Bicyclist	3230	Dying Man
5779		Courtyard	9620	Shipwreck
8501		Money	9910	Auto accident
4610		Romance	2981	DeerHead
1640		Coyote	6020	Electric chair
2346		Kids	1280	Rat
4150		AttractiveFem	1310	Leopard
2310		Mother	9440	Skulls
1710		Puppies	2900	Crying boy
2391		Boy	9810	KKK rally
2030		Woman	9080	Wires
2345		Children	1112	Snake
1610		Rabbit	6415	DeadTiger
7330		Ice cream	8485	Fire
1602		Butterfly	9401	Knives
2650		Boy	9920	Auto accident
1440		Seal	9830	Cigarettes
2501		Couple	6830	Guns
4250	AttractiveFem	2702	BingeEating	
7460	French fries	6300	Knife	

Table 2-2. IAPS picture codes for the thought listing task (Experiment 1)

Picture set	Code	Description	Pleasure	Arousal
Positive	5628	Mountains	6.51 (1.95)	5.46 (2.09)
	5891	Clouds	7.22 (1.46)	3.29 (2.57)
Negative	2750	Bum	2.56 (1.32)	4.31 (1.81)
	9341	Pollution	3.38 (1.89)	4.50 (2.10)

Table 2-3. Mean response times for evaluative and non-evaluative tasks to new and repeated stimuli (Experiment 1)

Judgment type	Stimuli	Block			
		One	Two	Three	Four
Evaluative	Repeated	1862.92 (432.10)	1549.98 (463.63)	1284.83 (386.12)	1162.74 (285.55)
	New	1868.34 (325.72)	1697.75 (345.64)	1705.26 (394.33)	1514.17 (363.98)
Non-evaluative	Repeated	1747.94 (580.65)	1419.73 (644.01)	1180.04 (550.86)	1057.02 (482.55)
	New	1690.69 (527.61)	1566.16 (598.54)	1446.09 (590.37)	1327.65 (544.68)

Data presented in the cells are response times in milliseconds. Data in the parentheses are standard deviations of corresponding cell means.

Table 2-4. Ratings of pleasant and unpleasant images in each practice block (Experiment 1)

Judgment type	Valence	Block			
		One	Two	Three	Four
Evaluative	Pleasant	5.58 (0.87)	5.59 (0.91)	5.30 (0.95)	5.44 (0.79)
	Unpleasant	2.15 (0.94)	2.07 (1.02)	2.05 (0.98)	2.13 (1.02)
Non-evaluative	Pleasant	3.29 (1.26)	3.37 (1.34)	3.35 (1.41)	3.52 (1.50)
	Unpleasant	2.81 (1.06)	2.58 (1.08)	2.56 (1.24)	2.55 (1.09)

Data presented in the cells are ratings to images presented in each block. Data in the parentheses are standard deviations of corresponding cell means.

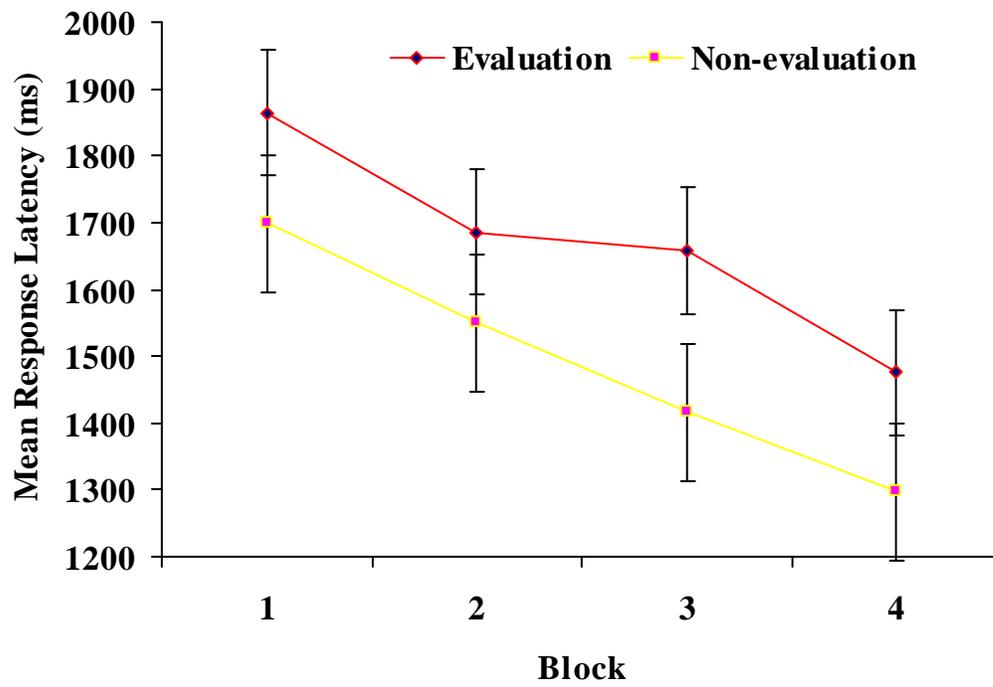


Figure 2-1. Effects of task and practice block on response time (Experiment 1)

CHAPTER 3 EXPERIMENT 2

Method

Overview

The aim of Experiment 2 was to explore the effects of evaluation proceduralization at the brain level. The procedures used in Experiment 2 were similar to the ones in Experiment 1 with two exceptions. First, the participants were placed in an MRI scanner while they were completing the practice tasks. Second, to test the effects of evaluation practice, the brain activities of each participant were recorded during evaluative and non-evaluative ratings both before and after a training run in evaluative tasks. Specifically, in the pre-training run, we presented 60 images (30 for evaluative tasks, and 30 for non-evaluative tasks) to all participants. Then, in the training run, all participants were asked to make evaluative judgments of 150 IAPS images. Towards the end of the experiment, in the post-training run, participants reported evaluative judgments and non-evaluative judgments of a new set of images. The brain activity of each participant was measured during both the pre-training and the post-training runs using functional magnetic resonance imaging (fMRI). In addition, response times were recorded for all judgments.

In both the pre-training and post-training runs, participants had to attend to pictures, generate ratings, and make motor responses for both types of tasks. However, only the evaluative skill was trained in the training run. Thus, by comparing neural responses during evaluative (vs. null trials) condition and non-evaluative (vs. null trials) condition before and after evaluative skill learning, we could distinguish the underlying processes that are specific to proceduralization of evaluation.

We hypothesized that the evaluation practice may influence the brain activity while participants make evaluative judgments. Specifically, after the practice run, activities in the amygdala and other evaluation related regions for evaluative tasks would either increase or decrease compared to activities prior to the evaluative training run. Furthermore, increased regional activities should be observed in the procedural learning regions and late visual regions, whereas decreased activities should be detected in declarative learning related regions and prefrontal areas.

Participants

Sixteen male students⁴ at the University of Florida participated in Experiment 2 to fulfill the requirement of a general psychology class. One participant was excluded due to discrete head movements greater than 1mm during the scanning. Due to technical reasons, data from another participant were missing. Thus, data from 14 participants remained in the analysis. Participants' ages ranged from 18 to 24 ($M = 19.71$, $SD = 1.68$).

Based on the results of screening tests and safety checks, none of the participants had a history of medical, neurological or psychiatric disorder. Also, participants were not taking psychotropic medication and did not have a history of substance abuse. Also, all participants had normal visual acuity.

Procedures

The participants were recruited for participation in a social cognitive neuroscience study that involved MRI scanning while viewing pictures. After turning in the signed informed consent

⁴ Because there was no difference in evaluation proceduralization between male and female participants in Experiment 1, $F < 1$, and the greater safety of fMRI for males, only male participants were recruited in the fMRI study.

forms, participants entered the scanning room. The scanning technician assisted participants to get ready for the scan.

After completing a pre-training run on 30 evaluative and 30 non-evaluative judgments, each participant completed an evaluation training run as well as a post-training run. In these three runs of the study, participants were presented with pictures selected from the International Affective Picture System (IAPS; Center for the Study of Emotion and Attention, 2001) which contains a diverse range of pictures that have been reliably coded along several continuous dimensions of emotionality (i.e., valence, and arousal) (see Table 3-1, 3-2, 3-3 for information of IAPS pictures presented in the pre-training, training, post-training runs, respectively). Specifically, in the pre- and post- training runs of the study, a cue below each picture instructed participants to make either an evaluative or a non-evaluative judgment of the picture being presented, while in the training run, only evaluative judgment cues were presented. The purpose of the training run was to proceduralize evaluation, and the post-training run was performed to evoke neural responses to evaluative and non-evaluative judgments to provide comparisons of these responses with brain activities for evaluative and non-evaluative judgments in the pre-training run.

Functional Imaging Data Acquisition

Participants were scanned using a Siemens Allegra 3 Tesla scanner (Siemens, Munich, Germany) with a standard head coil. Anatomic images were acquired using an MPRAGE sequence with TR = 1500 ms, TE = 4.38 ms, and flip angle = 8°. In the axial plane, 160 slices were acquired (thickness 1.0–1.2 mm, according to the height of the brain) with in-plane field of view of 240 mm × 180 mm and a matrix size of 256 × 192 voxels. Functional images covering the whole brain were acquired using echo-planar imaging sensitive to blood-oxygenation level dependent (BOLD) effects, with TR = 3000 ms, TE = 30 ms, and flip angle = 90°. In the axial

plane, 38 slices with a thickness of 3.8 mm were aligned with the plane of the intercommissural line and had a 240×240 mm in-plane field of view and a matrix size of 64×64 voxels. The functional tasks were presented using an Integrated Functional Imaging System (IFIS, MRI Devices, Inc., Waukesha, WI) with a 7-inch LCD screen at 640×480 pixel resolution, mounted over the participant's head and viewed using a fixed prism mirror. The screen subtended approximately $14^\circ \times 11^\circ$ of the visual field. A PC running E-Prime (Psychology Software Tools, Pittsburgh, PA) presented each task trial in synchronization with the first RF pulse of each scan. Responses were collected using a MRI-compatible button glove attached to the participant's right hand⁵.

Materials and Measures

Image selection. The images selected from the IAPS picture system were moderately intensive according to normative valence and arousal ratings obtained from a pilot study. Pleasant pictures included images of a blue sky, food, and flowers, whereas unpleasant pictures included stimuli such as images of a snake, a pit bull, and garbage. Different sets of stimuli were used in the pre-training (see Table 3-1), the training (see Table 3-2), and the post-training (see Table 3-3) runs of the study. In the pre-training run, pictures selected as pleasant images had higher normative ratings in pleasantness [$M = 6.39$, $SD = 0.64$; $t(29) = 11.93$, $p < .001$], compared to the neutral point of the 9-point scale used in IAPS system, whereas pictures in the unpleasant set had lower pleasantness scores than the neutral scale point, $M = 3.85$, $SD = 1.15$, $t(29) = -5.45$, $p < .001$. The same pattern was found for images selected for the post-training. That is, pictures selected as pleasant received higher scores than the neutral point of the scale (M

⁵ All participants are right-handed, according to the pre-screening self-reports.

= 6.79, $SD = 0.83$; $t(29) = 11.76, p < .001$), whereas pictures selected as unpleasant received lower scores than the neutral point of the scale, $M = 3.82, SD = 0.89$; $t(29) = -7.24, p < .001$.

More importantly, the IAPS picture sets selected for Experiment 2 were matched in valence and arousal distribution across judgment type (evaluative vs. non-evaluative tasks) and run (pre- vs. post- training runs). Specifically, in the pre-training run, the mean valence (pleasant vs. unpleasant) score was 5.08 ($SD = 0.64$) for evaluative tasks and 5.16 ($SD = 0.64$) for non-evaluative tasks, pairwise comparison, *ns*, and the mean arousal (exciting vs. calm) score was 4.44 ($SD = 0.79$) for evaluative tasks and 4.76 ($SD = 0.79$) for non-evaluative tasks, pairwise comparison, *ns*. In the post-training run, the mean valence (pleasant vs. unpleasant) score was 5.30 ($SD = 0.60$) for evaluative tasks and 5.31 ($SD = 0.60$) for non-evaluative tasks, pairwise comparison, *ns*, and the mean arousal (exciting vs. calm) score was 4.98 ($SD = 0.90$) for evaluative tasks and 4.68 ($SD = 0.90$) for non-evaluative tasks, pairwise comparison, *ns*. In addition, for evaluative tasks, there were no significant differences in pleasantness ratings ($M = 5.08$ vs. 5.30 , *ns*, pre- vs. post- training run) or arousal ratings ($M = 4.44$ vs. 4.98 , *ns*, pre- vs. post- training run) between images presented in the pre- and post- training run. Also, there were no between run differences in valence ($M = 5.16$ vs. $M = 5.31$, *ns*, pre- vs. post- training run) and arousal ($M = 4.76$ vs. $M = 4.68$, *ns*, pre- vs. post- training run) ratings in pictures selected for non-evaluative tasks. This similarity of input images should ensure that different brain responses are due to evaluation proceduralization or judgment type, but not to the images themselves.

Parameters of images presentation. Unlike in Experiment 1, we did not use a between-subjects design in the pre- and post-training sessions. Instead, we alternated the presentation of the evaluative and non-evaluative tasks in a random order to avoid confounding training effects with anticipation effects. Specifically, in the pre- and post- training runs, each participant was

presented with 60 images (30 for evaluative judgments, and 30 for non-evaluative judgments) for 3 seconds each, along with 30 null trials, during which a fixation cross was displayed for 3 seconds. Thus, the pre- and post-training runs each lasted 4 minutes and 30 seconds. Null trials were included in the random sequence in order to jitter the stimulus onset asynchrony (SOA) between trials, and to increase the variance in the resulting fMRI response and make the response to rapid stimuli (SOA < 15 seconds) detectable (Burock et al., 1998). Moreover, jittering the SOA with randomly interspersed null trials creates a geometric distribution of SOAs, which is believed to be more efficient than uniform randomization (Serences, 2004). To minimize response attenuation when repeating images while maximizing the number of trials in the pre-training and post-training sessions (Soon, Venkatraman, & Chee, 2003), the resulting mean SOA was set to 4.5 seconds, with a minimum of 3 seconds.

In the evaluative skill training run, 150 evaluative trials were presented for 2 seconds each in ten 30-second blocks of 15 images, which were separated by 12-second rest blocks during which a fixation cross was displayed. Thus, the training run lasted 7 minutes and 12 seconds. The number of positive and negative trials was balanced in every two blocks. That is, if 7 positive and 8 negative trials were presented in the previous block, then 8 positive and 7 negative trials were presented in the following block. The trials were presented more rapidly during training than testing to induce proceduralization.

Evaluative and non-evaluative ratings. In the pre-training and the post-training sessions, both evaluative and non-evaluative judgment cues were used (see Appendix A for instructions). In the evaluation-training session, only evaluative judgments were requested. Specifically, in Experiment 2, the evaluative-judgment cue was “How pleasant do you find the content of this image?” (see Figure 3-1 for sample images), which was followed by a 4-point scale ranging from

extremely unpleasant to *extremely pleasant*. In contrast, the non-evaluative-judgment cue read, “How frequently do images with similar content appear on television?” (see Figure 3-1 for sample images) and was followed by a 4-point scale ranging from *rarely/never* to *always*. The brain activities during evaluative and non-evaluative ratings were recorded as the dependent measures.

Regions-of-interest selection. In the current research, a regions-of-interest (ROI) approach was employed to test our hypothesized effects of practice of evaluative skills on brain activity. There are advantages to an ROI approach. When subtracting two conditions in a whole-brain group-analysis, the significance of all voxels is determined using a Bonferroni correction for the number of voxels. Therefore, arguably, the correction for the number of all voxels is too strict, as only a few regions are of real interest. Thus, regional analyses afford considerable power by reducing the number of multiple comparisons and averaging multiple voxels within each region, thereby increasing signal-to-noise ratios (Poldrack, 2007). In addition, because regions are derived a priori, their signal estimates are unbiased (Maccotta & Buckner, 2004).

Our regional analyses explored signal magnitude estimates within a set of a priori regions that spanned the basal ganglia system, prefrontal cortex, evaluative processing regions, early and late visual cortex, and the motor cortex. First, peak locations of these regions were derived from prior research on related tasks. For example, regions related to evaluative processing were mainly derived from previous work on social evaluation and subjective emotional responses, and regions related to learning were selected based on previous research on motor and cognitive skill learning. Then, three-dimensional regions of interest were defined by including all voxels within 5 mm of each activation peak (Etkin et al., 2006; Maccotta & Buckner, 2004). This method of creating small ROIs at the peaks of activation clusters based on previous research has been

regarded as particularly suitable for complex designs, such as factorial designs, and it can depict signal patterns in specific regions within larger anatomical clusters (Poldrack, 2007).

Results

Our study was aimed at exploring the brain activity during evaluation proceduralization, using null trials as the comparison condition. We hypothesized that practice with evaluation changes activation patterns in major brain regions related to affect and evaluation, such as the activation patterns in the amygdala, the insula, the orbito-frontal cortex, the anterior cingulate cortex, the temporal pole, and the frontal operculum. In addition, we expected that task instructions (evaluative vs. non-evaluative task instructions) would influence the pattern of activation change in regions associated with controlled (vs. automatic) evaluation. The direction of the difference was an empirical question that we hoped analyses would resolve. Also, because evaluative judgments are proceduralized during the training run, evaluative judgments (vs. null trials) may produce differential activation in the procedural learning regions (declarative learning regions) more (less) in the post-training run than in the pre-training run.

Behavioral Findings

Response Time

Response times for evaluative and non-evaluative tasks were recorded during both the pre-training and the post-training runs. Unlike in Experiment 1, responses to images in Experiment 2 had a 3000ms window in both pre-training and post-training runs. Consequently, 47 responses (3.22% of all responses) faster than 300 ms were regarded as missing data as they most likely reflected late responses to the previously presented images. In addition, response times outside the range of $[M - 2.5SD, M + 2.5SD]$ for each individual in each run were deleted as outliers. Overall, 20 response times were regarded as outliers (1.37% of all responses).

Response times were analyzed as a function of run (pre- vs. post-training) and task (evaluative vs. non-evaluative) using a mixed model with linear and quadratic trends in time as covariates. The analysis revealed a significant main effect of run on response time, $F(1, 1387) = 14.99, p < .001$. Specifically, participants responded to images faster in the post-training run than in the pre-training run, $M_{\text{diff}} = -94.44$ ms. In addition, there was a significant main effect of task, $F(1, 1387) = 32.72, p < .001$. That is, across the pre- and post- training runs, participants responded faster to evaluations than to frequency judgments, $M_{\text{diff}} = -139.55$ ms. Moreover, there was a marginal interaction between run and task in response time, $F(1, 1387) = 2.98, p < .10$. Participants reported evaluations faster during the post-training run ($M = 1866.87$ ms) than the pre-training run ($M = 2003.41$ ms), $p < .001$. Although response times for non-evaluative tasks tended to be faster in the post-training run than in the pre-training run, the effect was not significant, $M = 2048.51$ vs. 2100.86 ms, $p > .10$. In sum, these findings suggest that trained evaluative responses speeded up, whereas untrained non-evaluative responses did not.

A manipulation check was also performed to examine whether evaluative and non-evaluative judgments were proceduralized in the pre-training run. For this purpose, separate mixed models of the effects of experiment time on response time were used for evaluative tasks and non-evaluative tasks in the pre-training run. Results showed no linear trend or quadratic trend in response times for either evaluative or non-evaluative tasks in the pre-training run, $F_s < 1$. Furthermore, the same analysis was performed for the post-training run to see whether evaluative judgments received further proceduralization in the post-training run. Results showed no speeding up in evaluations during the post-training run, $F < 1$, confirming that evaluations were proceduralized during the evaluative skill learning session. In contrast, in the post-training run, the linear trend in response times for non-evaluative judgments was marginally significant,

$F(1, 21.85) = 3.68, p = .07$. This manipulation check confirmed that there were no training effects on either evaluative or non-evaluative tasks in the pre-training run. In contrast, evaluative tasks were proficiently proceduralized in the evaluation training session as the speed was not improved in the post-training run. However, because non-evaluative tasks were not practiced between the pre- and post- training runs, we observed practice effects on non-evaluative tasks during the post-training run.

Responses to Tasks

Ratings of visual stimuli that were made with invalid response times were regarded as missing ratings. Then, to examine the effects of training on evaluative judgments on participants' ratings of pleasantness, a 2 (run: pre-training vs. post-training run) X 2 (valence: pleasant vs. unpleasant images) ANOVA was performed on task ratings. Means of responses related to this analysis appear in Table 3-4. Results indicated a significant main effect of valence on pleasantness ratings, $F(1, 174) = 208.69, p < .001$. Not surprisingly, pictures selected as pleasant did receive higher pleasantness ($M = 3.84$) ratings than pictures selected as unpleasant ($M = 2.86$). Moreover, there was a significant interaction between run and valence, $F(1, 24.70) = 29.64, p < .001$. That is, the difference in pleasantness ratings of positive and negative images was greater in the post-training run ($M = 3.99$ vs. 2.64 , positive vs. negative images, pairwise comparison, $p < .001$) than in the pre-training run ($M = 3.69$ vs. 3.08 , positive vs. negative images, pairwise comparison, $p < .001$). Furthermore, tests of simple effects showed that pleasant images were rated as more pleasant in the post-training run than in the pre-training run, $M = 3.99$ vs. $3.69, p < .01$. In addition, unpleasant images were rated as more unpleasant after the evaluation training, $M = 2.64$ vs. 3.08 , post-training vs. pre-training run, $p < .001$. No main effect of run was found on evaluative responses, $p < .30$.

A comparison between non-evaluative (frequency-related) ratings in pre-training and post-training runs was examined by conducting a 2 (run: pre-training vs. post-training run) X 2 (valence: pleasant vs. unpleasant images) ANOVA. Means of responses related to this analysis appear in Table 3-4. First, the main effect of run was significant, $F(1, 4.87) = 6.54, p < .05$. That is, images presented in the post-training run ($M = 3.20$) were rated as less frequently seen on TV than the ones presented in the pre-training run ($M = 3.37$). Moreover, we found a marginal 2-way interaction between run and valence, $F(1, 2.26) = 3.04, p = .08$. Specifically, there was no difference in frequency ratings between positive ($M = 3.36$) and negative images ($M = 3.37$) in the pre-training run, *ns*. However, in the post-training run, negative images ($M = 3.09$) were regarded as seen less often than positive images ($M = 3.31$), $p < .05$. In other words, frequency ratings to pleasant images did not differ across runs, whereas those to unpleasant images decreased. No main effect of valence on frequency ratings was found, $p > .10$.

Furthermore, the distribution of ratings for both types of tasks in the pre- and post-training run appears in Table 3-5. Specifically, participants made use of all four buttons during both evaluative and non-evaluative tasks, rather than simplifying the task by using only the extreme ratings. Importantly, although participants rated positive images as more pleasant than negative images to a greater extent in the post-training (vs. pre-training) run, an equality test indicated that the distribution of the frequency of responses did not change from the pre- to the post-training runs, $K-S Z < 1, ns$. However, the frequency of using different buttons for non-evaluative tasks was distributed differently in the post-training run than in the pre-training run, $K-S Z = 1.65, p < .01$.

In addition, as another indicator of improved performance across runs, the percentage of omitted trials for each type of task decreased significantly in the post-training (vs. pre-training)

run (see Table 3-5 for number of omitted trials for each condition). Specifically, for evaluative tasks, the percentage of omitted trials dropped significantly from the pre- (rate = 19.50%) to the post-training run (rate = 6.90%), $\chi^2(1, N = 840) = 29.16, p < .001$. Reduced omit rate was also found for non-evaluative tasks (26.70% vs. 10.95%, pre-training vs. post-training run, respectively), $\chi^2(1, N = 840) = 33.96, p < .001$.

Functional Imaging Data Analyses

The functional imaging data of each participant were analyzed using BrainVoyager 1.7.6 (Brain Innovations, Maastricht, Holland) and SPSS 13. The functional images were coregistered with anatomic images, and normalized to Talairach space for each participant. Functional data were processed with 3D motion correction, linear trend removal, slice scan time correction, and spatial smoothing. The pre-training and post-training runs underwent Gaussian spatial smoothing using a kernel of 5.7 mm (1.5 voxels) full-width half-maximum (FWHM).

Task-related activity was mapped using a voxel-wise general linear modeling analysis. For event-related analyses, the BOLD responses were estimated using a standard hemodynamic model (Friston, Josephs, Rees, & Turner, 1998). The estimated responses were fit to the MR signal for each individual to generate a beta weight. Then, in the pre- and post-training runs, BOLD responses in each ROI at each time point were obtained, including evaluative, non-evaluative, and null trials.

After that, for each pre-training and post-training run event, percentage signal change was calculated. Specifically, voxels within each ROI were averaged to create a single time series (containing 90 time points) for each participant during each run. Within each run, percent changes in BOLD signal associated with evaluative (non-evaluative) responses were calculated as the difference between the magnetic resonance signal during the evaluative (non-evaluative) tasks and the signal during the null trials, divided by the average BOLD signal during the null

trials. At last, a mixed model with linear and quadratic time trends as covariates was used to estimate the effects of task (evaluative vs. non-evaluative judgments) and run (pre- vs. post-training).

Tests of Evaluation Proceduralization

Regions-of-interest were created for regions proposed to be involved in evaluation proceduralization (see Table 3-6 for relevant coordinates of each ROI). As ROIs were defined a priori, the same ROI template was applied to all participants. For each individual participant, separate estimates of the hemodynamic response were generated for each condition at each voxel using a deconvolution analysis. All voxels within 5mm around the centers of the ROIs in Table 3-6 were included in the analysis. Specifically, the percentage of BOLD signal changes in these ROIs at each second in the pre-training and the post-training runs were calculated as the difference between the BOLD signal during the (evaluative, non-evaluative) tasks and the BOLD signal during the fixation points (i.e., the null trials), divided by the BOLD signal in fixation points in the corresponding run. For example, a BOLD signal change of 0.50 (–0.50) at a certain time point indicates a regional activity of 50% percentage higher (lower) than the baseline activity of that individual during the corresponding run (pre- or post- training run).

Mixed model analysis. In the current study, the evaluative and non-evaluative tasks, as well as the null trials, were randomly presented in both the pre- and the post- training runs. Therefore, for each participant, the time intervals between evaluative-task trials and between non-evaluative-task trials were not constant. In this situation, autocorrelation coefficients can only be obtained directly by fitting a smoothed approximation to the time series. Therefore, we fitted time series using the mixed-model module of SPSS. This model incorporates between-subjects variability and allows modeling covariances that need to be considered.

To test the significance of signal change, regional amplitude estimates in each region were entered into the mixed model module of SPSS. Specifically, the mixed model entailed practice run (pre- vs. post- training), valence (pleasant vs. unpleasant), and task (evaluative vs. non-evaluative) as factors, with linear and quadratic time trends as covariates. The linear and quadratic time trends were included to model the time series. All factors were fixed, and an autoregressive residual covariance structure (AR1) was used to account for the autocorrelation in the time series data. In addition, correlations between linear (quadratic) time trend and other factors (i.e., task, valence, and run) were included in the analysis. The degrees of freedom in the mixed model were calculated using the Satterthwaite approximation, which produces data dependent degrees of freedom. Statistical thresholds for mixed-model analyses for each ROI were set at $p < .05$.

Cluster analysis. To test our hypotheses of activity change in regions of similar functions, estimated regional BOLD signals of ROIs with similar predicted functions were congregated into clusters before entered to mixed models. Correction of alpha errors was applied at the cluster level.

Findings in Regions Associated with Learning

Regions associated with procedural learning. To confirm our hypotheses that evaluation proceduralization produces increased activities in brain regions previously associated with procedural learning, we centered the caudate nucleus on $\pm 9, 15, 4$ (Poldrack et al., 1999), the putamen on $18, -1, 15$ (Mallol et al., 2007) and $-27, 8, 4$ (located in an independent study, $N = 8$), the nucleus accumbens on $-4, 6, -2$ (Lieberman et al., 2004), the cerebellum on $31, -65, -18$ (Willingham et al., 2002), the precuneus on $12, -67, 50$ (Willingham et al., 2002), the inferior parietal lobe on $50, -26, 36$ (Poldrack et al., 1999) and $-34, -46, 56$ (Mallol et al., 2007), and the inferior frontal gyri on $\pm 47, 17, 24$ and $\pm 43, 3, 32$ (Maccotta & Buckner, 2004) (see Table 3-6

for a list of information for each ROI). These regions were included in the cluster of procedural learning in the cluster analysis.

Caudate nucleus. The right caudate nucleus area (located around 9, 15, 4; Poldrack et al., 1999) showed a significant main effect of run, $F(1, 1310) = 9.46, p = .002$. The activation of the right caudate nucleus was higher in the post-training run than in the pre-training run, $M_{\text{diff}} = 0.11, t(1310) = 3.08, p = .002$. This between-run effect was present in the evaluative tasks ($M = 0.14, 95\% \text{ CI} = 0.04, 0.24$, vs. $M = 0.29, 95\% \text{ CI} = 0.18, 0.39$; pre-training vs. post-training run, $p < .01$), but not in non-evaluative tasks ($M = 0.21, 95\% \text{ CI} = 0.10, 0.32$, vs. $M = 0.28, 95\% \text{ CI} = 0.18, 0.38$; pre-training vs. post-training run, $p > .15$). However, the interaction between run and task did not reach significance, $F(1, 1559) = 1.11, p > .20$. Also, there were no simple effects of different types of task on the right caudate nucleus in either the pre-training or the post-training run, both $ps > .30$.

We found a similar BOLD signal change pattern in the left caudate nucleus (centered on $-9, 15, 4$). Specifically, the effect of different run (pre-training vs. post-training run) was marginally significant, $F(1, 1293) = 3.45, p = .06$. The left caudate nucleus was more active in the post-training run ($M = 0.25, 95\% \text{ CI} = 0.14, 0.36$) than in the pre-training run ($M = 0.19, 95\% \text{ CI} = 0.08, 0.30$). Moreover, the interaction between run and task reached a marginal significance, $F(1, 1534) = 3.66, p = .06$. As in the right caudate nucleus, the activation of the left caudate nucleus for evaluative tasks was higher in the post-training run ($M = 0.28, 95\% \text{ CI} = 0.16, 0.40$) than in the pre-training run ($M = 0.15, 95\% \text{ CI} = 0.03, 0.27; p < .01$), but there was no between-run difference in the activation for non-evaluative tasks ($M = 0.23, 95\% \text{ CI} = 0.11, 0.36$, vs. $M = 0.23, 95\% \text{ CI} = 0.11, 0.35$, pre-training vs. post-training run, *ns*). Again, we found no between-task differences in the left caudate nucleus either before or after the training run, both $ps > .05$.

Because the findings in the left and right caudate nucleus were similar, BOLD signals were combined to test the overall effects of evaluation proceduralization in the caudate nucleus region. Results of the mixed model showed a main effect of run, $F(1, 1297) = 6.94, p < .01$. That is, the bilateral caudate nucleus was more active in the post-training run ($M = 0.27, 95\% \text{ CI} = 0.17, 0.37$) than the pre-training run ($M = 0.18, 95\% \text{ CI} = 0.09, 0.28$). In addition, evaluative tasks triggered higher activation in the bilateral caudate nucleus in the post-training run ($M = 0.28, 95\% \text{ CI} = 0.18, 0.39$) than in the pre-training run ($M = 0.14, 95\% \text{ CI} = 0.04, 0.25$), $p < .01$. In contrast, the activation in the bilateral caudate nucleus for non-evaluative tasks did not change ($M = 0.22, 95\% \text{ CI} = 0.11, 0.33$ vs. $M = 0.26, 95\% \text{ CI} = 0.15, 0.37$, pre-training vs. post-training run, *ns*). However, the interaction between task and run did not reach significance, $F(1, 1541) = 2.44, p = .12$. No main effect of task was found, $F < 1$.

Putamen. There were main effects of run and task on the caudoventral regions of putamen (centered on 18, -1, 15; Mallol et al., 2007). Specifically, activation in this putamen area was higher in the post-training run ($M = 0.27, 95\% \text{ CI} = 0.21, 0.33$) than the pre-training run ($M = 0.18, 95\% \text{ CI} = 0.11, 0.24$), $F(1, 1410) = 12.67, p < .001$. Moreover, this increased activation in the caudoventral putamen was found for both evaluative ($M = 0.21, 95\% \text{ CI} = 0.14, 0.28$, vs. $M = 0.29, 95\% \text{ CI} = 0.22, 0.36$; pre- vs. post- training run, $p < .05$) and non-evaluative tasks ($M = 0.14, 95\% \text{ CI} = 0.07, 0.22$, vs. $M = 0.25, 95\% \text{ CI} = 0.18, 0.32$; pre- vs. post- training run, $p < .01$). In addition, evaluative tasks ($M = 0.25, 95\% \text{ CI} = 0.19, 0.31$) triggered more brain activity in the caudoventral putamen than non-evaluative tasks ($M = 0.20, 95\% \text{ CI} = 0.13, 0.26$), $F(1, 1625) = 4.63, p < .05$. No other main effects or interactions were found, $F_s < 1$.

The rostradorsal regions of the putamen (centered on -27, 8, 4; located in an independent study, $N = 8$) exhibited a different pattern reflected in a significant main effect of run, $F(1,$

1392) = 18.36, $p < .001$. Specifically, activation in the rostradorsal putamen decreased with practice, both for evaluative tasks ($M = 0.33$, 95% CI = 0.18, 0.48, vs. $M = 0.22$, 95% CI = 0.07, 0.37, pre-training vs. post-training run, $p < .01$) and non-evaluative tasks ($M = 0.35$, 95% CI = 0.20, 0.49, vs. $M = 0.20$, 95% CI = 0.05, 0.35, pre-training vs. post-training run, $p < .001$).

Nucleus accumbens. There was a significant main effect of run on the left nucleus accumbens area (located around $-4, 6, -2$; Lieberman et al., 2004), $F(1, 1322) = 54.61$, $p < .001$. Specifically, the activation of the nucleus accumbens was higher in the post-training run than in the pre-training run, for both evaluative tasks ($M = 0.30$, 95% CI = 0.12, 0.47, vs. $M = -0.11$, 95% CI = $-0.28, 0.07$, post-training vs. pre-training run, $p < .001$) and non-evaluative tasks ($M = 0.34$, 95% CI = 0.17, 0.52, vs. $M = 0.01$, 95% CI = $-0.17, 0.19$, post-training vs. pre-training run, $p < .001$). There was no difference in nucleus accumbens activation between different types of task within either the pre-training or the post-training run, *ns*.

Furthermore, we found a significant interaction between task and valence in the left nucleus accumbens, $F(1, 1562) = 4.08$, $p < .05$. Specifically, when tasks were evaluative, the average BOLD signal change in the nucleus accumbens was 0.11 (95% CI = $-0.07, 0.29$) for pleasant images and 0.06 (95% CI = $-0.11, 0.24$) for unpleasant images, *ns*. In contrast, when tasks were non-evaluative, the average BOLD signal change was higher for unpleasant images ($M = 0.26$, 95% CI = 0.08, 0.44) than for pleasant images ($M = 0.11$, 95% CI = $-0.07, 0.29$), $p < .05$. No other main effects or interactions were significant, $ps > .10$.

Cerebellum. There was a main effect of run on the activation of the right cerebellum area (located around $31, -65, -18$; Willingham et al., 2002), $F(1, 1217) = 15.01$, $p < .001$. That is, the cerebellum was more active in the post-training run ($M = 1.54$, 95% CI = 1.30, 1.79) than was in the pre-training run ($M = 1.29$, 95% CI = 1.05, 1.54), $p < .001$. There was also a

significant interaction between run and task, $F(1, 1499) = 4.52, p < .05$. Specifically, the cerebellum was more active for evaluative tasks in the post-training run ($M = 1.59, 95\% \text{ CI} = 1.35, 1.85$) than in the pre-training run ($M = 1.20, 95\% \text{ CI} = 0.93, 1.45$), $p < .001$. In contrast, there was no between-run difference in the cerebellum activation for non-evaluative tasks, $M = 1.39$ ($95\% \text{ CI} = 1.13, 1.66$) vs. $M = 1.50$ ($95\% \text{ CI} = 1.24, 1.76$), pre-training vs. post-training, *ns*. In addition, during the pre-training run, the cerebellum was more active for non-evaluative tasks ($M = 1.39$) than for evaluative tasks ($M = 1.20$), $p < .05$. However, the activation of the cerebellum in the post-training run did not differ across non-evaluative ($M = 1.50$) and evaluative tasks ($M = 1.59$), *ns*. No other main effects or interactions were found, *ns*.

Superior parietal lobe. We found a significant main effect of run on the precuneus area (BA 7; located around 12, -67, 50; Willingham et al., 2002), $F(1, 1185) = 12.37, p < .001$. In general, the right BA 7 was more active after the training run ($M = 0.42, 95\% \text{ CI} = 0.28, 0.55$) than before the training run ($M = 0.28, 95\% \text{ CI} = 0.15, 0.41$). Moreover, there was a significant interaction between run and task, $F(1, 1493) = 4.32, p < .05$. Specifically, the precuneus activation for evaluative tasks increased significantly in the post-training run ($M = 0.44, 95\% \text{ CI} = 0.29, 0.58$) compared to the activation in the pre-training run ($M = 0.22, 95\% \text{ CI} = 0.08, 0.36$), $p < .001$. In contrast, the activation in the precuneus did not change for non-evaluative tasks ($M = 0.34, 95\% \text{ CI} = 0.19, 0.49$ vs. $M = 0.39, 95\% \text{ CI} = 0.25, 0.54$, pre-training vs. post-training run, *ns*). In addition, the activity of the precuneus was higher for non-evaluative tasks (vs. evaluative tasks) in the pre-training run, $p < .05$, but did not differ for the post-training run, *ns*. No other main effects or interactions were found.

Inferior parietal lobe. In addition to the superior part of the parietal lobe, we tested effects of run, task, and valence on the right inferior parietal lobe (centered on 50, -26, 36;

Poldrack et al., 1999). Results showed a marginally significant interaction between run and task in this region, $F(1, 1595) = 3.14, p = .08$. Specifically, the right inferior parietal lobe was less active for evaluative tasks in the post-training run ($M = 0.15, 95\% \text{ CI} = 0.04, 0.25$) than in the pre-training run ($M = 0.23, 95\% \text{ CI} = 0.12, 0.33$), $p < .05$. However, there was no between-run difference in the activation of the right inferior parietal lobe for non-evaluative tasks, ($M = 0.14, 95\% \text{ CI} = 0.04, 0.25$, vs. $M = 0.16, 95\% \text{ CI} = 0.06, 0.27$; pre-training vs. post-training run, *ns*). No other main effects or interactions were found, $F_s < 1$.

We also found a marginally significant interaction between task type and run for the left inferior parietal lobe (centered on $-34, -46, 56$; Mallol et al., 2007), $F(1, 1654) = 3.35, p = .07$. However, the pattern of signal change was different from that of the right inferior parietal lobe. Specifically, the activation at the left inferior parietal region for evaluative tasks increased significantly from the pre- ($M = -0.97, 95\% \text{ CI} = -1.757, -0.185$) to the post- ($M = 0.62, 95\% \text{ CI} = -0.20, 1.44$) training run, $p < .01$. In contrast, there was no significant regional activity change for non-evaluative tasks ($M = 0.33, 95\% \text{ CI} = -0.53, 1.20$, vs. $M = 0.39, 95\% \text{ CI} = -0.43, 1.22$; pre- vs. post- training run, *ns*).

BA 46. To test effects of training on evaluation in the inferior frontal area, we centered the BA 46 on $-47, 17, 24$ (Maccotta & Buckner, 2004). Results showed a significant main effect of run (pre-training vs. post-training), $F(1, 1185) = 26.28, p < .001$, indicating that the BA 46 region was more active in the post-training run ($M = 0.56, 95\% \text{ CI} = 0.46, 0.66$) than in the pre-training run ($M = 0.40, 95\% \text{ CI} = 0.30, 0.50$). Moreover, there was an interaction between run and task, $F(1, 1484) = 4.47, p < .05$. Specifically, post training increases in the activation in the left BA 46 were greater for evaluative ($M = 0.36, 95\% \text{ CI} = 0.25, 0.47$, vs. $M = 0.58, 95\% \text{ CI} = 0.47, 0.69$; pre-training vs. post-training run, $p < .001$) than non-evaluative tasks ($M = 0.45, 95\%$

CI = 0.34, 0.56, vs. $M = 0.54$, 95% CI = 0.43, 0.64; pre-training vs. post-training run, $p = .05$).

Further analysis revealed that, in the pre-training run, non-evaluative tasks ($M = 0.45$) triggered higher left BA 46 activation than evaluative tasks ($M = 0.36$), $p < .05$, a pattern not present after the training run for either evaluative or non-evaluative tasks ($M_s = 0.58$ and 0.54), *ns*.

In addition, we found a similar BOLD change pattern in the right BA 46 area (centered on 47, 17, 24). After evaluative training, activity in the right BA 46 area increased ($M = 0.30$, 95% CI = 0.21, 0.40, vs. $M = 0.41$, 95% CI = 0.31, 0.50; pre- vs. post- training run), $F(1230) = 13.80$, $p < .001$. Moreover, there was a marginally significant interaction between task and run, $F(1, 1498) = 3.59$, $p = .06$. The activity in the right BA 46 increased for evaluative tasks ($M = 0.26$, 95% CI = 0.16, 0.36 vs. $M = 0.42$, 95% CI = 0.32, 0.52; pre-training vs. post-training run, $p < .001$), but did not change for non-evaluative tasks ($M = 0.34$, 95% CI = 0.24, 0.44 vs. $M = 0.39$, 95% CI = 0.29, 0.49; pre-training vs. post-training run, *ns*). Similar to the left BA 46 region, in the pre-training run, the right BA 46 region was more active for non-evaluative tasks ($M = 0.34$) than for evaluative tasks ($M = 0.26$), $p = .06$. However, the post-training run showed no effect of type of task ($M = 0.39$ vs. 0.42 , non-evaluative vs. evaluative tasks), *ns*. No effects of valence (pleasant vs. unpleasant images) were found on either the left or right BA 46 areas.

BOLD signals in the left and right BA 46 areas were combined to represent the activation change in bilateral BA 46 areas. Results of the mixed model revealed a main effect of run, $F(1, 1201) = 26.23$, $p < .001$. That is, the bilateral BA 46 was more active after ($M = 0.47$, 95% CI = 0.39, 0.55) than before ($M = 0.35$, 95% CI = 0.27, 0.42) the evaluative training, $p < .001$. As in the left and right BA 46, there was an interaction between task and run in the bilateral BA 46, $F(1, 1483) = 5.40$, $p < .05$. Specifically, the post-training activation of the bilateral BA 46 increased for evaluative tasks ($M = 0.30$, 95% CI = 0.22, 0.39, vs. $M = 0.49$, 95% CI = 0.41,

0.58, pre- vs. post- training run, $p < .001$), but not for non-evaluative tasks ($M = 0.39$, 95% CI = 0.30, 0.48, vs. $M = 0.45$, 95% CI = 0.37, 0.54, pre- vs. post- training run, $p > .05$).

BA 9. Similarly, we found an interaction of run and task in another inferior frontal area around 43, 3, 32 (BA 9; located in Maccotta & Buckner, 2004), $F(1, 1475) = 4.13$, $p < .05$. After training, activation in the right BA 9 increased more for evaluative tasks ($M = 0.34$ vs. 0.58, pre- vs. post- training run, $p < .001$), than non-evaluative tasks ($M = 0.44$ vs. 0.56, pre- vs. post- training run, $p < .01$). Also, activation in the left BA 9 (centered on $-43, 3, 32$) increased after the training run for both evaluative ($M = 0.38$ vs. 0.62; pre-training vs. post-training run, $p < .001$) and non-evaluative tasks ($M = 0.43$ vs. 0.60; pre-training vs. post-training run, $p < .001$).

Similarly to the BA 46, the left and right BA 9 areas were combined to represent the activation change in bilateral BA 9 areas. Analyses revealed a main effect of run, $F(1, 1199) = 56.72$, $p < .001$, indicating more activity after ($M = 0.59$, 95% CI = 0.50, 0.68) than before ($M = 0.39$, 95% CI = 0.31, 0.48) the evaluative training, $p < .001$. Unlike in the left and right BA 9, however, we found a marginal interaction between task and run in the bilateral BA 9, $F(1, 1472) = 3.16$, $p = .08$. Specifically, the post-training activation of the bilateral BA 9 increased for evaluative tasks ($M = 0.36$, 95% CI = 0.26, 0.45, vs. $M = 0.60$, 95% CI = 0.50, 0.69, pre- vs. post- training run, $p < .001$) to a greater extent than for non-evaluative tasks ($M = 0.43$, 95% CI = 0.34, 0.53, vs. $M = 0.58$, 95% CI = 0.48, 0.67, pre- vs. post- training run, $p < .001$).

Summary. Results in above brain regions previously associated with procedural learning showed that, when evaluations are proceduralized, activations in the striatal system (i.e., the caudate nucleus, the caudoventral putamen, and the nucleus accumbens), the cerebellum, the precuneus, and the inferior frontal cortices, increase. Moreover, as predicted, unlike the caudoventral putamen, the rostradorsal putamen activation decreased with evaluation

proceduralization. Also, different areas of the inferior parietal lobe showed different patterns of signal change with evaluation proceduralization. A summary of findings in regions associated with procedural learning appears in Table 3-7. Maps for brain activity changes for evaluative tasks in regions linked to procedural learning are included in Figure 3-3.

Regions associated with declarative learning. To test our hypotheses that evaluation proceduralization is associated with decreased activity in brain regions implicated in declarative learning, we centered the medial temporal lobe on coordinates $-32, -15, -24$ (Rose et al., 2004), the dorsolateral prefrontal cortex on $-30, 55, 24$ (Klingberg et al., 1997) and $48, 41, 9$ (Taylor et al., 2003), and the ventromedial prefrontal lobe on $-22, 30, -16$ (Lieberman et al., 2004) (see Table 3-6 for a list of information for each ROI). These regions were included in the cluster of declarative learning in the analysis at the cluster level.

Medial temporal lobe (MTL). Analyses revealed a marginally significant main effect of run on the activation of the left medial temporal lobe area (located around $-39, -15, -24$; Rose et al., 2004), $F(1, 1458) = 3.08, p = .08$. That is, the MTL area was less active during the post-training run ($M = -0.07, 95\% \text{ CI} = -0.17, 0.02$) than the pre-training run ($M = 0.05, 95\% \text{ CI} = -0.05, 0.14$). More interestingly, the decreased activation was present for evaluative tasks ($M = 0.09, 95\% \text{ CI} = 0, 0.18$, vs. $M = -0.12, 95\% \text{ CI} = -0.21, -0.03$; pre- vs. post- training run, $p = .002$), but not for non-evaluative tasks ($M = 0.07, 95\% \text{ CI} = -0.07, 0.21$, vs. $M = 0.01, 95\% \text{ CI} = -0.12, 0.15$; pre- vs. post- training run, ns), $p > .10$. Thus, in the pre-training run, the MTL was equally active for evaluative ($M = 0.09$) and non-evaluative tasks ($M = 0.07$), ns . In contrast, in the post-training run, evaluative tasks ($M = -0.12$) triggered lower activation in the MTL than non-evaluative tasks ($M = 0.01$), $p < .05$. No effects of valence were found.

Dorsolateral prefrontal cortex (dlPFC). We found a main effect of task (evaluative vs. non-evaluative tasks) on the dlPFC (located around $-30, 55, 24$; Klingberg et al., 1997), $F(1, 1676) = 6.59, p = .01$. The activation of dlPFC was higher for evaluative tasks ($M = 0.37, 95\% \text{ CI} = -0.01, 0.75$) than for non-evaluative tasks ($M = 0.12, 95\% \text{ CI} = -0.27, 0.50$). In addition, the interaction between task and run reached significance, $F(1, 1673) = 3.77, p = .05$. Specifically, the dlPFC activation for evaluative tasks decreased significantly from the pre- ($M = 0.55, 95\% \text{ CI} = 0.15, 0.95$) to the post- training run ($M = 0.20, 95\% \text{ CI} = -0.21, 0.60$), $p = .01$. However, the activation at the dlPFC for non-evaluative tasks did not change ($M = 0.09, 95\% \text{ CI} = -0.32, 0.50$, vs. $M = 0.14, 95\% \text{ CI} = -0.27, 0.54$, *ns*, pre- vs. post- training run).

Furthermore, we found a main effect of run on the right dlPFC area (centered on $48, 41, 9$; Taylor et al., 2003), $F(1, 1312) = 8.80, p < .01$, indicating lower activation in the post-training ($M = 0.01, 95\% \text{ CI} = -0.06, 0.07$) than in the pre-training ($M = 0.15, 95\% \text{ CI} = 0.08, 0.21$) run. Moreover, this decreased activation was present for evaluative tasks ($M = 0.17, 95\% \text{ CI} = 0.08, 0.26$, vs. $M = -0.01, 95\% \text{ CI} = -0.10, 0.08$; pre- vs. post- training run, $p < .01$), but not for non-evaluative tasks ($M = 0.13, 95\% \text{ CI} = 0.03, 0.23$, vs. $M = 0.02, 95\% \text{ CI} = -0.07, 0.12$; pre- vs. post- training run, *ns*), $p > .10$. No other main effects or interactions were found, $F_s < 1$.

Because the findings in the left and right dlPFC areas are similar, the signal changes in these two areas were combined to represent the activation change in the dlPFC region. Results revealed a main effect of run, $F(1, 1581) = 6.43, p = .01$. That is, the dlPFC activation was lower in the post-training run ($M = 0.10, 95\% \text{ CI} = -0.15, 0.34$) than the pre-training run ($M = 0.24, 95\% \text{ CI} = -0.01, 0.48$), $p = .01$. There was also a main effect of task on this region, $F(1, 1635) = 5.51, p < .05$. That is, across the runs, evaluative tasks ($M = 0.23, 95\% \text{ CI} = -0.01, 0.47$) triggered higher activation in the dlPFC than did non-evaluative tasks ($M = 0.10, 95\% \text{ CI} =$

-0.14, 0.34). Moreover, we found an interaction between task and run, $F(1, 1630) = 4.68, p < .05$. Specifically, the activation in the dlPFC for evaluative tasks decreased significantly ($M = 0.37, 95\% \text{ CI} = 0.11, 0.62$, vs. $M = 0.10, 95\% \text{ CI} = -0.15, 0.35$, pre-training vs. post-training run), $p < .001$. In contrast, the dlPFC activation for non-evaluative tasks did not change ($M = 0.11, 95\% \text{ CI} = -0.15, 0.36$, vs. $M = 0.09, 95\% \text{ CI} = -0.16, 0.34$, pre-training vs. post-training run), *ns*.

Ventromedial prefrontal cortex (vmPFC). There was a main effect of task on the left vmPFC area (located around $-22, 30, -16$; Lieberman et al., 2004), $F(1, 1656) = 7.32, p < .01$. That is, the left vmPFC was more active for evaluative ($M = 0.09, 95\% \text{ CI} = -0.09, 0.27$) than for non-evaluative ($M = -0.27, 95\% \text{ CI} = -0.45, -0.08$) tasks. In addition, there was an interaction between run and task, $F(1, 1660) = 4.88, p < .05$. Specifically, the activation in the vmPFC for evaluative tasks decreased from the pre- ($M = 0.32, 95\% \text{ CI} = 0.08, 0.57$) to the post-training run ($M = -0.14, 95\% \text{ CI} = -0.40, 0.12$), $p = .01$, whereas the activation for non-evaluative tasks did not change ($M = -0.33, 95\% \text{ CI} = -0.60, -0.06$, vs. $M = -0.21, 95\% \text{ CI} = -0.46, 0.05$, pre-training vs. post-training, *ns*). In addition, when looking at the activation pattern within each run, we found that before the evaluation training run, the left vmPFC was more active for evaluative ($M = 0.32$) than non-evaluative tasks ($M = -0.33$) tasks, $p < .001$. However, there was no between-task difference after the training run ($M = -0.14$ vs. -0.21 , evaluative vs. non-evaluative tasks), *ns*. No other main effects or interactions were found, $F_s < 1$.

Summary. The above results in regions previously associated with declarative learning indicate that evaluation proceduralization reduces brain activities in these regions. Specifically, when evaluations were proceduralized, brain activities in the medial temporal lobe, the dorsolateral prefrontal cortex, and the ventromedial prefrontal cortex decreased to or

significantly below the baseline activation. A summary of findings in regions associated with declarative learning appears in Table 3-8. Maps for brain activity changes for evaluative tasks in regions linked to declarative learning are included in Figure 3-3.

Findings in Regions Associated with Evaluation

To test the effects of practice with evaluations in regions associated with evaluative processing, we obtained coordinates of ROIs from different sources. First, the bilateral amygdala was located using a computer-generated image based on the Talairach-defined coordinates (Norris et al., 2004). Specifically, regions capturing the right and left amygdala ROIs extended from ± 33 (left) to ± 12 (right) in the x -plane; from 2 (posterior) to -12 (anterior) in the y -plane; and from -37 (inferior) to -7 (superior) in the z -plane. Moreover, several regions associated with evaluative processing of images were taken directly from previous research. That is, voxels within 5mm of the temporal pole (BA 38; 42, 8, -30) and the frontal operculum ($-46, 14, 6$) were used to define the regions of interest (Lane et al., 1997). In addition, we located the anterior cingulate cortex around $-4, 24, 32$ (Cunningham et al., 2004), the insula around $-30, 23, 7$ (located in an independent study, $N = 8$), and the orbito-frontal cortex around $45, 35, -4$ (BA47; Maccotta & Buckner, 2004) (see Table 3-6 for a list of coordinates of ROIs related to evaluation). We expected that evaluation proceduralization would either increase or decrease activities in these evaluation-related brain regions. Moreover, evaluation proceduralization should produce comparable changes in regions associated with both automatic and controlled evaluation. Regions previously linked to automatic (controlled) evaluation were included in the cluster of automatic (controlled) evaluation in the cluster analysis of regional change with evaluation proceduralization.

Amygdala. We found a significant between-run difference in the activation of the left amygdala area, $F(1, 1330) = 9.82, p = .002$. Specifically, the left amygdala was more active

during the post-training run ($M = 0.32$, 95% CI = 0.21, 0.43) than the pre-training run ($M = 0.22$, 95% CI = 0.11, 0.34). This increased activation of the left amygdala was present for both evaluative ($M = 0.22$, 95% CI = 0.10, 0.34, vs. $M = 0.30$, 95% CI = 0.18, 0.42; pre- vs. post-training run, $p = .09$) and non-evaluative ($M = 0.23$, 95% CI = 0.11, 0.35, vs. $M = 0.35$, 95% CI = 0.23, 0.47; pre- vs. post- training run, $p < .01$) tasks.

Moreover, we found a significant main effect of valence in the activation of the left amygdala, $F(1, 1577) = 4.27$, $p < .05$. That is, the left amygdala had the tendency to be more active for pleasant images ($M = 0.31$, 95% CI = 0.19, 0.42) than unpleasant images ($M = 0.25$, 95% CI = 0.13, 0.36), $F(1, 1579) = 3.29$, $p = .07$. Interestingly, there was a marginal interaction between run and valence, $F(1, 1553) = 3.01$, $p = .08$. After the training run, the activation of the left amygdala for pleasant images increased ($M = 0.23$, 95% CI = 0.11, 0.35, vs. $M = 0.38$, 95% CI = 0.26, 0.51, $p < .001$), whereas the activation for unpleasant images did not change ($M = 0.22$, 95% CI = 0.11, 0.34, vs. $M = 0.27$, 95% CI = 0.15, 0.39, *ns*). In addition, in the pre-training run, there was no difference in the activity of the left amygdala for pleasant ($M = 0.23$) and unpleasant images ($M = 0.22$), *ns*. However, in the post-training run, the amygdala was significantly more active for pleasant ($M = 0.38$) than for unpleasant images ($M = 0.27$), $p < .05$. Thus, we can conclude that, over time, the more emotional images participants viewed, the more the left amygdala was active, regardless of the explicit task participants performed.

In addition, consistent with previous findings (e.g., Cunningham et al., 2003), the left amygdala was equally significantly active (vs. null trials) for both types of task in both the pre-training run ($M = 0.22$ vs. 0.23, evaluative vs. non-evaluative tasks, *ns*) and the post-training run ($M = 0.30$ vs. 0.35; evaluative vs. non-evaluative tasks, *ns*). Active amygdala function in

response to emotional images regardless of explicit task instructions and run supports the idea that the amygdala is involved in the automatic aspect of evaluation.

Interestingly, the pattern of activity change in the left amygdala was not present in the right amygdala. Specifically, although there was a significant main effect of run on the right amygdala, $F(1, 1386) = 8.15, p < .01$, this effect was present only for non-evaluative tasks and comprised an increase in activity ($M = 0.24, 95\% \text{ CI} = 0.11, 0.38$, vs. $M = 0.39, 95\% \text{ CI} = 0.25, 0.52$, pre- vs. post- training run, $p < .01$). In contrast, for evaluative tasks, run did not influence activity of the right amygdala ($M = 0.27, 95\% \text{ CI} = 0.13, 0.40$, vs. $M = 0.32, 95\% \text{ CI} = 0.18, 0.45$, pre- vs. post- training run, ns). No other main effects or interactions were found, $F_s < 1$.

Insula. Like the left amygdala area, the left insula (BA 13; $-30, 23, 7$) was more active during the post-training than the pre-training run, $M_{\text{diff}} = 1.08, F(1, 1655) = 109.55, p < .001$. This pattern was found for both evaluative ($M = 0.34, 95\% \text{ CI} = -0.52, 1.19$, vs. $M = 1.38, 95\% \text{ CI} = 0.53, 2.24$; pre-training vs. post-training, $p < .001$) and non-evaluative tasks ($M = 0.30, 95\% \text{ CI} = -0.55, 1.16$, vs. $M = 1.42, 95\% \text{ CI} = 0.57, 2.28$; pre-training vs. post-training, $p < .001$). Moreover, in the pre-training run, the insula was not active (vs. null trials) for either evaluative or non-evaluative tasks. Furthermore, the insula was equally active for evaluative and non-evaluative tasks in the pre-training as well as the post-training run, both $t_s < 1$. Therefore, in the current study, the insula was apparently involved in automatic evaluation, as its activation was not influenced by task instructions in either the pre-training or the post-training run.

Orbito-frontal cortex (OFC). After the evaluative training, the activation in the right lateral orbito-frontal region (BA 47; located around $45, 35, -4$; Maccotta & Buckner, 2004) increased significantly, $M_{\text{diff}} = 0.53, F(1, 1655) = 40.95, p < .001$. The increased activation was present for both evaluative tasks ($M = -0.06, 95\% \text{ CI} = -0.45, 0.33$, vs. $M = 0.43, 95\% \text{ CI} =$

0.04, 0.82, pre- vs. post- training, $p < .001$) and non-evaluative tasks ($M = -0.07$, 95% CI = $-0.46, 0.33$, vs. $M = 0.49$, 95% CI = $0.10, 0.89$, pre- vs. post- training, $p < .001$). Moreover, the right OFC region was equally active for evaluative and non-evaluative tasks in the pre-training (pairwise comparison, *ns*) and the post-training run (pairwise comparison, *ns*). No other main effects or interactions were found, $F_s < 1$. As the pattern of activation change in the OFC was identical to the ones in the amygdala and the insula, we can conclude that, as expected, the OFC was involved in automatic evaluation.

Anterior cingulate cortex. There was a marginal interaction between run and task in the left dorsal ACC area (BA 32; centered on $-4, 24, 32$; Cunningham et al., 2004), $F(1, 1491) = 3.53$, $p = .06$. Specifically, for evaluative tasks, the activity of the ACC was higher in the post-training run ($M = 0.09$, 95% CI = $0.02, 0.16$) than in the pre-training run ($M = 0.02$, 95% CI = $-0.05, 0.09$), $p = .01$. However, for non-evaluative tasks, the ACC activation did not change across runs ($M = 0.06$, 95% CI = $-0.01, 0.13$, vs. $M = 0.07$, 95% CI = $0, 0.14$; pre- vs. post-training run respectively, *ns*). In addition, there were no between-task differences in the ACC activation in either the pre-training run ($M = 0.02$ vs. 0.06 , for evaluative and non-evaluative tasks, *ns*) or the post-training run ($M = 0.09$ vs. 0.07 , for evaluative and non-evaluative tasks, *ns*). No other effects were found in this region, $F_s < 1$. In sum, as predicted, the activation of the ACC only increased for the trained evaluative tasks, not for the untrained non-evaluative tasks.

Frontal operculum. We centered the frontal operculum area on $-46, 14, 6$ (Lane et al., 1997), and found an increased activation in the BOLD signal across runs. That is, this region was more active in the post-training run ($M = 0.43$, 95% CI = $0.31, 0.54$) than in the pre-training run ($M = 0.34$, 95% CI = $0.23, 0.45$), $F(1, 1271) = 4.33$, $p < .05$. The increased activation in the post-training (vs. pre-training) run was present for evaluative tasks ($M = 0.42$, 95% CI = 0.30 ,

0.55, vs. $M = 0.28$, 95% CI = 0.16, 0.41; $p < .05$), but not for non-evaluative tasks ($M = 0.43$, 95% CI = 0.30, 0.56, vs. $M = 0.39$, 95% CI = 0.26, 0.52; *ns*), $p > .15$. Further analysis indicated that, the left frontal operculum was marginally more active for non-evaluative tasks ($M = 0.39$, 95% CI = 0.26, 0.52) than for evaluative tasks ($M = 0.28$, 95% CI = 0.16, 0.41) in the pre-training run, $p = .08$, with no task differences ($M = 0.43$ vs. 0.43, evaluative vs. non-evaluative tasks) in the post-training run, *ns*.

In addition, there was a significant interaction between task and valence in the left frontal operculum area, $F(1, 1554) = 5.94$, $p < .05$. Specifically, during evaluative tasks, the average BOLD signal of the left frontal operculum area was 0.29 (95% CI = 0.16, 0.41) for unpleasant images and 0.41 (95% CI = 0.28, 0.53) for pleasant images, $p = .05$. However, when tasks were non-evaluative, there was no difference between unpleasant ($M = 0.46$, 95% CI = 0.33, 0.59) and pleasant ($M = 0.36$, 95% CI = 0.23, 0.49) images, *ns*.

Temporal pole. The right temporal pole (centered on 42, 8, -30; Lane et al., 1997) was more active during the post-training run ($M = 0.28$, 95% CI = 0.17, 0.39) than during the pre-training run ($M = 0.16$, 95% CI = 0.05, 0.27), $F(1, 1296) = 13.47$, $p < .001$. Moreover, there was an interaction between run and task in this area, $F(1, 1523) = 4.28$, $p < .05$. Specifically, the activation in the temporal pole during evaluative tasks was higher in the post-training run ($M = 0.31$, 95% CI = 0.19, 0.43) than in the pre-training run ($M = 0.12$, 95% CI = 0.01, 0.24), $p < .001$. However, there was no between-run difference in the temporal pole activation during non-evaluative tasks ($M = 0.20$, 95% CI = 0.08, 0.32, vs. $M = 0.25$, 95% CI = 0.13, 0.37; pre-training and post-training run respectively, *ns*). This difference in temporal pole activation change for evaluative and non-evaluative tasks confirmed that the temporal pole is involved in controlled

evaluation. Again, there was no between-task difference in the right temporal pole activation in either the pre- or the post-training runs, *ns*.

Summary. Although activities in the evaluative processing ROIs all increased after evaluation training, there are several differences in the change patterns. For example, regions previously associated with automatic evaluation (i.e., the amygdala, the OFC, and the insula) were more active in the post-training (vs. the pre-training) run for both evaluative and non-evaluative tasks. In contrast, after the evaluation training, regions previously associated with controlled evaluation (i.e., the anterior cingulate cortex, the temporal pole, and the frontal operculum) were more active for evaluative tasks, but not for non-evaluative tasks. Nonetheless, evaluation training enhanced the activation during evaluative tasks in various evaluative processing regions. A summary of findings in regions associated with evaluation appears in Table 3-9. Maps for brain activity changes for evaluative tasks in regions linked to evaluation are included in Figure 3-4.

Findings in Visual Areas

For visual processing regions, we focused on both early and late visual regions (see Table 3-6 for a summary of ROI coordinates). Specifically, the early visual region was selected around $-17, -73, -17$ (calcarine, Maccotta & Buckner, 2004). Moreover, in current study, late visual regions included the posterior fusiform around $-36, -73, -13$ (Maccotta & Buckner, 2004), the superior occipital lobe ($32, -74, 29$; Garavan et al., 1999), and the parietal occipital lobe ($44, -70, 20$; Lane et al., 1997). Proceduralization was expected to produce no change in activation in the early visual region but increases in the late visual regions. These regions were included in the cluster of visual processing in the cluster analysis of brain activity change.

Calcarine. As predicted, we did not find any effects of evaluative skill training on the calcarine area (centered on $-17, -93, -17$; Maccotta & Buckner, 2004), $F < 1$. In addition, this region showed no effects of type of tasks, or image valence, $F_s < 1$.

Posterior fusiform. There was a main effect of run in the late visual region near the left posterior fusiform gyrus (BA 18/19; $-36, -73, -13$; Maccotta & Buckner, 2004), $F(1, 1227) = 13.70, p < .001$. The means corresponding to this main effect indicated greater activation in the left posterior fusiform gyrus in the post-training run ($M = 1.15, 95\% \text{ CI} = 1.01, 1.30$) than in the pre-training run ($M = 0.98, 95\% \text{ CI} = 0.84, 1.12$), $p < .001$. There was also a marginal interaction between run and task in this area, $F(1, 1486) = 3.05, p = .08$. For evaluative tasks, the left posterior fusiform was more active after than before training ($M = 0.90, 95\% \text{ CI} = 0.74, 1.05$, vs. $M = 1.16, 95\% \text{ CI} = 1.00, 1.32$; pre-training vs. post-training run), $p < .01$. However, there was no between-run difference in activation for non-evaluative tasks ($M = 1.06, 95\% \text{ CI} = 0.90, 1.22$, vs. $M = 1.15, 95\% \text{ CI} = 0.99, 1.30$; pre-training vs. post-training run, *ns*). No effects of image valence were found, $F < 1$.

Parietal-occipital cortex. We also tested whether training in evaluation changed the brain activity at the parietal-occipital cortex (BA 39), BOLD signals within 5mm around $44, -70, 20$ (Lane et al., 1997). Results showed a significant main effect of run on this late visual area, $F(1, 1268) = 64.31, p < .001$. That is, the parietal-occipital cortex was more active in the post-training run ($M = 0.46, 95\% \text{ CI} = 0.40, 0.57$) than in the pre-training run ($M = 0.18, 95\% \text{ CI} = 0.07, 0.28$). After training in evaluation, the activation in the right parietal-occipital region increased for evaluative tasks ($M = 0.15, 95\% \text{ CI} = 0.04, 0.27$, vs. $M = 0.47, 95\% \text{ CI} = 0.35, 0.58$, pre-training vs. post-training run, pairwise comparison, $p < .001$), as well as for non-evaluative tasks

($M = 0.20$, 95% CI = 0.09, 0.32, vs. $M = 0.46$, 95% CI = 0.34, 0.57, pre-training vs. post-training run, pairwise comparison, $p < .001$). No other effects were found, $F_s < 1$.

Superior occipital gyrus. For the brain activity in the superior occipital gyrus (located around 32, -74, 29; Garavan et al., 1999), analyses showed a significant main effect of run, $F(1, 1142) = 25.44$, $p < .001$, and a significant interaction between task and run, $F(1, 1479) = 5.41$, $p = .02$. Generally, the right superior occipital gyrus was more active during the post-training run ($M = 0.54$, 95% CI = 0.43, 0.65) than the pre-training run ($M = 0.37$, 95% CI = 0.26, 0.48), $p < .001$. Moreover, post training activation in this area increased for evaluative tasks ($M = 0.31$, 95% CI = 0.19, 0.43, vs. $M = 0.57$, 95% CI = 0.45, 0.69; pre-training vs. post-training, $p < .001$), but not for non-evaluative tasks ($M = 0.43$, 95% CI = 0.30, 0.55 vs. $M = 0.52$, 95% CI = 0.39, 0.64, pre-training vs. post-training run, $p > .05$).

Summary. In sum, training in evaluative tasks did not have an effect on early visual regions such as the calcarine. However, late visual regions, such as the posterior fusiform and the superior occipital lobes showed greater activity increases for evaluative tasks than non-evaluative tasks. In addition, there was increased activation in the parietal occipital gyrus for both types of tasks. A summary of findings in the visual areas appears in Table 3-10. Maps for brain activity changes in visual processing regions for evaluative tasks are included in Figure 3-5.

Findings in Motor Areas

Motor cortex. To examine whether training in evaluative skills influenced the activity in motor areas, the hand response execution region (BA 4) in the left motor cortex was selected around -37, -25, 50 (Maccotta & Buckner, 2004). Results revealed a significant main effect of training on the left motor cortex. That is, overall, activity in the left motor cortex decreased in the post-training run ($M = 0.50$, 95% CI = 0.41, 0.60) relative to the pre-training run ($M = 0.61$, 95%

CI = 0.51, 0.70), $F(1, 1156) = 8.15, p < .01$. Specifically, this decrease was found in non-evaluative tasks ($M = 0.65, 95\% \text{ CI} = 0.54, 0.77$, vs. $M = 0.50, 95\% \text{ CI} = 0.39, 0.60$, pre-training vs. post-training, pairwise comparison, $p < .01$), but not in evaluative tasks ($M = 0.56, 95\% \text{ CI} = 0.46, 0.67$, vs. $M = 0.51, 95\% \text{ CI} = 0.40, 0.62$; pre-training vs. post-training, pairwise comparison, *ns*), $F(1, 1503) = 1.94, p > .15$. Moreover, before the training run, non-evaluative tasks ($M = 0.65$) tended to trigger higher activation in the motor cortex than did evaluative tasks ($M = 0.56$), $p < .10$. In contrast, there was no between-task difference in the motor cortex activation after the training run ($M = 0.51$ vs. 0.50 , evaluative vs. non-evaluative tasks, *ns*).

More interestingly, there was a 3-way interaction between run, task, and valence in the left motor cortex, $F(1, 1543) = 5.07, p < .05$. Specifically, after training, activity in the left motor cortex decreased significantly for pleasant images ($M = 0.61$ vs. 0.44 ; pre- vs. post- training run, $p < .05$), but did not change for unpleasant images ($M = 0.51$ vs. 0.57 ; pre- vs. post- training run, *ns*), $F(1, 730) = 3.95, p < .05$. However, the pattern of brain activity in the left motor cortex was different when the tasks were non-evaluative. Compared to the activation during the pre-training run, the left motor cortex was less active in the post-training run for both pleasant ($M = 0.65$ vs. 0.49 ; pre- vs. post- training run, $p = .05$) and unpleasant images ($M = 0.66$ vs. 0.50 ; pre- vs. post- training run, $p < .05$).

Therefore, as predicted, overall, evaluation proceduralization had no effects on the activation in the motor cortex (BA 4, the hand region) for evaluative tasks. However, we observed a decreased activation in the BA 4 region for evaluative tasks of pleasant images (vs. unpleasant images). A summary of these findings appears in Table 3-10. Maps for brain activity changes in the motor cortex for evaluative tasks are included in Figure 3-5.

Correlations between Behavioral Performance and Brain Activities in Regions Associated with Learning and Evaluation

ROIs activation change. It was also important to show that BOLD signal changes correlated with our behavioral measures. For each ROI, we computed a regional-activity-change score by taking the difference between BOLD signals for evaluative tasks in the post-training and the pre-training run. Thus, a positive regional activation change indicates higher regional activity in the post-training (vs. pre-training) run, whereas a negative regional change indicates lower regional activity after training in evaluative skills. Then, we conducted correlational analyses of activity changes in each ROI and task response time (see Appendix B).

Response time and ROIs. To examine association between brain activity and our behavioral data, we grouped regions with significant training effects for evaluative tasks. The cluster of regions previously linked to procedural learning included the striatal regions (i.e., the nucleus accumbens, the bilateral caudate nucleus, and the putamen areas), bilateral BA 46, bilateral BA 9, the cerebellum, and the precuneus ($\alpha = 0.72$), whereas the cluster of regions previously linked to declarative learning included the medial temporal lobe, the dorsolateral prefrontal cortices, and the ventromedial prefrontal cortex ($\alpha = 0.69$). Furthermore, the cluster of regions involved in automatic evaluation included the amygdala, the orbito-frontal cortex, and the insula ($\alpha = 0.70$), whereas the cluster of regions involved in controlled evaluation consisted of the temporal pole, the anterior cingulate cortex, and the frontal operculum ($\alpha = 0.86$). Last, a cluster of regions previously associated with late visual processing included the posterior fusiform, the superior occipital gyrus, and the parietal-occipital cortex ($\alpha = 0.82$).

Using these clusters, we next examined the effect of evaluation training on brain activation changes for evaluative tasks by using the earlier mixed model of run (pre-training vs. post-training) with time linear trend and quadratic trend as covariates. Results showed significant

main effects of run in each cluster, $ps < .004$ (Bonferroni correction was applied, the α level was set at .01 as there are five clusters in this analysis). Specifically, activations for evaluative tasks increased in the procedural-learning cluster ($M = 0.32$, 95% CI = 0.22, 0.41, vs. $M = 0.56$, 95% CI = 0.46, 0.66; pre-training vs. post-training run), $F(1, 582) = 54.02$, $p < .001$, the automatic-evaluation cluster ($M = 0.14$, 95% CI = -0.25, 0.54, vs. $M = 0.68$, 95% CI = 0.28, 1.08; pre-training vs. post-training run), $F(1, 821) = 47.02$, $p < .001$, the controlled-evaluation cluster ($M = 0.20$, 95% CI = 0.10, 0.29, vs. $M = 0.31$, 95% CI = 0.21, 0.41; pre-training vs. post-training run), $F(1, 605) = 8.44$, $p < .004$, and the late-visual cluster ($M = 0.44$, 95% CI = 0.35, 0.54, vs. $M = 0.73$, 95% CI = 0.63, 0.82; pre-training vs. post-training run, $p < .001$). At the same time, the activation in the declarative learning cluster decreased to baseline following training ($M = 0.24$, 95% CI = 0.07, 0.40, vs. $M = -0.07$, 95% CI = -0.23, 0.10; pre-training vs. post-training run), $F(1, 791) = 14.02$, $p < .001$. Practice-related activation changes for evaluative tasks of each cluster are shown in Figure 3-2.

Analysis of these regional clusters indicated that the change in activation of regions of controlled evaluation from the pre- to the post- training run positively correlated with the change in the procedural learning regions ($r = 0.78$, $p < .001$), the late visual regions ($r = 0.57$, $p < .05$), and the motor cortex ($r = 0.60$, $p < .05$). In addition to the activation changes in controlled evaluation regions, activation change in the motor cortex also correlated with the changes in late visual regions ($r = 0.64$, $p < .05$) and procedural learning regions ($r = 0.58$, $p < .05$). The activation change in procedural learning regions was also marginally correlated with the change in late visual regions, $r = 0.48$, $p < .10$. No other significant correlations between cluster activation changes (pre- vs. post- training run) were found, *ns*. Correlation coefficients between activation changes in each cluster appear in Table 3-11.

We next examined the relation between effects of training on regional activity and behavioral response time by regressing behavioral practice effects for evaluative tasks on activation changes for evaluative tasks. Behavioral practice effects were computed by subtracting response time for evaluative tasks in the post-training run from the response time for evaluative tasks in the pre-training run. Therefore, larger differences in response time indicate faster response time in the post-training (vs. pre-training) run and are an indication of proceduralization. Results of the regression analysis revealed that this score correlated positively with activation change in the automatic evaluation regions ($Beta = 0.43, t = 4.83, p < .01$), the controlled evaluation regions ($Beta = 0.52, t = 3.87, p < .01$), and the declarative learning regions ($Beta = 0.61, t = 6.66, p < .001$). Moreover, this score correlated negatively with activation change in the procedural learning regions ($Beta = -0.49, t = -3.58, p < .05$), the motor cortex (BA 4, $Beta = -0.32, t = -2.81, p < .05$), and the early visual region (the calcarine, $Beta = -0.35, t = -3.03, p < .05$). No significant relation between the change in response time and the change in brain activation at the late visual regions was found, $Beta = 0.21, t = 1.76, p > .10$. The regression model was significant, $R^2 = 0.96, F(7, 13) = 22.22, p < .001$.

Omit rate and ROIs. Similar procedures were applied to examine the relation between changes in omit rate across runs and changes in brain activity. Specifically, the change in omit rate was computed by subtracting the omit rate in the post-training run from the one in the pre-training run. Therefore, larger differences in omit rate indicate improved behavioral performance. Then, we correlated changes in brain activity and changes in omit rate (see Appendix B). The change in omit rate from the pre- to the post- training run was positively correlated with the change in BA 4 activation, $r = 0.51, p = .07$. That is, increased activation in

BA 4 across runs contributed to greater omit rate reduction for evaluative tasks. No other significant relations were found.

Discussion

Experiment 2 was conducted to explore the underlying brain functional processes of evaluation proceduralization observed in Experiment 1. As in Experiment 1, at the behavioral level, participants responded to evaluative tasks more quickly after than before receiving training. In contrast, with no training in non-evaluative tasks, the response times to non-evaluative tasks did not change over runs. Moreover, the omit rate decreased for both evaluative and non-evaluative tasks after the training in evaluative skills.

In addition to the response times to tasks, we observed changes in the pattern of how participants responded to different types of task (evaluative vs. frequency-related tasks). Specifically, unpleasant images presented in the post-training run were rated as less frequently seen on TV than the unpleasant images presented in the pre-training run. Moreover, the pleasantness ratings were more polarized after than before the evaluation training run. That is, in the post-training run, pleasant images were rated as more pleasant and unpleasant images as more unpleasant than comparable images in the pre-training run. This finding is consistent with previous research on attitude polarization in which repeated attitude expressions lead to attitude extremity (Brauer, Judd, & Gliner, 1995). Importantly, the current research indicated that the increased attitude extremity can also occur with practiced expressions of evaluations of different targets. Furthermore, a distribution test indicated that practice with evaluative judgments polarized pleasantness ratings to images but not the pattern of selection of response buttons during evaluative tasks. In contrast, the pattern of response selection for untrained non-evaluative tasks did change.

At the brain level, evaluation proceduralization was reflected by increased activation in the striatal system and other procedural learning regions (i.e., the cerebellum, the precuneus, and inferior frontal cortices) during evaluative tasks after evaluation training. The increased regional activity in striatal areas (e.g., the bilateral caudate nucleus, the putamen, and the nucleus accumbens) suggests that the striatal system is involved in proceduralization not only of cognitive tasks, but also of evaluative tasks. Within the striatal system, we also detected specific functions of sub-putamen areas in evaluation proceduralization. That is, consistent with previous findings (Lehericy et al., 2005), post training activation increased in the caudoventral putamen but decreased in the rostradorsal putamen. Also, there were significant decreases in activation in several regions previously linked to declarative learning, such as the medial temporal pole and the prefrontal cortices (e.g., the dorsolateral prefrontal cortex, and the ventromedial prefrontal cortex).

The finding that activity in the medial temporal lobe declined as activity in fronto-striatal regions increased is consistent with Seger and Cincotta's (2006) research on explicit rule learning. In addition, the increased activation in the inferior frontal regions along with decreased activation in the prefrontal regions suggests the facilitation of frontally mediated processes in evaluation proceduralization. Moreover, the findings in the posterior parietal lobe offer further evidence indicating that the superior parietal lobe is involved in procedural learning (see also Nadel et al., 2007). However, the findings in the inferior parietal lobe were not congruent. The right inferior parietal became less active with practice (see also Klingberg et al., 1997), whereas the left inferior parietal became more active with practice. Moreover, changes in these two inferior parietal areas did not correlate with any other regional activation change. More research

needs to be conducted to address directly the role of inferior parietal lobe in evaluative procedural learning.

In conclusion, the current research demonstrated that proceduralization of evaluation was accompanied by decreases in the involvement of the declarative learning regions, along with increases in the involvement of the procedural learning regions. These changes in turn suggest that after being proceduralized in the practice run, the evaluation processes were transformed from declarative memory to procedural memory. Specifically, converging evidence supports the notion that the functional brain network for implicit learning includes the basal ganglia, the cerebellum, the superior parietal lobe, and the prefrontal cortices, whereas the network for explicit learning includes the medial temporal pole and the inferior frontal cortices. Therefore, our study supports the well-known independence of brain correlates of declarative and procedural learning (see also Willingham et al., 2002).

Another important finding was that proceduralization affected brain areas related to evaluation. Specifically, we found significant increases for evaluative tasks in the activation in evaluative processing regions (i.e., the amygdala, the insula, the OFC, the ACC, the temporal pole, and the frontal operculum). This finding suggests that practice with evaluative judgments increases instead of decreases brain activation of task-specific regions (Grossman, Blake, & Kim, 2004). Among these evaluative processing regions, there are several unique patterns in each region. First, while evaluative judgments are proceduralized, the activity in the left amygdala increased whereas in the activity in the right amygdala remained unaltered. This finding is consistent with previous findings of dissociable function of bilateral amygdala in emotional memory and the involvement of the left amygdala in emotional memory retrieval (Sergerire, Lepage, & Armony, 2006). Interestingly, the increased activation of the left amygdala

was found for positive but not for negative targets. One might relate this finding to a developmental view of evaluative-skill learning. For example, Mather and colleagues (2004) found that viewing positive pictures led to greater amygdala activation than viewing negative pictures for adults over 70 years but not for adults under 30 years. Therefore, with age/practice, the amygdala may show decreased reactivity to negative information along with increased reactivity to positive information. Second, although all the evaluative processing regions were more active in the post-training than in the pre-training run, their post-training activation levels differed as a function of task instructions. That is, activations in regions previously associated with automatic evaluation (i.e., the amygdala, the insula, and the OFC) increased for both evaluative and non-evaluative tasks. In contrast, activation in regions associated with controlled evaluation (i.e., the ACC, the temporal pole, and the frontal operculum) only increased for trained evaluative tasks. Furthermore, the finding of increased amygdala activity and decreased vmPFC activity when evaluations are proceduralized is consistent with reports of the top-down inhibitory effect of the vmPFC on the amygdala (Urry et al., 2006).

Moreover, similar to findings from previous research (e.g., Maccotta & Buckner, 2004), we found no significant training effects of evaluative judgments on the motor cortex (e.g., the hand response execution region) or the early visual cortex (e.g., the calcarine). Therefore, practice with evaluative judgments did not alter brain activity in regions associated with basic motor and visual functions. In contrast, we observed increased activation of late visual regions (e.g., the superior occipital cortex, the posterior fusiform, and the parietal occipital cortex) for previously trained evaluative tasks. This finding also supports the hypothesis that practice increases activation in task-related regions, including late visual areas when the stimuli are visual.

In sum, practice with evaluation produced both increases and decreases in brain activity. As summarized by Kelly and Garavan (2005), decreased activation during task practice is usually a result of a reduced neural representation of the stimulus or a more efficient firing of a more precise functional circuit. In contrast, increased activation during task practice often indicates recruitment of additional cortical units resulting in increased spatial extent of activation or a strengthened response within a region. As different regions engaged in evaluative task performance before and after practice, we can conclude that practice in evaluative judgments *reorganizes* functional activations in several brain regions. Specifically, before practice in evaluation, active regions related to procedural learning, declarative learning, controlled evaluation, and late visual processing. After practice in evaluation, however, regions associated with declarative learning were no longer active, whereas regions related to automatic evaluation became involved.

Table 3-1. IAPS picture codes, valence and arousal ratings for images presented in the pre-training run (Experiment 2)

Task	Valence set	Code	Description	Valence rating	Arousal rating	
Evaluative	Negative	5731	Flowers	5.39 (1.58)	2.74 (1.95)	
		9471	Burnt bull dog	3.16 (1.35)	4.48 (2.02)	
		9040	Starving child	1.67 (1.07)	5.82 (2.15)	
		7036	Shipyards	4.88 (1.08)	3.32 (2.04)	
		1113	Snake	3.81 (1.75)	6.06 (2.12)	
		9472	Bridge	4.07 (1.34)	4.16 (2.00)	
		7035	Mug	4.98 (0.96)	2.66 (1.82)	
		9700	Trash	4.77 (1.24)	3.21 (1.92)	
		9140	Cow	2.19 (1.37)	5.38 (2.19)	
		2810	Boy	4.31 (1.65)	4.47 (1.92)	
		3170	Baby tumor	1.46 (1.01)	7.21 (1.99)	
		6560	Attack	2.16 (1.41)	6.53 (2.42)	
		5535	Still life	4.81 (1.52)	4.11 (2.31)	
		1303	Dog	4.68 (2.11)	5.70 (2.04)	
		2393	Factory worker	4.87 (1.06)	2.93 (1.88)	
		Positive	4220	Erotic female	6.60 (1.72)	5.18 (2.33)
			7430	Candy	7.11 (1.78)	4.72 (2.29)
	5811		Flowers	7.23 (1.60)	3.30 (2.33)	
	8130		Pole vaulter	6.58 (1.34)	5.49 (2.07)	
	1620		Sprg bok	7.37 (1.56)	3.54 (2.34)	
	5849		Flowers	6.65 (1.93)	4.89 (2.43)	
	4000		Artist	4.82 (1.66)	3.97 (2.15)	
	4003		Erotic female	5.48 (2.05)	5.09 (2.07)	
	8040		Diver	6.64 (1.56)	5.61 (2.01)	
	1601		Giraffes	6.86 (1.51)	3.92 (2.07)	
	7500		Building	5.33 (1.44)	3.26 (2.18)	
	1670		Cow	5.82 (1.63)	3.33 (1.98)	
	8330		Winner	6.65 (1.39)	4.06 (2.28)	
	7620		Jet	5.78 (1.72)	4.92 (2.11)	
	5220		Nature	7.01 (1.50)	3.91 (2.27)	
	Non-evaluative		Negative	4536	Attractive man	6.01 (1.49)
		9594		Injection	3.76 (1.70)	5.17 (2.17)
		9342		Pollution	2.85 (1.41)	4.49 (1.88)
6230		Aimed gun		2.37 (1.57)	7.35 (2.01)	
2795		Boy		3.92 (1.77)	4.70 (2.00)	
1321		Bear		4.32 (1.87)	6.64 (1.89)	
6550		Attack		2.73 (2.38)	7.09 (1.98)	
2200		Neutral face		4.79 (1.38)	3.18 (2.17)	
6242		Gang		2.69 (1.59)	5.43 (2.36)	
9913		Truck		4.38 (1.89)	4.42 (2.14)	
7161		Pole		4.98 (1.02)	2.98 (1.99)	

Table 3-1. Continued

Task	Valence set	Code	Description	Valence rating	Arousal rating
Non-evaluative	Negative	9101	Cocaine	3.62 (1.96)	4.02 (2.33)
		8010	Runner	4.38 (1.86)	4.12 (2.08)
		9390	Dishes	3.67 (1.58)	4.14 (2.52)
		2745.2	Shoplifter	3.91 (2.00)	5.17 (2.14)
	Positive	8280	Diver	6.38 (1.46)	5.05 (2.18)
		2331	Chef	7.24 (1.72)	4.30 (2.38)
		4640	Romance	7.18 (1.97)	5.52 (2.28)
		8041	Diver	6.65 (1.67)	5.49 (2.29)
		7350	Pizza	7.10 (1.98)	4.97 (2.44)
		2320	Girl	6.17 (1.51)	2.90 (1.89)
		8031	Skier	6.76 (1.39)	5.58 (2.24)
		4279	Erotic female	5.47 (2.04)	4.38 (2.61)
		2600	Beer	5.84 (1.85)	4.16 (1.74)
		2352	Kiss	6.94 (1.87)	4.99 (1.98)
		7289	Food	6.32 (2.00)	5.14 (2.51)
		7481	Food	6.53 (1.78)	4.92 (2.13)
		1947	Octopus	5.85 (1.77)	4.35 (2.37)
		2375.2	Attractive female	6.34 (1.54)	4.30 (2.29)
		2394	Medical worker	5.76 (1.47)	3.89 (2.26)

Table 3-2. IAPS picture codes, description, valence, and arousal ratings of images presented in the training run (Experiment 2)

Block	Valence set	Code	Description	Valence rating	Arousal rating
One	Negative	2205	Hospital	1.95 (1.58)	4.53 (2.23)
		2221	Judge	4.39 (1.21)	3.07 (2.08)
		9230	Oil fire	3.89 (1.58)	5.77 (2.36)
		9050	Plane crash	2.43 (1.61)	6.36 (1.97)
		9800	Skin head	2.04 (1.57)	6.05 (2.71)
		2215	Neutral man	4.63 (1.24)	3.38 (2.00)
		1051	Snake	3.80 (1.75)	5.95 (1.98)
		7595	Traffic	4.55 (1.46)	3.77 (2.22)
	Positive	8116	Football	6.82 (1.77)	5.97 (2.29)
		2080	Babies	8.09 (1.47)	4.70 (2.59)
		2515	Harvest	6.09 (1.54)	3.80 (2.12)
		2030	Woman	6.71 (1.73)	4.54 (2.37)
		8060	Boxer	5.36 (2.23)	5.31 (1.99)
		8540	Athletes	7.48 (1.51)	5.16 (2.37)
		5201	Nature	7.06 (1.71)	3.83 (2.49)
		Two	Negative	2053	Baby
1390	Bees			4.50 (1.56)	5.29 (1.97)
3022	Scream			3.70 (1.91)	5.88 (2.08)
7950	Tissue			4.94 (1.21)	2.28 (1.81)
7493	Man			5.35 (1.34)	3.39 (2.08)
2681	Police			4.04 (1.60)	4.97 (2.26)
7002	Towel			4.97 (0.97)	3.16 (2.00)
Positive	5900			Desert	5.93 (1.64)
	8620		Woman	6.04 (1.43)	4.60 (2.08)
	5600		Mountains	7.57 (1.48)	5.19 (2.70)
	4610		Romance	7.29 (1.74)	5.10 (2.29)
	1600		Horse	7.37 (1.56)	4.05 (2.37)
	5700		Mountains	7.61 (1.46)	5.68 (2.33)
	7281		Food	6.40 (1.52)	4.41 (2.26)
	4631		Biker couple	5.36 (1.86)	5.19 (2.04)
Three	Negative		2749	Smoking	5.04 (1.39)
		3220	Hospital	2.49 (1.29)	5.52 (1.86)
		6830	Guns	2.82 (1.81)	6.21 (2.23)
		9910	Car accident	2.06 (1.26)	6.20 (2.16)
		6250	Aimed gun	2.83 (1.79)	6.54 (2.61)
		7360	Flies on pie	3.59 (1.95)	5.11 (2.25)
		9220	Cemetery	2.06 (1.54)	4.00 (2.09)
		9440	Skulls	3.67 (1.86)	4.55 (2.02)
	Positive	1590	Horse	7.24 (1.45)	4.80 (2.10)
		2510	Elderly woman	6.91 (1.91)	4.00 (2.10)
		8461	Happy teens	7.22 (1.53)	4.69 (2.20)
		8033	Ice skater	6.66 (1.52)	5.01 (2.15)

Table 3-2. Continued

Block	Valence set	Code	Description	Valence rating	Arousal rating
Three	Positive	5982	Sky	7.61 (1.48)	4.51 (2.85)
		4004	Erotic female	5.14 (1.85)	4.44 (2.14)
		7480	Pasta	7.08 (1.62)	4.55 (2.42)
Four	Negative	2830	Woman	4.73 (1.60)	3.64 (2.23)
		2190	Man	4.83 (1.28)	2.41 (1.80)
		5130	Rocks	4.45 (1.13)	2.51 (1.72)
		7034	Hammer	4.95 (0.87)	3.06 (1.95)
		2840	Chess	4.91 (1.52)	2.43 (1.82)
		6350	Attack	1.90 (1.29)	7.29 (1.87)
		9470	Ruins	3.05 (1.51)	5.05 (1.98)
		7200	Brownie	7.63 (1.74)	4.87 (2.59)
	Positive	2499	Neutral male	5.34 (1.43)	3.08 (1.73)
		2340	Family	8.03 (1.26)	4.90 (2.20)
		4535	Weight lifter	6.27 (1.70)	4.95 (2.32)
		5830	Sunset	8.00 (1.48)	4.92 (2.65)
		9156	Plane	6.43 (1.59)	5.79 (2.30)
		2191	Farmer	5.30 (1.62)	3.61 (2.14)
		4150	Attractive female	6.53 (1.86)	4.86 (2.55)
Five	Negative	2700	Woman	3.19 (1.56)	4.77 (1.97)
		9181	Dead cows	2.26 (1.85)	5.39 (2.41)
		7700	Office	4.25 (1.45)	2.95 (2.17)
		9530	Boys	2.93 (1.84)	5.20 (2.26)
		1930	Shark	3.79 (1.92)	6.42 (2.07)
		2493	Neutral male	4.82 (1.27)	3.34 (2.10)
		6571	Car theft	2.85 (5.59)	5.59 (2.50)
		8497	Carnival ride	7.26 (1.44)	4.19 (2.18)
	Positive	2435	Mom/Son	5.84 (1.27)	3.94 (1.93)
		2395	Family	7.49 (1.69)	4.19 (2.40)
		2530	Couple	7.80 (1.55)	3.99 (2.11)
		7286	Pancakes	6.36 (1.72)	4.44 (2.44)
		2580	Chess	5.71 (1.41)	2.79 (1.78)
		2389	Teens	6.61 (1.69)	5.63 (2.00)
		7320	Desserts	6.54 (1.63)	4.44 (2.12)
Six	Negative	7590	Traffic	4.75 (1.55)	3.80 (2.13)
		2710	Drug addict	2.52 (1.69)	5.46 (2.29)
		9330	Garbage	2.89 (1.74)	4.35 (2.07)
		1220	Spider	3.47 (1.82)	5.57 (2.34)
		2455	Sad girls	2.96 (1.79)	4.46 (2.12)
		9010	Barbed wire	3.94 (1.70)	4.14 (2.05)
	Positive	6313	Attack	1.98 (1.38)	6.94 (2.23)
		2501	Couple	6.89 (1.78)	3.09 (2.21)
		2311	Mother	7.54 (1.37)	4.42 (2.28)
		8490	Roller coaster	7.20 (2.35)	6.68 (1.97)

Table 3-2. Continued

Block	Valence set	Code	Description	Valence rating	Arousal rating
Six	Positive	2240	Neutral child	6.53 (1.48)	3.75 (2.14)
		8300	Pilot	7.02 (1.60)	6.14 (2.21)
		4623	Romance	7.13 (1.80)	5.44 (2.23)
		1900	Fish	6.65 (1.80)	3.46 (2.32)
		1460	Kitten	8.21 (1.21)	4.31 (2.63)
Seven	Negative	9046	Family	3.32 (1.49)	4.31 (1.99)
		2272	Lonely boy	4.50 (1.78)	3.74 (1.94)
		9320	Vomit	2.65 (1.92)	4.93 (2.70)
		8465	Runner	5.96 (1.49)	3.93 (2.34)
		9920	Car accident	2.50 (1.52)	5.76 (1.96)
		3550	Injury	2.54 (1.60)	5.92 (2.13)
		3300	Disabled child	2.74 (1.56)	4.55 (2.06)
		9911	Car accident	2.30 (1.37)	5.76 (2.10)
	Positive	8200	Water skier	7.54 (1.37)	6.35 (1.98)
		7340	Ice cream	6.68 (1.63)	3.69 (2.58)
		2381	Girl	5.25 (1.22)	3.04 (1.97)
		5870	Clouds	6.78 (1.76)	3.10 (2.22)
		1603	Butterfly	6.90 (1.48)	3.37 (2.20)
		4605	Couple	5.59 (1.52)	3.84 (2.12)
		5460	Astronaut	7.33 (1.51)	5.87 (2.50)
Eight	Negative	2271	Woman	4.20 (1.26)	3.74 (1.69)
		2750	Bum	2.56 (1.32)	4.31 (1.81)
		9400	Soldier	2.50 (1.61)	5.99 (2.15)
		7224	File cabinets	4.45 (1.36)	2.81 (1.94)
		9280	Smoke	2.80 (1.54)	4.26 (2.44)
		9041	Scared child	2.98 (1.58)	4.64 (2.26)
		2745.1	Shopping	5.31 (1.08)	3.26 (1.96)
		2005	Attractive man	6.00 (1.82)	4.07 (2.44)
	Positive	7352	Pizza	6.20 (2.20)	4.58 (2.45)
		2224	Boys	7.24 (1.58)	4.85 (2.11)
		2791	Balloons	6.64 (1.70)	3.83 (2.09)
		8034	Skier	7.06 (1.53)	6.30 (2.16)
		1450	Gannet	6.37 (1.62)	2.83 (1.87)
		8192	Volcano skier	5.52 (1.53)	6.03 (1.97)
		7250	Cake	6.62 (1.56)	4.67 (2.15)
Nine	Negative	4534	Male dancer	5.70 (1.68)	4.16 (2.37)
		2900	Crying boy	2.45 (1.42)	5.09 (2.15)
		6311	Distressed female	2.58 (1.56)	4.95 (2.27)
		1200	Spider	3.95 (2.22)	6.03 (2.38)
		9080	Wires	4.07 (1.45)	4.36 (2.17)
		9830	Cigarettes	2.54 (1.75)	4.86 (2.63)
		1932	Shark	4.00 (2.28)	6.80 (2.02)
		Positive	1740	Owl	6.91 (1.38)

Table 3-2. Continued

Block	Valence set	Code	Description	Valence rating	Arousal rating
Nine	Positive	1710	Puppies	8.34 (1.12)	5.41 (2.34)
		1942	Turtles	6.26 (1.76)	4.01 (2.05)
		5532	Mushrooms	5.19 (1.69)	3.79 (2.20)
		2341	Children	7.38 (1.59)	4.11 (2.31)
		1616	Bird	5.21 (1.12)	3.95 (1.95)
		8232	Boxer	5.07 (1.80)	5.10 (2.21)
		8160	Rock climber	5.07(1.97)	6.97 (1.62)
Ten	Negative	3530	Attack	1.80 (1.32)	6.82 (2.09)
		1201	Spider	3.55 (1.88)	6.36 (2.11)
		9210	Rain	4.53 (1.82)	3.08 (2.13)
		3301	Injured child	1.80 (1.28)	5.21 (2.26)
		8230	Boxer	2.95 (1.88)	5.91 (2.15)
		2751	Drunk driving	2.67 (1.87)	5.18 (2.39)
		6900	Aircraft	4.76 (2.06)	5.64 (2.22)
		9120	OilFires	3.20 (1.75)	5.77 (1.94)
	Positive	2150	Baby	7.92 (1.59)	5.00 (2.63)
		7475	Shrimp	6.33 (1.66)	4.17 (2.49)
		4614	Romance	7.15 (1.44)	4.67 (2.47)
		2222	Boys reading	7.11 (1.54)	4.08 (2.15)
		7402	Pastry	5.98 (2.04)	5.05 (2.12)
		5621	Sky divers	7.57 (1.42)	6.99 (1.95)
		2235	Butcher	5.64 (1.27)	3.36 (1.92)

Table 3-3. IAPS picture codes, description, valence, and arousal ratings of images presented in the post-training run (Experiment 2)

Task	Valence set	Code	Description	Valence	Arousal		
Evaluative	Negative	5531	Mushroom	5.15 (1.45)	3.69 (2.11)		
		9600	Ship	2.48 (1.62)	6.46 (2.31)		
		2870	Teenager	5.31 (1.41)	3.01 (1.72)		
		9102	Heroin	3.34 (1.76)	4.84 (2.50)		
		6000	Prison	4.04 (1.74)	4.91 (2.17)		
		1280	Rat	3.66 (1.75)	4.93 (2.01)		
		1050	Snake	3.46 (2.15)	6.87 (1.68)		
		2440	Neutral girl	4.49 (1.03)	2.63 (1.70)		
		7006	Bowl	4.88 (0.99)	2.33 (1.67)		
		1052	Snake	3.50 (1.87)	6.52 (2.23)		
		2691	Riot	3.04 (1.73)	5.85 (2.03)		
		4621	Harassment	3.19 (1.59)	4.92 (2.24)		
		1101	Snake	4.10 (1.85)	5.83 (2.25)		
		1300	Pit bull	3.55 (1.78)	6.79 (1.84)		
		1120	Snake	3.79 (1.93)	6.93 (1.68)		
	Positive	8340	Plane	6.85 (1.69)	5.80 (2.36)		
		8186	Sky surfer	7.01 (1.57)	6.84 (2.01)		
		2391	Boy	7.11 (1.77)	4.63 (2.43)		
		5910	Fireworks	7.80 (1.23)	5.59 (2.55)		
		5480	Fireworks	7.53 (1.63)	5.48 (2.35)		
		5750	Nature	6.60 (1.84)	3.14 (2.25)		
		1726	Tiger	4.79 (2.10)	6.23 (2.19)		
		1670	Cow	5.82 (1.63)	3.33 (1.98)		
		5780	Nature	7.52 (1.45)	3.75 (2.54)		
		5260	Waterfall	7.34 (1.74)	5.71 (2.53)		
		7080	Fork	5.27 (1.09)	2.32 (1.84)		
		1812	Elephants	6.83 (1.33)	3.60 (2.11)		
		4533	Attractive man	6.22 (2.24)	5.01 (2.47)		
		8021	Skier	6.79 (1.44)	5.67 (2.37)		
		7270	Ice cream	7.53 (1.73)	5.76 (2.21)		
		Non-evaluative	Negative	6315	Beaten female	2.31 (1.69)	6.38 (2.39)
				9190	Woman	3.90 (1.44)	3.91 (1.73)
				9415	Handicapped	2.82 (2.00)	4.91 (2.35)
2880	Shadow			5.18 (1.44)	2.96 (1.94)		
7090	Book			5.19 (1.46)	2.61 (2.03)		
2752	Alcoholic			4.07 (1.84)	4.30 (1.94)		
9182	Horses			3.52 (2.04)	4.98 (2.07)		
2312	Mother			3.71 (1.64)	4.02 (1.66)		
2690	Terrorist			4.78 (1.43)	4.02 (2.07)		
7110	Hammer			4.55 (0.93)	2.27 (1.70)		
2141	Grieving female			2.44 (1.64)	5.00 (2.03)		

Table 3-3. Continued

Task	Valence set	Code	Description	Valence	Arousal	
Non-evaluative	Negative	7037	Trains	4.81 (1.12)	3.71 (2.08)	
		6243	Aimed gun	2.33 (1.49)	5.99 (2.23)	
		9110	Puddle	3.76 (1.41)	3.98 (2.23)	
			6200	Aimed gun	3.20 (1.62)	5.82 (1.99)
		Positive	5623	Wind surfers	7.19 (1.44)	5.67 (2.32)
			8178	Cliff diver	6.50 (2.00)	6.82 (2.33)
			1313	Frog	5.65 (1.47)	4.39 (2.03)
			2170	Mother	7.55 (1.42)	4.08 (2.48)
			5270	Nature	7.26 (1.57)	5.49 (2.54)
			4274	Attractive female	5.42 (1.83)	4.18 (2.39)
			4689	Erotic couple	6.90 (1.55)	6.21 (1.74)
			2160	Father	7.58 (1.69)	5.16 (2.18)
			5991	Sky	6.55 (2.09)	4.01 (2.44)
			2579	Bakers	5.53 (1.35)	3.85 (2.00)
			8370	Rafting	7.77 (1.29)	6.73 (2.24)
			1920	Porpoise	7.90 (1.48)	4.27 (2.53)
			1340	Women	7.13 (1.57)	4.75 (2.31)
			1999	Mickey	7.43 (1.47)	4.77 (2.40)
			6250.2	Ice cream	6.32 (1.70)	5.13 (2.06)

Table 3-4. Ratings of pleasant and unpleasant images in the pre-training and the post-training run (Experiment 2)

Judgment type	Valence	Run	
		Pre-training run	Post-training run
Evaluative	Pleasant	3.69 (1.01)	3.99 (0.84)
	Unpleasant	3.08 (1.09)	2.64 (0.71)
Non-evaluative	Pleasant	3.36 (0.92)	3.31 (0.85)
	Unpleasant	3.37 (0.91)	3.09 (0.79)

Data presented in the cells are ratings to images presented in each run. Data in the parentheses are standard deviations of corresponding cell means.

Table 3-5. Distribution of responses for evaluative and non-evaluative tasks in pre-training and post-training runs (Experiment 2)

Judgment type	Run	Responses (frequency and %)				
		Button 1	Button 2	Button 3	Button 4	omitted
Evaluative	Pre-training	93 (27.5)	86 (25.4)	92 (27.2)	67 (19.8)	82 (19.5)
	Post-training	105 (26.9)	116 (29.7)	111 (28.4)	59 (15.1)	29 (6.9)
Non-evaluative	Pre-training	58 (18.8)	112 (36.4)	105 (34.1)	33 (10.7)	112 (26.7)
	Post-training	72 (19.3)	182 (48.7)	94 (25.1)	26 (7.0)	46 (11.0)

For evaluative tasks, button 1 represents *extremely unpleasant*, button 2 represents *unpleasant*, button 3 represents *pleasant*, and button 4 represents *extremely pleasant*. For non-evaluative tasks, button 1 represents *rarely/never*, button 2 represents *occasionally*, button 3 represents *often*, and button 4 represents *always*. For button 1, 2, 3 and 4, the data in the parentheses are percentage of frequency of button selection in all valid responses for corresponding tasks in corresponding run. For missing responses, data in the parentheses are percentage of omitted trials in all 420 possible responses for corresponding tasks in corresponding run.

Table 3-6. List of references of regions-of interest selected in the fMRI study of evaluation proceduralization (Experiment 2)

Region	BA	Side	Coordinates			Voxels	Reference
			x	y	z		
Caudate nucleus		L & R	±9	15	4	485	Poldrack et al., 1999
Putamen		L	-27	8	4	485	An independent study
		R	18	-1	15	485	Mallol et al., 2007
Nucleus accumbens		L	-4	6	-2	485	Lieberman et al., 2004
Cerebellum		R	31	-65	-18	485	Willingham et al., 2002
Superior parietal lobe	7	R	12	-67	50	485	Willingham et al., 2002
Inferior parietal lobe		L	-34	-46	56	485	Mallol et al., 2007
	40	R	50	-26	36	485	Poldrack et al., 1999
Medial temporal lobe		L	-39	-15	-24	485	Rose et al., 2004
Dorsolateral prefrontal cortex		L	-30	55	24	485	Klingberg et al., 1997
		R	48	41	9	485	Taylor et al., 2003
Ventromedial prefrontal cortex		L	-22	30	-16	485	Lieberman et al., 2004
Amygdala		L	-24	-1	-14	1764	Anatomically defined (Norris et al., 2004)
Insula	13	L	-30	23	7	111	An independent study
Orbito-frontal cortex	47	R	45	35	-4	485	Maccotta & Buckner, 2004
Anterior cingulate cortex	32	L	-4	24	32	485	Cunningham et al., 2004
Frontal operculum		L	-46	14	6	485	Lane et al., 1997
Temporal pole	21/38	R	42	8	-30	485	Lane et al., 1997
Calcarine		L	-17	-93	-17	485	Maccotta & Buckner, 2004
Posterior fusiform	18/19	L	-36	-73	-13	485	Maccotta & Buckner, 2004
Superior occipital gyrus		R	32	-74	29	485	Garavan et al., 1999
Parieto-occipital cortex	39	R	44	-70	20	485	Lane et al., 1997
Motor cortex	4	L	-37	-25	50	485	Maccotta & Buckner, 2004
Inferior frontal gyrus	46	L & R	±47	17	24	485	Maccotta & Buckner, 2004
	9	L & R	±43	3	32	485	Maccotta & Buckner, 2004

BA = Brodmann's area; L, left; R, right; x, y, z: coordinates of the centroid of the region in Tailarach coordinates; Voxels: volume of the region in mm³. References indicate the articles from which the coordinates of ROIs were extracted.

Table 3-7. Means of BOLD signals in ROIs previously linked to procedural learning for evaluative and non-evaluative tasks in the pre-training and post-training runs (Experiment 2)

Region	BA	Side	Evaluative tasks		Non-evaluative tasks		Interaction	
			Pre-training run	Post-training run	Pre-training run	Post-training run	df	<i>F</i>
Caudate nucleus		L & R	0.14*	0.28*	0.22*	0.26*	1541	2.44 [†]
Putamen		L	0.33*	0.22*	0.35*	0.20*	1558	< 1
		R	0.21*	0.29*	0.14*	0.25*	1602	< 1
Nucleus accumbens		L	-0.10	0.30*	0.34*	0.01	1546	< 1
Cerebellum		R	1.19*	1.59*	1.39*	1.50*	1499	4.52*
Superior parietal lobe	7	R	0.22*	0.44*	0.34*	0.39*	1493	4.32*
Inferior parietal lobe		L	-0.97*	0.62	0.33	0.39	1654	3.35 ^{††}
		R	0.23*	0.15*	0.14*	0.16*	1595	3.14 ^{††}
Inferior frontal gyrus	46	L & R	0.30*	0.49*	0.39*	0.45*	1483	5.40*
	9	L & R	0.36*	0.60*	0.43*	0.58*	1472	3.16 ^{††}

Table entries for evaluative and non-evaluative tasks are means of BOLD signals of ROIs in each condition (vs. null trials).

Significant BOLD signals indicate that the corresponding ROI was significantly activated or deactivated comparing to the activation baseline of null trials. *F* = *F* score for interaction between task and run in each ROI. BA = Brodmann's area; L, left; R, right; df, degrees of freedom; Between-run comparisons in activations for evaluative tasks in all regions were significant at a .005 level, except for the putamen areas ($p < .05$) and the right inferior parietal lobe ($p < .05$) (Bonferroni correction was applied to reduced the Type I error in multiple comparisons, the α level was set at .005).

[†], $p < .15$

^{††}, $p < .10$

*, $p < .05$

Table 3-8. Means of BOLD signals in ROIs previously linked to declarative learning for evaluative and non-evaluative tasks in the pre-training and post-training runs (Experiment 2)

Region	BA	Side	Evaluative tasks		Non-evaluative tasks		Interaction	
			Pre-training run	Post-training run	Pre-training run	Post-training run	df	<i>F</i>
Medial temporal lobe		L	0.09*	-0.12*	0.07	0.01	1656	< 1
Dorsolateral prefrontal cortex		L & R	0.37*	0.10	0.11	0.09	1630	4.68*
Ventromedial prefrontal cortex		L	0.32*	-0.14	-0.33	-0.21	1660	4.88*

Table entries for evaluative and non-evaluative tasks are means of BOLD signals of ROIs in each condition (vs. null trials).

Significant BOLD signals indicate that the corresponding ROI was significantly activated or deactivated comparing to the activation baseline of null trials. *F* = *F* score for interaction between task and run in each ROI. BA = Brodmann's area; L, left; R, right; df, degrees of freedom; Between-run comparisons in activations for evaluative tasks in all regions were significant at a .01 level (Bonferroni correction was applied to reduced the Type I error in multiple comparisons, the α level was set at .017).

*, $p < .05$

Table 3-9. Means of BOLD signals in ROIs previously linked to evaluative processing for evaluative and non-evaluative tasks in the pre-training and post-training runs (Experiment 2)

Region	BA	Side	Evaluative tasks		Non-evaluative tasks		Interaction	
			Pre-training run	Post-training run	Pre-training run	Post-training run	df	<i>F</i>
Regions associated with automatic evaluation								
Amygdala		L	0.22*	0.30*	0.23*	0.35*	1535	< 1
Insula	13	L	0.34	1.38*	0.30	1.42*	1655	< 1
Orbito-frontal cortex	47	R	-0.06	0.43*	-0.07	0.49*	1655	< 1
Regions associated with controlled evaluation								
Anterior cingulate cortex	32	L	0.02	0.09*	0.06	0.07	1491	3.53 ^{††}
Frontal operculum		L	0.28*	0.42*	0.39*	0.43*	1528	1.52
Temporal pole	21/38	R	0.12*	0.31*	0.20*	0.25*	1523	4.28*

Table entries for evaluative and non-evaluative tasks are means of BOLD signals of ROIs in each condition (vs. null trials).

Significant BOLD signals indicate that the corresponding ROI was significantly activated or deactivated comparing to the activation baseline of null trials. *F* = *F* score for interaction between task and run in each ROI. BA = Brodmann's area; L, left; R, right; df, degrees of freedom; Between-run comparisons in activations for evaluative tasks in all regions were significant at a .001 level, except for the amygdala ($p < .10$), the anterior cingulate cortex ($p = .01$), and the frontal operculum ($p = .02$) (Bonferroni correction was applied to reduced the Type I error in multiple comparisons, the α level was set at .008).

^{††}, $p < .10$

*, $p < .05$

Table 3-10. Means of BOLD signals in ROIs previously linked to motor function and visual processing for evaluative and non-evaluative tasks in the pre-training and post-training runs (Experiment 2)

Region	BA	Side	Evaluative tasks		Non-evaluative tasks		Interaction	
			Pre-training run	Post-training run	Pre-training run	Post-training run	df	<i>F</i>
Calcarine		L	0.88*	0.95*	1.02*	0.90*	1545	< 1
Posterior fusiform	18/19	L	0.90*	1.16*	1.06*	1.15*	1486	3.05 ^{††}
Superior occipital gyrus		R	0.31*	0.57*	0.43*	0.52*	1479	5.41*
Parieto-occipital cortex	39	R	0.15*	0.47*	0.20*	0.46*	1532	< 1
Motor cortex	4	L	0.56*	0.51*	0.65*	0.50*	1503	1.94

Table entries for evaluative and non-evaluative tasks are means of BOLD signals of ROIs in each condition (vs. null trials).

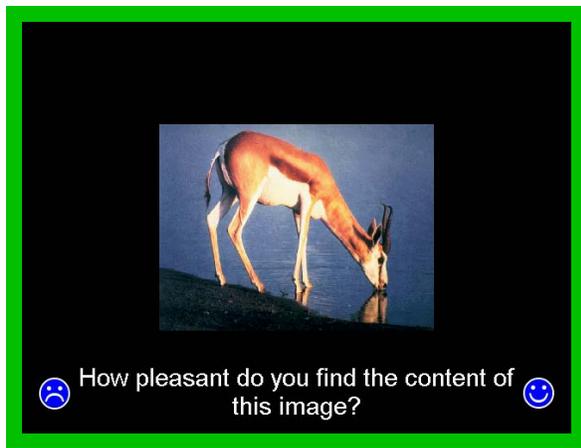
Significant BOLD signals indicate that the corresponding ROI was significantly activated or deactivated comparing to the activation baseline of null trials. *F* = *F* score for interaction between task and run in each ROI. BA = Brodmann's area; L, left; R, right; df, degrees of freedom; Between-run comparisons in activations for evaluative tasks in all regions were significant at a .001 level, except for the calcarine (*ns*) and the motor cortex (*ns*) (Bonferroni correction was applied to reduced the Type I error in multiple comparisons, the α level was set at .01).

^{††}, $p < .10$; *, $p < .05$

Table 3-11. Correlation coefficients of BOLD signal changes (pre- vs. post- training run) during evaluative tasks in regional clusters (Experiment 2)

	Declarative learning regions	Procedural learning regions	Automatic evaluation regions	Controlled evaluation regions	Early visual regions	Late visual regions	Motor regions
Declarative learning regions	1						
Procedural learning regions	0.15	1					
Automatic evaluation regions	-0.02	-0.03	1				
Controlled evaluation regions	0.04	0.78 ^{***}	0.07	1			
Early visual regions	0.35	0.35	0.16	0.11	1		
Late visual regions	-0.15	0.48 [†]	0.27	0.57 [*]	0.12	1	
Motor regions	-0.07	0.58 [*]	0	0.60 [*]	0.16	0.64 [*]	1

***: $p < .001$, *: $p < .05$, †: $p < .10$.



A



B



C



D

Figure 3-1. Sample IAPS pictures used in Experiment 2. A) Sample pleasant image presented for evaluative tasks. B) Sample unpleasant image presented for evaluative tasks. C) Sample pleasant image presented for non-evaluative tasks. D) Sample unpleasant image presented for non-evaluative tasks.

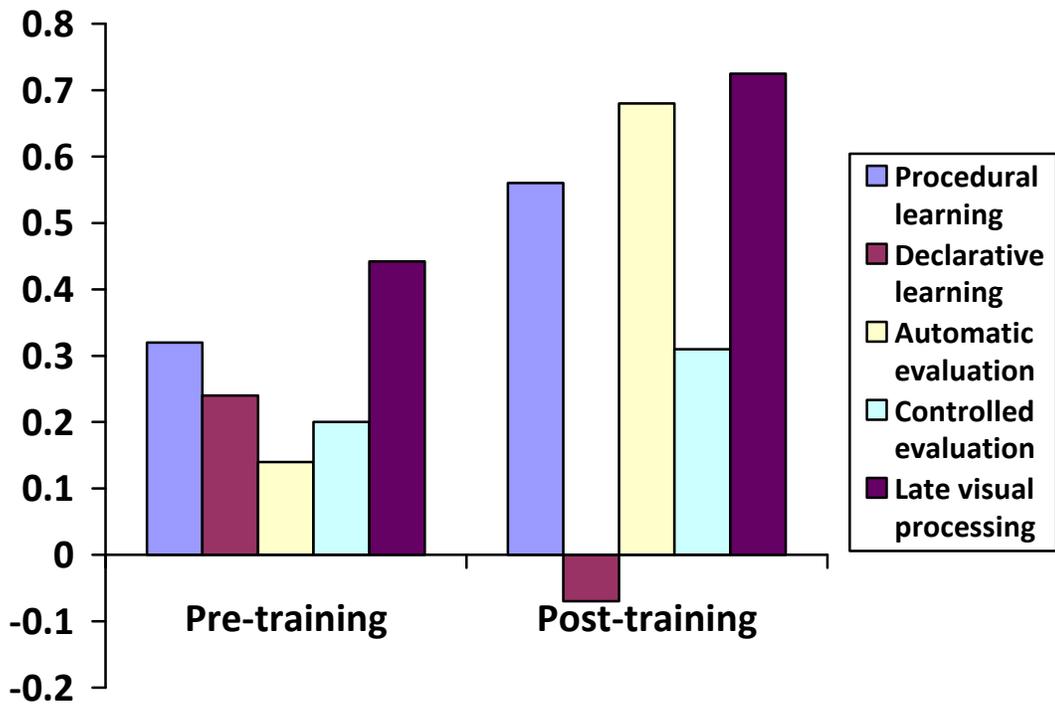


Figure 3-2. Practice-related activation changes for evaluative tasks (Experiment 2).

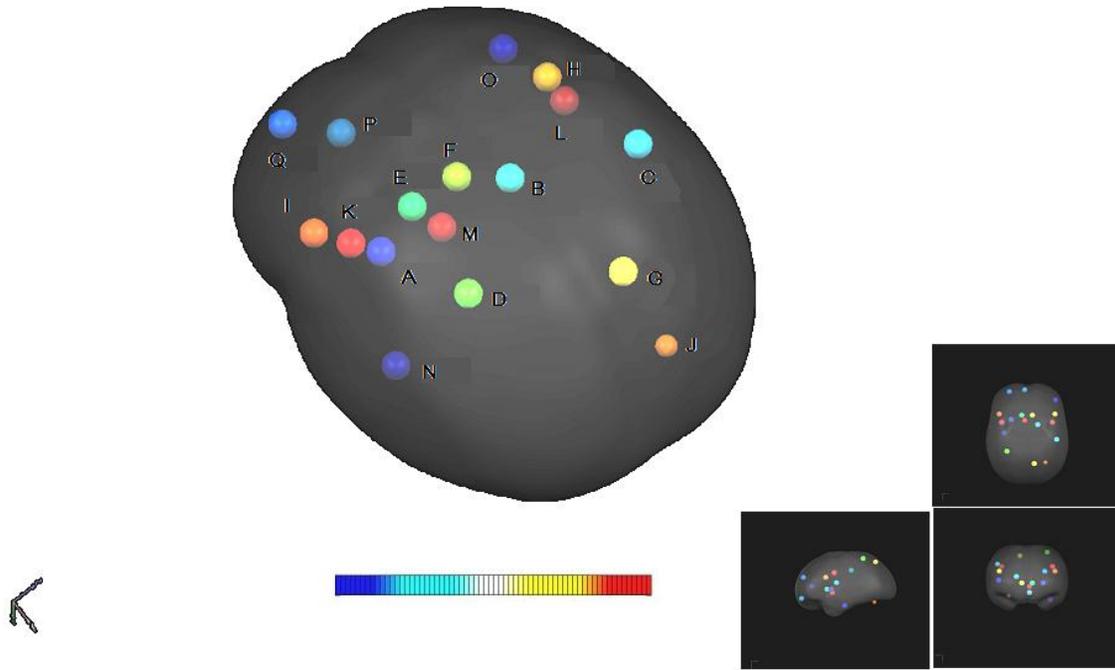


Figure 3-3. Maps for brain activity changes for evaluative tasks in learning-related regions (Experiment 2). Areas previously linked to procedural learning include the putamen (A, the left putamen, $t = -7.04$; B, the right putamen, $t = 5.03$), the inferior parietal lobe (C, the right IPL, $t = -4.41$; D, the left IPL, $t = 7.53$), the caudate nucleus (E, the left caudate nucleus, $t = 7.42$; F, the right caudate nucleus, $t = 8.79$), the right superior parietal lobe (G, $t = 16.04$), the BA 46 (H, the right BA 46, $t = 16.23$; I, the left BA 46, $t = 26.75$), the cerebellum (J, $t = 18.68$), the BA 9 (K, the left BA 9, $t = 30.95$; L, the right BA 9, $t = 37.31$), and the left nucleus accumbens (M, $t = 33.58$). Areas previously linked to declarative learning include the medial temporal lobe (N, $t = -10$), the dorsolateral prefrontal cortex (O, the right dlPFC, $t = -7.41$; P, the left dlPFC, $t = -6.51$), and the left ventromedial prefrontal cortex (Q, $t = -6.49$). Color scale represents the order of t -values of pre- vs. post- training comparisons in BOLD responses for evaluative tasks.

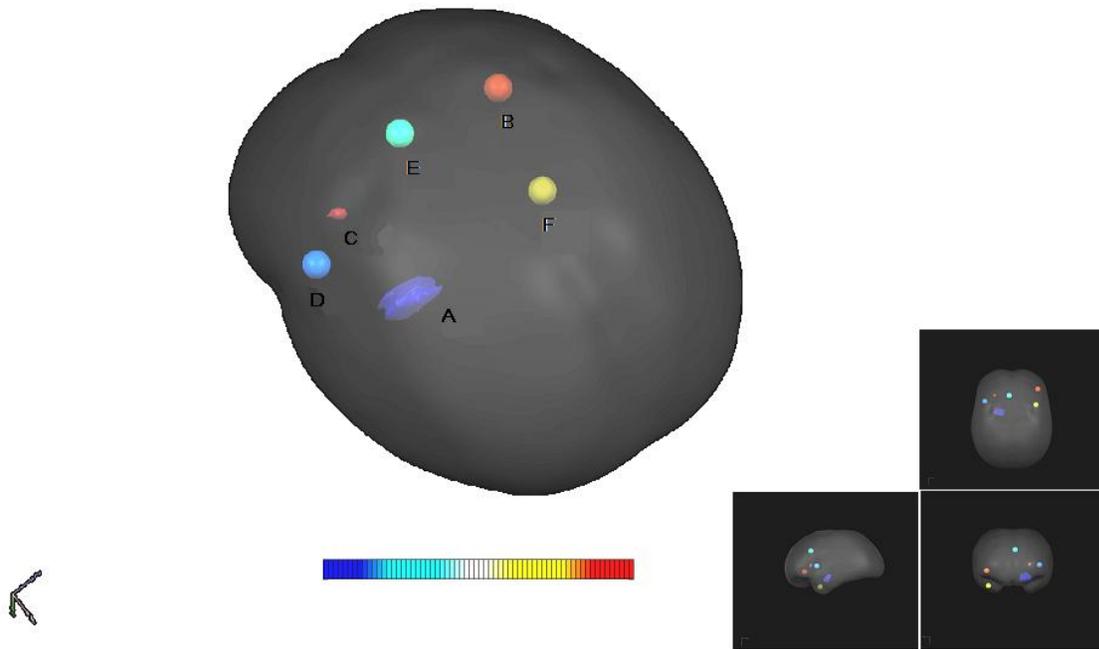


Figure 3-4. Maps for brain activity changes for evaluative tasks in evaluation-related regions (Experiment 2). Areas previously linked to automatic evaluation include the left amygdala (A, $t = 2.96$), the right orbitofrontal cortex (B, $t = 18.78$), and the left insula (C, $t = 53.49$). Areas previously linked to controlled evaluation include the left frontal operculum (D, $t = 5.60$), the anterior cingulate cortex (E, $t = 6.74$), and the right temporal pole (F, $t = 16.93$). Color scale represents the order of t -values of pre- vs. post- training comparisons in BOLD responses for evaluative tasks.

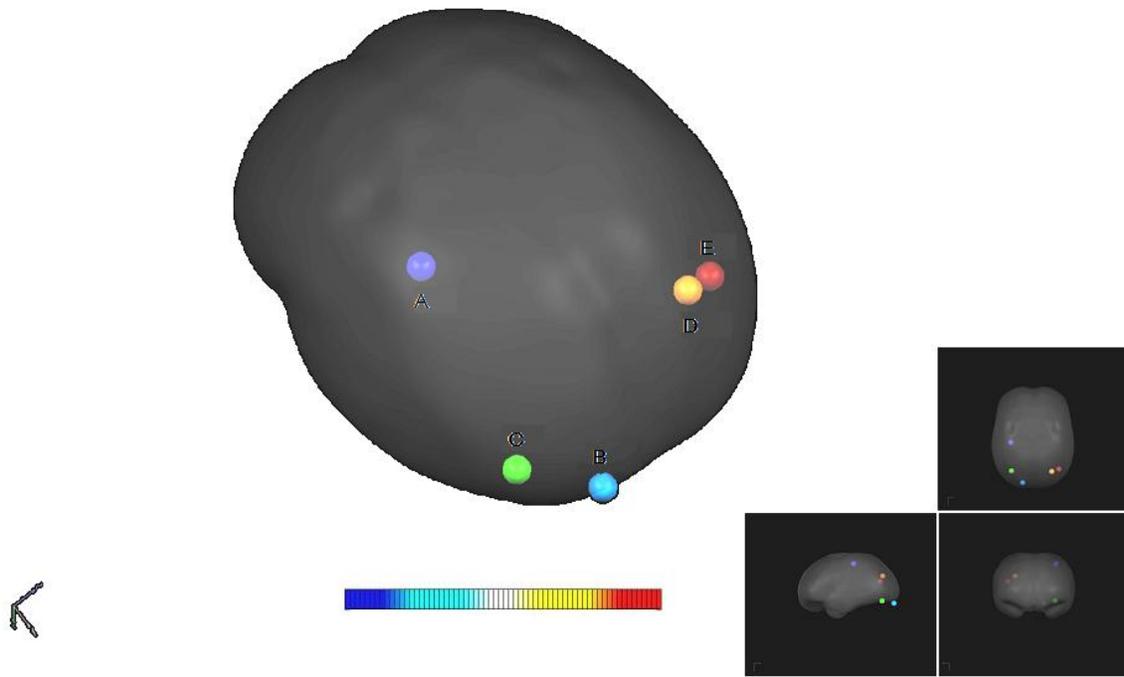


Figure 3-5. Maps for brain activity changes for evaluative tasks in regions related to visual and motor processing (Experiment 2). Areas previously linked to primary motor skills is represented by the left BA 4 (hand region) (A, $t = -1.11$). Areas previously linked to primary visual processing is represented by the calcarine (B, $t = 0.23$). Areas previously linked to late visual processing include the posterior fusiform (C, $t = 15.21$), the superior occipital gyrus (D, $t = 27.84$), and the parietal occipital cortex (E, $t = 39.75$). Color scale represents the order of t -values of pre- vs. post- training comparisons in BOLD responses for evaluative tasks.

CHAPTER 4 GENERAL DISCUSSION

We began with a question: As evaluation is often automatic, is there room for increases in the procedural efficiency of explicit evaluative judgments? That is, can evaluative judgments be proceduralized through practice, and if so, what aspects of the process of making evaluative judgments are being proceduralized? To answer these questions, we first investigated whether there are decreases in the times required to make evaluative judgments of emotional visual stimuli following practice, and subsequently explored the functional anatomic correlates of proceduralized evaluations of emotional stimuli. Together, our findings provide important evidence of the effects of proceduralization on behavioral and neural responses to emotional stimuli.

Summary of Findings

The results from Experiment 1 demonstrated that, like various cognitive, social and motor skills, evaluative judgments can also be proceduralized or speeded up through practice. Moreover, consistent with Smith and his colleagues' (1986, 1994) work on procedural efficiency, Experiment 1 showed that evaluative judgments quickly automate with repeated execution. More importantly, evaluation proceduralization does not have to be content-specific, but instead generalizes or transfers to novel stimuli. Specifically, participants who had practiced evaluations of pictures were more likely to make spontaneous evaluative responses of new pictures than participants who had practiced non-evaluative judgments. Interestingly, non-evaluative (frequency-rating) judgments of the same set of images were also proceduralized through practice, but their procedural efficiency did not facilitate corresponding responses to new stimuli.

Experiment 2 further contributed to understanding which aspects of evaluation proceduralize by providing evidence on brain correlates of evaluation proceduralization. Generally, the results of Experiment 2 suggest that multiple brain regional systems are involved in evaluation proceduralization. Specifically, following practice, evaluative judgments evoked higher responses in task-related areas, such as regions associated with automatic and controlled evaluation (i.e., the amygdala, the insula, the anterior cingulate cortex, the temporal pole, the frontal operculum and the orbitofrontal cortex), as well as regions associated with late visual processing (i.e., the posterior fusiform, the parietal occipital lobe, and the superior occipital lobe). Also, when evaluative tasks proceduralized, regions related to procedural learning (i.e., the striatal system, the superior parietal lobe, the inferior frontal cortex, and the cerebellum) were more responsive to evaluative tasks, whereas regions related to declarative learning (i.e., the medial temporal lobe, the dorsolateral prefrontal cortex, and the ventromedial prefrontal cortex) were correspondingly less responsive. These fMRI results provide insight into how practice proceduralizes evaluations at the brain level.

Contributions

The current study contributes to the area of social cognitive neuroscience of evaluation in several aspects. First, we found that the amygdala, as well as the frontal operculum, showed different activation patterns for pleasant and unpleasant images. These findings suggest that the amygdala and the frontal operculum are sensitive to valence.

Second, the findings in the present research confirm that evaluation is not a single process but involves both automatic and controlled aspects. Brain regions associated with automatic evaluation, as well as those associated with controlled evaluation, were more active after than before the training in evaluative tasks. However, regions previously associated with automatic evaluation were more active regardless of explicit task instruction, whereas regions related to

controlled evaluation were only more active for trained evaluative tasks but not untrained non-evaluative tasks. Therefore, effects of practice with evaluation on regions related to automatic evaluation generalized to other type of judgments, whereas the effects on controlled evaluation regions were task-specific.

Third, extensive research has distinguished functions of cerebral regions in implicit and explicit evaluation based on their differential activities during explicit and implicit evaluative tasks (e.g., Cunningham et al., 2003; Cunningham et al., 2004). Specifically, previous research suggest that the amygdala, the insula, and the OFC are involved in automatic evaluation as they are active with the presentation of emotional stimuli regardless of whether or not explicit evaluations are required. In contrast, the ACC, the temporal lobe, and the frontal operculum might be involved in controlled evaluation as their activation were higher when explicit evaluations of targets were required than when they were not (Lane et al., 1997). Consistently with the above previous findings in regions associated with automatic evaluation (Cunningham, Raye, & Johnson, 2004; Cunningham et al., 2003; Lane et al., 1997; Wright & Liu, 2005; Wright et al., 2008), we did not detect task (evaluation vs. non-evaluation) differences in activations in the amygdala, the insula, or the OFC either before or after training in evaluation. However, the current study also did not detect any differences between activations in the controlled-evaluation regions for either evaluative or non-evaluative tasks during either the pre-training and the post-training run. That is, the anterior cingulate, as well as the temporal pole and the frontal operculum, were equally activated (vs. null trials) for evaluative and non-evaluative tasks before and after training. One possible reason for the lack of between-task difference in activations in controlled-evaluation regions might be the design of the current study. That is, our rapid

presentation of stimuli (less than 3000 ms) may have reduced the detectability of differential responses. Further research should be conducted to explain this discrepancy.

Importantly, the present findings shed light on the processes that contribute to evaluation proceduralization. Although numerous studies have suggested a decreased regional activation due to practice, our findings suggest that evaluation practice produces an increased regional activation in evaluative processing areas. One possible explanation is that experimental paradigms of repetition suppression (Buchel et al., 1999; Maccotta & Buckner, 2004) only entail repeated presentation of the *same* stimuli. Therefore, increased activations in regions linked to evaluative processing can also reflect a progressive optimization of neuronal responses elicited by evaluative tasks. In addition, this progressive optimization may be facilitated by more focused activation voxels when evaluations proceduralized. In any case, the findings of increased brain activation in the evaluative processing areas are consistent with previous reports of practice induced increases in task-specific brain areas (Grossman et al., 2004). Moreover, the increased activation in the left amygdala when evaluation proceduralizes can be explained by increased left amygdala demands for evaluative-memory retrieval (Sergeier, Lepage, & Armony, 2006). More direct comparisons of brain function during evaluations of identical stimuli and non-repeated stimuli should be done to understand how progressive optimization occurs in each case.

In closing, the current study supports a model in which brain activation changes as a function of experience. Practice with evaluative judgments reorganizes regional activations, as brain regions activated early in the practice differ from the ones activated late in the practice. More specifically, evaluation proceduralization increases activity in brain regions associated with automatic evaluation but decreases activity in brain regions associated with declarative learning. Moreover, regression analyses revealed that the effects of practice on response times

for evaluative judgments can be predicted from activation changes in declarative and procedural learning regions, automatic and controlled evaluation regions, motor cortex, as well as the early visual regions.

Taken together, our findings show the ways in which long-standing theories of attitude and evaluation can be tested using a social-cognitive-neuroscience approach. Such analyses demonstrate the value of social psychological theories for understanding the work of the brain during practice with evaluation. By using neuroimaging to identify these brain correlates and drawing inferences from what is already known about the processing roles of these regions, we were able to generate new insights regarding the behavioral and brain functional consequences of practice in evaluation. Such insights suggest that a social cognitive neuroscience approach can trigger promising advance for both social psychological theory and neuroscience.

APPENDIX A
INSTRUCTIONS AND CUES FOR EVALUATIVE AND NON-EVALUATIVE TASKS
(EXPERIMENT 2)

- Evaluative tasks instructions: This task involves evaluating the content of images. Please discriminate between images that contain pleasant (i.e., positive, good, pleasing, etc.) content vs. unpleasant (i.e., negative, bad, displeasing, etc.) content. We are interested in both your evaluation and the speed with which you make it. Therefore, try to respond as quickly and as accurately as you can. Click any button when you are ready to begin.
- Evaluative tasks questions: How pleasant do you find the content of this image? 4-points scale: extremely unpleasant; unpleasant; pleasant; extremely pleasant
- Non-evaluative tasks instructions: This task involves estimating the frequency with which images of similar content appear on television. Please estimate the frequency using the scale provided. We are interested in both your estimate and the speed with which you make it. Therefore, try to respond as quickly and as accurately as you can.
- Non-evaluative tasks questions: How frequently do images with similar content appear on television? 4-points scale: rarely/never; occasionally; often; always

APPENDIX B
CORRELATION COEFFICIENTS OF ROI ACTIVITY CHANGES AND BEHAVIORAL
PERFORMANCE CHANGE FROM THE PRE- TO THE POST- TRAINING RUN
(EXPERIMENT 2).

Table B-1. Correlation coefficients of ROI activity changes and behavioral performance change from the pre- to the post- training run (Experiment 2).

	RT	Omit rate	CN	PT	NA	CB	PC	BA 46	BA 9	MTL	dIPFC	vmPFC
omit rate	-0.35											
CN	-0.41	0.09										
PT	-0.36	0.24	0.37									
NA	0.10	0.29	0.50 [†]	0.50 [†]								
CB	-0.23	-0.33	0.06	0.00	-0.55 [*]							
PC	0.04	0.08	0.47 [†]	0.16	0.18	0.33						
BA 46	-0.29	-0.23	0.42	0.48 [†]	-0.16	0.62 [*]	0.42					
BA 9	0.03	-0.03	0.16	0.22	0.03	0.53 [*]	0.47 [†]	0.38				
MTL	0.19	-0.18	-0.27	-0.09	-0.24	0.29	0.03	0.31	0.55 [*]			
dIPFC	0.39	-0.32	-0.06	-0.13	-0.01	0.03	-0.11	0.01	0.49 [†]	0.47 [†]		
vmPFC	0.31	0.21	-0.07	0.09	0.22	0.11	0.05	0.14	0.35	0.39	0.41	
IPL (L)	-0.29	-0.05	0.12	0.02	0.07	0.04	-0.08	-0.20	-0.32	-0.36	-0.37	-0.34
IPL (R)	-0.33	-0.28	0.30	0.35	0.17	0.22	-0.06	0.20	0.37	0.01	-0.04	-0.45
AG	0.16	-0.35	0.54 [*]	0.38	0.28	0.27	0.65 [*]	0.59 [*]	0.16	-0.14	-0.03	-0.01
IS	0.70 ^{**}	-0.24	-0.09	-0.46	0.02	-0.14	0.23	-0.33	-0.03	-0.24	0.23	-0.13
OFC	0.59 [*]	0.03	-0.16	0.05	0.19	0.00	0.32	-0.19	0.20	-0.26	0.02	0.04
ACC	-0.05	-0.43	0.46	0.36	-0.03	0.54 [*]	0.69 ^{**}	0.76 ^{**}	0.57 [*]	0.18	0.15	-0.11
FO	-0.13	0.01	0.20	0.24	-0.25	0.62 [*]	0.65 [*]	0.73 ^{**}	0.43	0.21	-0.22	0.15
TP	0.12	-0.32	0.53 [*]	0.27	0.26	0.15	0.69 ^{**}	0.60 [*]	0.37	0.20	0.03	-0.08
CA	-0.08	0.25	0.22	0.22	-0.01	0.24	0.11	0.27	0.39	-0.18	0.36	0.43
PF	-0.14	-0.34	0.33	0.15	0.00	0.24	0.40	0.25	0.43	-0.09	0.18	-0.26
SOG	0.01	-0.43	0.31	-0.07	0.02	0.41	0.47 [†]	0.19	0.13	-0.31	-0.28	-0.23
POC	0.31	-0.27	0.33	-0.08	0.35	-0.06	0.60 [*]	0.06	0.12	-0.20	0.00	-0.05
MC	-0.29	0.51 [†]	0.24	0.01	0.40	0.72 ^{**}	0.40	0.54 [*]	0.49 [†]	0.12	0.09	0.33

Table B-1. Continued

	IPL (L)	IPL (R)	AG	IS	OFC	ACC	FO	TP	CA	PF	RSOG	RPOC
IPL (R)	0.12											
AG	0.19	0.10										
IS	-0.18	-0.15	0.25									
OFC	-0.17	0.01	0.30	0.75**								
ACC	-0.20	0.37	0.72**	0.04	0.12							
FO	0.00	-0.03	0.54*	-0.19	0.05	0.64*						
TP	-0.26	0.26	0.69**	0.07	0.05	0.84***	0.54*					
CA	-0.43	-0.08	0.07	0.11	0.25	0.19	0.20	-0.06				
PF	-0.24	0.41	0.21	-0.01	-0.01	0.70**	0.21	0.56*	0.23			
SOG	-0.03	0.31	0.38	0.24	0.25	0.52†	0.21	0.43	0.00	0.61*		
POC	-0.24	0.05	0.48†	0.45	0.31	0.47†	0.09	0.61*	0.03	0.52*	0.70**	
MC	0.03	0.51†	0.34	0.01	0.07	0.75**	0.43	0.44	0.16	0.67**	0.59*	0.36

RT: response time; CN: caudate nucleus; PT: putamen areas; NA: nucleus accumbens; CB: cerebellum; PC: precuneus; MTL: medial temporal lobe; dlPFC: dorsolateral prefrontal cortex areas; vmPFC: ventromedial prefrontal cortex; IPL: inferior parietal lobe (L: left side, R: right side); AG: amygdala; IS: insula; OFC: orbitofrontal cortex; ACC: anterior cingulate cortex; FO: frontal operculum; TP: temporal pole; CA: calcarine; PF: posterior fusiform; SOG: superior occipital gyrus; POC: parietal occipital cortex; MC: motor cortex.

†, $p < .10$

*, $p < .05$

**, $p < .01$

***, $p < .001$

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