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Implicit Sequence Learning: Target Identity versus Location

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Abstract

In recent decades research in implicit learning has expanded beyond classic stimulus-response accounts. Mounting evidence indicates that prior classifications of implicit learning as a purely motor learning process may no longer be viable. Recent debate has focused upon the validity of implicit learning as a process dissociable from explicit learning. Alternative accounts propose unitary learning processes regardless of learning conditions. To better resolve these controversies we compare measures of implicit and explicit learning in a classic serial reaction time task with those of a novel serial reaction time task. By comparing measures of learning under both implicit and explicit conditions, we examine the distinctness of the implicit learning process. Whereas in the classic serial reaction time task subjects must respond to and learn a sequence of stimulus *locations*, in the novel serial reaction time task subjects must respond to and learn a sequence of stimulus *identities*. The successful acquisition of a sequence of stimulus *identities* challenges notions of the specificity of implicit learning as a phenomenon of non-cognitive motor learning.

Keywords: Implicit; Explicit; Sequence; Learning; Memory

Introduction

Implicit learning (IL) has been defined as the ability to acquire information without awareness and in a manner that is difficult to verbalize (Cleeremans, Destrebecqz, & Boyer, 1998). IL has been investigated for over 45 years and has sparked a plethora of explanations since Lashley's work in sequence learning (1951), Gibson and Gibson's research in information processing of stimuli (1955), and Reber's experiments in IL of artificial grammar (1967). Prior interpretations of IL phenomena include the manifestation of an intelligent unconscious requiring mere exposure for sub-awareness levels of cognitive processing (Loftus & Klinger, 1992), as well as assertions that learning is always accompanied by awareness (Shanks & St John, 1994).

As early as 1951, Lashley demonstrated sequence learning to be incompatible with earlier behavioral theories that had equated serially ordered response with a reflexive chaining of motor responses. Lashley noted that decreases of mean response time (MRT) to patterns of stimulus locations indicated a preparatory configuration of the subject's nervous system. Building upon demonstrations of sequence learning as separate from reflexive motor chains, a full and thorough body of literature has been developed around reaction time tasks (for a review see Clegg, DiGirolamo, & Keele, 1998). Recent findings have confirmed sequence learning to be beyond the complexity limits imposed by a motor reflex chain interpretation (Rosenbaum, Cohen, Jax, Weiss, & van der Wel, 2007). Despite consistent evidence that motor learning alone cannot fully account for serial learning, it may certainly contribute to the acquisition of learned responses in measures such as the serial reaction time task (SRT) (Robertson, 2007).

The Serial Reaction Time Task

Nissen and Bullemer (1987) developed a now classic assessment of IL, the SRT. In the standard SRT paradigm, subjects respond to the location of a visual stimulus as displayed within one of several fields. Unbeknownst to the subject, the location of the visual stimulus follows a deterministic sequence across trials. Over several blocks composing the learning phase, subjects serially respond to the sequence of locations. In the test phase, subjects respond to an alternative sequence that breaks from the learned sequence of response locations. Comparisons of MRT are drawn between the final block of the learning phase and the test phase block that follows. As both practice and fatigue effects are assumed equal in the final blocks, differences in MRT are assumed to reflect the effects of learning (Robertson, 2007).

Motor Learning versus Cognitive Learning

Accounts and assessments of IL often focus solely upon motor learning tasks in response to the visuospatial location of stimuli (Jimenez & Mendez, 1999; Jimenez & Mendez, 2001; Jimenez-Fernandez, Vaquero, Jimenez, & Defior, 2011; Robertson, 2007; Schwarb & Schumacher, 2010; Shanks, Rowland, & Ranger, 2005). In contrast, examinations of explicit learning often focus on cognitive tasks. As reported by Shanks et al.: “The SRT task has been taken to be an ideal tool for studying procedural learning as the sequential structure is entirely incidental to the participant’s task and the nature of sequence learning appears to be very ‘low-level’ in the sense that participants develop a perceptual-motor rather than a cognitive skill” (2005, p. 370). Novel tasks that rely upon more cognitive learning capacities may assist in disentangling the forms and capacities of learning in the absence of awareness.

Given the differentiation of sequence learning from motor learning, and the SRT's status as an ideal tool for examining sequence learning, the basic question remains as to whether novel forms of the SRT may be developed to demonstrate sequence learning in the domain of cognitive learning. In the classic SRT, the subject is cued to their next response via a visual stimulus displayed at a location which corresponds to the appropriate response. As the information being learned by the subject is intimately tied to the physical location of the subject's overt response, motor learning may be implied as contributing strongly to resulting performance in the SRT. The novel stimuli used in our experiments dissociates subject performance from motor learning in that the information being learned by the subject is that of an inter-item association. Rather than anticipating, acquiring, or learning a series of locations, subjects acquire information governing the identity of a series of stimuli presented at a single location. It is via the subject's knowledge of the relationship between these stimuli that they may then learn and anticipate a sequence of target identities such that their performance is subsequently speeded.

Implicit Learning versus Explicit Learning

Reviews of IL have highlighted the complexity of theories regarding learning and awareness (Dienes & Berry, 1997; Frensch & Rünger, 2003). Recent investigations have focused on dissociating implicit and explicit processes in terms of behavior and their underlying neurophysiological substrates (Aly & Yonelinas, 2012; Ashby & Ell, 2002; Gabrieli, 1998; Graf & Schachter, 1985; Kaufman et al., 2010; Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Squire, 1994).

One oft cited dissociation of implicit and explicit learning is that of spared implicit learning abilities in amnesic subjects (Nissen, Willingham, & Hartman, 1989; Schacter, 1987). In contrast to common reports, Curran (1997) finds deficits in both associative and IL capacities in patients with amnesia. Likewise, experimental study of implicit acquisition of artificial grammar challenges claims that implicit learning is spared in amnesia (Channon et al., 2002). Indeed, reports of spared implicit abilities in cases of amnesia have faced mounting challenges in replication. There has been the suggestion that prior reports of spared IL capabilities in amnesia may instead reflect differential task demands on a unitary learning system (Buchner & Wippich, 2000; Kinder & Shanks, 2001; Kinder & Shanks, 2003; Zaki, Nosofsky, Jessup, & Unverzagt, 2003).

Conceptions of IL as distinct from explicit learning processes have been challenged in reports on the SRT (Shanks et al., 2005), and multiple publications have failed to replicate learning in the absence of awareness (Perruchet & Amorim, 1992; Perruchet, Bigand, & Benoit-Gonin, 1997; Shanks & St John, 1994; Shanks, Wilkinson, & Channon, 2003). Recent reports in mathematical modeling have yielded additional evidence against the existence of independent implicit and explicit memory systems (Berry, Shanks, Speekenbrink, & Henson, 2012; Shanks & Berry, 2012; Starns, Ratcliff, & Mckoon, 2012).

Questions

To probe the distinctness of IL we asked if measures of learning under implicit conditions meaningfully differ from those under explicit conditions. To probe the material specificity of IL we asked if measures of learning in response to the *identity* of a stimulus meaningfully differ from those in response to the *location* of a stimulus.

If implicit and explicit learning are indeed dissociable processes, we would expect to see evidence of this dissociation in the form of differing profiles of learning in measures such as response time savings and error rates, as well as in the contributions of familiarity and recollection as assessed via the process dissociation procedure (PDP). Also, if implicit learning is a process specific to motor tasks, we would expect not to be able to establish learning under implicit conditions in response to cognitive information such as the relationship governing the inter-item association of a series of stimulus identities.

Methods

Participants

Neurotypical participants, age 18-28, were recruited from the University of Nevada, Reno undergraduate research subject pool and participated in one of two experiments (Experiment 1: N= 10, 5 female, 5 male; Experiment 2: N= 11, 6 female, 5 male). Subjects received extra credit in undergraduate courses as compensation for their time and participation. All procedures and participation were carried out in accordance with protocol as reviewed and approved by the University of Nevada, Reno Institutional Review Board.

Apparatus

Stimulus presentation and response collection was conducted via PC laptop using code assembled in Microsoft's Visual Basic. The Windows API timing function QueryPerformanceCounter was utilized to provide millisecond timing resolution. Subjects were seated at an ocular distance of 28.5 inches (72.39 centimeters) from the screen. Visual stimuli were presented at 0.629 degrees of visual angle in height at that distance.

Materials

Stimuli were determined by two pairs of complementary 12-item second-order conditional (SOC) sequences (Figure 1). First-order conditional sequences involve a direct relationship between two stimuli. An example of a rule following first-order logic would be: "the number one always follows the number four". In comparison, second-order conditional sequences do not involve a direct relationship between two stimuli, but instead are mediated by an intervening stimulus. As such, for a second-order conditional sequence, a given stimuli depends not only upon its preceding stimulus, but rather upon the particular combination of the prior two preceding stimuli. Within each pairing of sequences used in this study, features such as reversals (e.g. 3-4-3) and proportion of numbers utilized were held constant. As discussed in Kaufman et al. (2010), first order logic was maintained across sequences, however second-order logic was altered (e.g. 4-1-3 versus 4-1-2).

Procedures

All subjects completed the Edinburgh Handedness survey, including responses regarding subject age and sex. Following the survey, participants were engaged in a SRT. Responses were acquired using the D, F, J, and K keys, with subjects resting their left and right index fingers on the F and J keys respectively, and their left and right middle fingers on the D and K keys respectively. Participants were instructed to respond as quickly and as accurately as possible. Subjects completed 50 responses to randomized stimuli as a warm-up. Following warm-up, eight blocks of 125 trials were completed per subject, with seven blocks of stimuli determined by one of the four 12-item SOC sequences. The eighth block for each subject consisted of the paired alternate sequence of that used during the preceding blocks. Subjects were encouraged to take a short self-paced break between blocks.

After completing the eighth block, subjects immediately completed a PDP designed to produce estimates of the contributions of recollection and familiarity to performance (Kelley & Jacoby, 2000; Ratcliff, McKoon, & Van Zant, 1995; Yonelinas, 2002)(for a review of the PDP see Yonelinas & Jacoby, 2012). Participants were presented with the two preceding stimuli for a given target stimulus, and in a two-alternative forced choice task were asked to either pick the target stimulus that would follow the two displayed stimuli in the sequence (inclusion condition) or pick the target stimulus that would *not* follow the two displayed stimuli in the sequence (exclusion condition).

After completing the PDP, participants were given explicit instruction as to the presence of a sequence that determines the stimulus for each given trial. Participants were instructed to attempt to learn the sequence and to use their knowledge of the presence of the sequence to boost their speed and accuracy of response. Following explicit instruction, subjects completed an additional eight blocks of 125 trials as well as an additional PDP. Stimuli presented during this explicit condition were drawn from the SOC pair alternate to that used previously in the implicit condition. Subjects were counterbalanced for order of presentation regarding the four SOC sequences used. Subjects were also counterbalanced for order of presentation regarding PDP response conditions, inclusion or exclusion.

In experiment 1, subjects completed a classic SRT in response to the presentation of visuospatial stimuli. The four response buttons corresponded spatially with four locations of presentation (Figure 2). For each trial, an X appeared in one of the four locations.

Whereas in experiment-1 the stimulus was displayed as an X in one of four locations corresponding with the SOC sequence, experiment-2 used a single display field in which the numeric identity of the sequence was presented (Figure 3). The D, F, J, and K keys corresponded to the identity of the stimuli, 1, 2, 3, or 4 respectively. This procedure is novel in that subjects are not cued to a location of motor response, but rather to a stimulus identity. It is via acquisition of the relationship governing the inter-item association of stimulus identities that the subject may then subsequently anticipate stimuli and speed response.

Analysis was limited to responses between 200 and 1,000 milliseconds (ms), with responses outside this window presumed to be accidental key press or missed trials. Additionally, prior to analysis, outlying scores more than two standard deviations above or below the mean of each distribution of response times were discarded.

MRT, error rate, and PDP performance data were collected for all subjects. Comparisons of response times across blocks, and comparisons of error rates and PDP performance across condition of learning (implicit versus explicit), were performed using paired-samples *t*-tests. Comparisons across task type (response to stimulus location versus stimulus identity) were performed using a mixed-design analysis of variance. All statistics were prepared and analyzed using the IBM SPSS Statistics package version 22.

Results

Experiment-1 (stimulus location task):

Under implicit conditions, savings in MRT due to the effects of learning in the final training block (block 7) were significant when compared to the test block (block 8) ($t(9) = 2.509$, $p = .017$, one-tailed). This comparison yielded a large effect size ($d = 1.025$), for a response time savings of 45.5 ms, or 8.4 percent (Figure 4). A PDP analysis provided estimates for the contributions of recollection and familiarity to learning in the implicit condition of 10.0 percent and 58.4 percent, respectively. In sum, we see significant implicit learning in response to a sequence of stimulus locations.

When comparing performance in the implicit and explicit learning conditions of the task, no significant differences were exhibited in MRT savings ($t(9) = 0.281$, $p = .785$) or error rates ($t(9) = 1.797$, $p = .106$). Neither were there significant differences between learning conditions in estimates of the contributions of recollection ($t(9) = 0.449$, $p = .664$) or familiarity ($t(9) = 2.186$, $p = .057$). Across these multiple measures of learning, we were unable to identify significant differences between implicit and explicit learning in response to a sequence of stimulus locations.

Experiment-2 (stimulus identity task):

Under implicit conditions, savings in MRT due to the effects of learning in the final training block (block 7) were significant when compared to the test block (block 8) ($t(10) = 3.556$, $p = .003$, one-tailed). This comparison yielded a medium effect size ($d = 0.554$), for a response time savings of 32.2 ms, or 5.0 percent (Figure 5). A PDP analysis provided estimates for the contributions of recollection and familiarity to learning in the implicit condition of 4.5 percent and 55.2 percent, respectively. In sum, we see significant implicit learning in response to a sequence of stimulus identities.

When comparing performance in the implicit and explicit learning conditions of the task, no significant differences were exhibited in MRT savings ($t(9) = 0.342$, $p = .740$) or error rates ($t(9) = 0.870$, $p = .407$). Neither were there significant differences between learning conditions in estimates of the contributions of recollection ($t(9) < 0.001$, $p > .999$) or familiarity ($t(9) = 1.941$, $p = .084$). Across these multiple measures of learning, we were unable to identify significant differences between implicit and explicit learning in response to a sequence of stimulus identities.

Cross-task comparisons:

Analyses comparing the effects of task type (response to stimulus location versus response to stimulus identity) between subjects, and condition of learning (implicit versus explicit) within subjects, demonstrated no significant MRT differences. There was no main effect of task type ($F(1,18) = 1.450$, $p = .244$, $\eta_p^2 = .075$), nor was there a main effect of condition of learning ($F(1,18) = 0.180$, $p = .676$, $\eta_p^2 = .010$). Likewise, there was no interaction effect ($F(1,18) = 0.002$, $p = .968$, $\eta_p^2 = .000$).

No cross-task significant differences were identified with regard to error rates, with no significant main effect of task type ($F(1,18) = 1.190$, $p = .290$, $\eta_p^2 = .062$), no significant effect of condition of learning ($F(1,18) = 3.314$, $p = .085$, $\eta_p^2 = .155$), and no interaction effect ($F(1,18) = 0.237$, $p = .632$, $\eta_p^2 = .013$).

No cross-task significant differences were identified with regard to PDP estimates of recollection, with no significant main effect of task type ($F(1,18) = 1.337$, $p = .263$, $\eta_p^2 = .069$), no significant effect of condition of learning ($F(1,18) = 0.126$, $p = .726$, $\eta_p^2 = .007$), and no interaction effect ($F(1,18) = 0.126$, $p = .726$, $\eta_p^2 = .007$).

Cross-task comparison of PDP estimates of familiarity demonstrated no main effect of task type ($F(1,18) = 1.604$, $p = .221$, $\eta_p^2 = .082$), and no significant effect of condition of learning ($F(1,18) = 0.009$, $p = .926$, $\eta_p^2 = .000$), although a significant interaction effect was identified ($F(1,18) = 8.481$, $p = .009$, $\eta_p^2 = .320$)(Figure 6).

To summarize, though subjects demonstrated significant implicit learning in response to sequences of both stimulus locations and of stimulus identities, we do not observe significant differences between profiles of learning under implicit or explicit conditions, neither do we see significant differences between profiles of learning in the motor or cognitive tasks. Additionally, effect size estimates across comparisons of motor versus cognitive tasks and across comparisons of implicit versus explicit conditions do not indicate any meaningful differences between these conditions of learning.

In total, fewer than 10.5 percent of scores were classified as outliers and removed prior to analysis. Also, response times for one subject in the explicit condition of experiment-2 were discarded as their error rate exceeded 20 percent. To test the robustness of our cross-task comparisons of effects upon index of learning, we repeated our analyses using subject age, sex, and handedness score as individual covariates. Our findings remained unaffected by these follow-up analyses.

Discussion

Our series of experiments set out to probe the distinctness of IL by asking if measures of learning under implicit conditions meaningfully differed from those under explicit conditions. To probe the material specificity of IL we asked if measures of learning in response to the *identity* of a stimulus meaningfully differed from those in response to the *location* of a stimulus.

As expected, we successfully replicated IL in the classic SRT paradigm. Interestingly, we also identified successful IL in the novel SRT task involving the inter-item association of stimulus identity. After confirming successful implicit learning in both tasks, we compared index of learning (MRT savings), error rates, and PDP estimates of recollection and familiarity between task types. Our results indicate similar profiles of learning in both the motor learning task in response to stimulus location, and in the cognitive task in response to stimulus identity.

Prior applications of the SRT have focused on the use of visuospatial stimuli with learning reflecting a motor mapping of responses. The establishment of successful IL in response to the identity of stimuli indicates learning of a cognitive nature. Rather than relying upon stimulus-response models of motor learning, this paradigm demonstrates learning of sequential identity in the absence of the subject's awareness of their learning, or of their resultant knowledge. This method allows for the investigation of IL in response to the inter-item association of stimulus identity, a form of information typically only examined within the realm of explicit learning.

Our analysis of learning under implicit and explicit conditions likewise demonstrates similar profiles. Index of learning, PDP estimates of recollection and familiarity, and error rates do not significantly differ in response to either motor or association learning tasks. In conjunction with a lack of statistically significant differences, across conditions of learning as well as across task type, we note negligible effect sizes as estimated by partial eta-squared. Within the context of current field debate, our findings are compatible with earlier reports indicating that implicit and explicit learning processes are behaviorally non-dissociable.

With results indicating that learning is equivalent in strength and accuracy regardless of task type (motor or cognitive) and regardless of condition of learning (implicit or explicit), we find no evidence of dissociable learning mechanisms. As discussed in Frensch and Rünger (2003), one hypothesized model of learning consists of a unitary learning system that either yields learned behavior, or that yields conscious awareness of regularity. A parsimonious interpretation of our data supports conceptions of a general learning mechanism in the SRT.

With regard to a post-hoc interpretation of the interaction effect identified in estimates of the contribution of familiarity across levels of task type (location-based or identity-based response) and across levels of condition of learning (implicit or explicit), we note that each of these conditions represents unique demands with regards to the recruitment of attention and cognitive processing. Whereas location-based responses are paradigmatic of motor learning and require little in the way of attentional recruitment, identity-based responses carry a heavier cognitive load and with it a greater demand for attention in processing or interpreting the relationship between a stimulus identity and the appropriate response. Likewise, whereas performance of a response task under implicit conditions with regard to the existence of a response-determining sequence makes little demand upon attention, a similar task under explicit conditions with regard to this same sequence now places active demands upon attention and yields increases in cognitive load.

In the case of the location-based response task, our interaction effect displays greater contributions of familiarity (automatic processes) under implicit conditions. In contrast, in the identity-based response task our interaction effect displays greater contributions of familiarity under explicit conditions. In explaining this seemingly paradoxical effect, we note a well-established body of research findings that demonstrate the detrimental effects of attention and cognitive loads specifically upon motor tasks (Beilock, Carr, MacMahon, & Starkes, 2002; Beilock, Wierenga, & Carr, 2002; Flegal & Anderson, 2008; Gray, 2004; Masters, 1992). Given the selectively detrimental effects of attention and cognitive load upon motor tasks, one might expect that an automated process like familiarity would display its greatest contributions in motor conditions with the least attentional recruitment and in cognitive conditions with the greatest attentional recruitment. Our obtained interaction effect is consistent with this expectation.

Aly and Yonelinas (2012) discuss the operation of both state- and strength-based properties in learning and memory. Whereas familiarity appears to be a strength-based process, recollection may be supported by an all-or-none representation. Additionally, Yonelinas and Jacoby (2012) discuss the separation between controlled and automatic processes as assessed respectively in the form of recollection and familiarity via the PDP. Given the assumption of independence of controlled and automatic processes as estimated by the PDP, we do not find it surprising that an independent all-or-none controlled process would not be susceptible to the same interactions as an independent strength-based automatic process, most especially when the detrimental effects of attention and cognitive load are seen specifically in the case of automatic or semi-automatic motor tasks.

We note that recent and similar investigations of IL regarding abstract or semantic content provide a supporting framework for our results. Of particular note is a report from Goschke and Bolte (2007) where the experimenters induced IL of abstract and semantic categorical representations in the absence of ordered stimulus presentations or overt responses. Subjects were instructed to vocally name an object that belonged to one of four semantic categories: animal, body part, clothing, or furniture. The order of presentation of the exemplars of these semantic categories was randomized, thus randomizing the specific overt response to the stimuli. Instead, solely the semantic category itself was serially ordered and implicitly acquired as a sequence by the subject. This experiment yields evidence in favor of systems of acquisition under implicit conditions of semantic content in the absence of ordered motor responses. Similarly, Tzelgov, Yehene, Kotler and Alon (2000) demonstrated implicit acquisition of magnitude decisions. In this experiment, subjects were trained to distinguish the greater of two magnitudes as represented by Gibson figures. Paired figures used during the training phase were not used during the test phase. As such, experimenters were able to demonstrate an implicit acquisition of magnitude knowledge in the absence of memory or experience with respect to specific pairings.

Given advances in the study of IL with regard to the handling of cognitive, abstract, and semantic representations, conceptions of IL may need to be expanded to include more than classic accounts of procedural learning. It would appear fruitful to expand accounts of IL to include non-procedural association learning as demonstrated in these and other novel IL procedures as well as procedural learning as outlined in classic motor theories of IL. It is within this category of implicit non-procedural association learning that contemporary findings such as cognitive, abstract, and semantic learning under implicit conditions may be acknowledged. Future works seeking to confirm the existence of associative learning capacities in the absence of awareness would do well to expand beyond classic location-based or motor serial learning paradigms and focus instead upon the further development of novel cognitive association tasks and paradigms.

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Sequence 1(a): **1–4–3–2–4–1–3–4–2–3–1–2**

Sequence 1(b): **3–4–1–2–4–3–1–4–2–1–3–2**

Sequence 2(a): **2–1–3–4–1–2–3–1–4–3–2–4**

Sequence 2(b): **3–1–2–4–1–3–2–1–4–2–3–4**

Figure 1. Paired second-order conditional sequences.

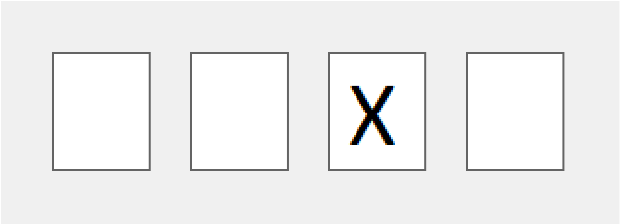


Figure 2. Location stimuli in experiment-1.

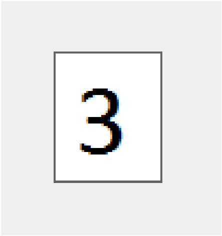
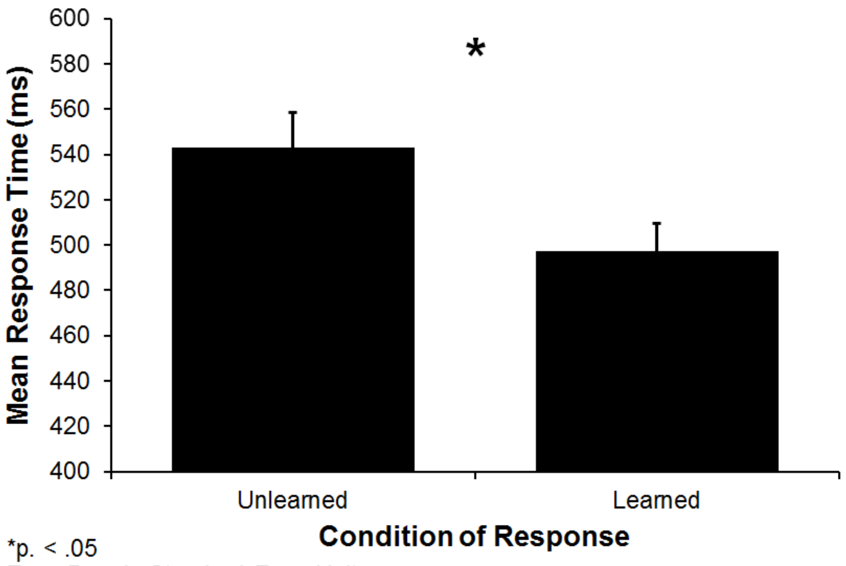


Figure 3. Identity stimuli in experiment-2.



*p. < .05
Error Bars in Standard Error Units

Figure 4. Mean response time savings in learning of stimulus location under implicit conditions.

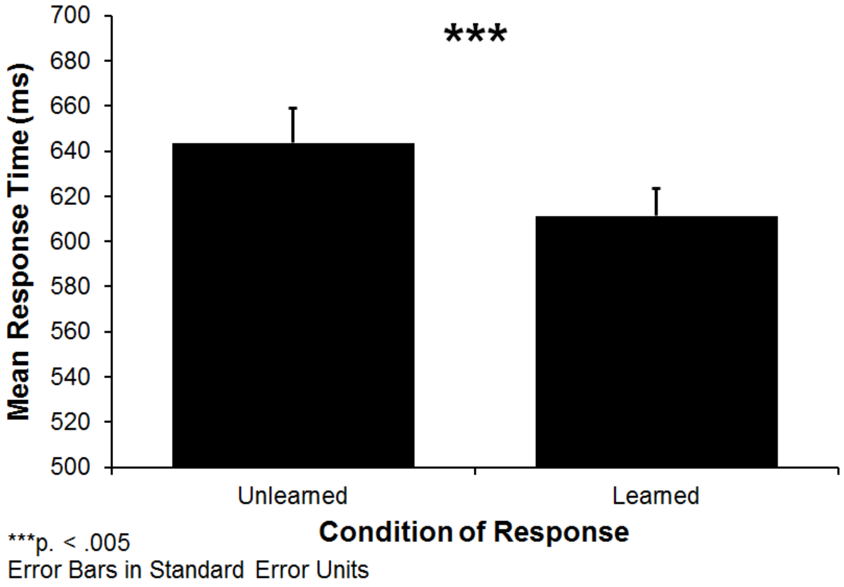
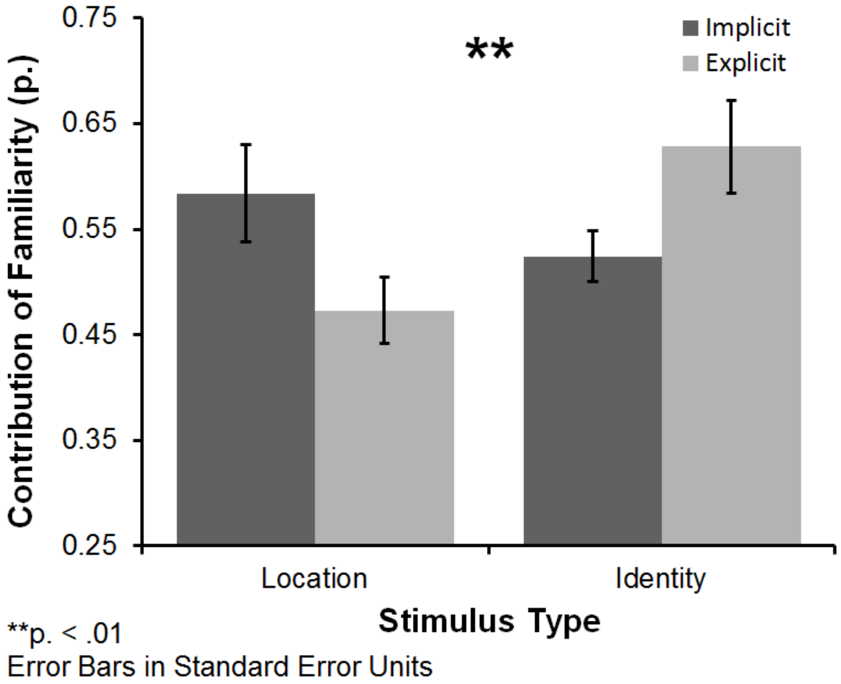


Figure 5. Mean response time savings in learning of stimulus identity under implicit conditions.



**p. < .01
Error Bars in Standard Error Units

Figure 6. Proportion of familiarity contributions to learning under conditions of implicit and explicit learning as estimated by the Process Dissociation Procedure.