UNCONSCIOUS PATTERN LEARNING USING FACIAL AND ABSTRACT STIMULI

by

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We are constantly processing information from our environment, although we are not conscious of most stimuli that reach our central nervous system. For this reason, some of our interactions with the world are based on unconscious processes. For the present experiment, unconscious, or implicit, learning was tested using abstract objects and faces. I compared the difference between unconsciously learning sequences with or without a social component, in this case, a face. Participants were given spot-the-difference trials consisting of sets of abstract objects or faces. A sequence of seven trials was repeatedly shown to participants with a distractor round of trials in the middle. The average mean reaction times for the seven spot-the-difference trials in each repetition of the sequence were used to assess participant improvement and learning over time. Analysis of the collected data was conducted in two parts. First, a paired samples t-test was used to compare average mean reaction times in the initial sequence and the final sequence to show whether learning occurred. Additionally, a repeated measures ANOVA was used to analyze the difference in average mean reaction times between the abstract objects and faces tasks to determine if the ability to unconsciously learn changed based on the presence of a facial social cue. The results showed implicit learning in both paradigms, as evidenced by faster reaction times and no reports of noticing the sequence in the post-task questionnaire. The faces task had a smaller change in reaction time between the initial and final pattern compared to the

abstract objects, although this trend was not significant. An explanation of the potential difference and data trend could be due to the way information is processed. There is evidence faces are holistically processed in the brain, so it takes time to break down a face into its component parts, while abstract objects use part-by-part processing (Wang, 2019). These results add to the increasing body of knowledge regarding how our unconscious influences our interactions with the people around us and our daily decisions.

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Introduction

Theories of Consciousness and Unconsciousness

Consciousness is a concept frequently used in everyday language in many different settings such as psychology, business, yoga, and martial arts. Even though consciousness is a commonly used word, there is still much unknown about consciousness in the field of neuroscience. Neuroscientists do not have a clear understanding or agreement on the concept, functions, and implications of consciousness. There are two approaches to the theory of consciousness: globalist and localist (Augustenborg, 2012).

Globalists theorize that consciousness is based in one brain area which controls everything related to consciousness. Globalists clearly outline attention as necessary for consciousness, while everything without explicit attention is unconscious. One of the top globalist theorists, Bernard Baars, created the Global Workspace Model (Augustenborg, 2012). According to the Global Workspace Model, stimuli compete to go from unconsciousness to the conscious workspace. One stimulus at a time falls under the attentional spotlight in the conscious workspace, resulting in that single stimulus becoming conscious while others are still unconscious. The stimuli that are not continually given attention either become unconscious specialized processors that help with other unconscious functions such as language, spatial skills, and facial recognition or they decay (Baars, 2005).

The other main approach to consciousness is the localist theory. The localist theory emerges from the idea that multiple brain areas control consciousness depending on the stimulus presented. The localist theory can be used to explain how implicit processes, or processes without our awareness, can occur, but in this theory, implicit processes can be conscious because not all conscious processes require attention. Therefore, it is more difficult to clearly state what is or is not consciousness in this theory. In the localist theory, a person can have various levels of consciousness that are not necessarily associated with attention or awareness. Claudia Carrara-Augustenborg's consciousness theory of the Endogenous Feedback Network (EFN) explains that if a stimulus is significant enough to be sent to the brain and enter a neuronal network, then it is conscious, whether or not a person becomes aware of the stimulus (Augustenborg, 2010). The EFN is a preparatory system that recruits nodes in a neural network to create individual meaning in case a person needs to become consciously aware of the stimulus.

To explain how both theories could be possible depending on the researcher's perspective, I am going to use the example of driving. Driving a car while talking to a friend is a good example of the duality of consciousness and how different models can explain multitasking. In Augustenborg's EFN, a person is conscious when the neural network is active in response to a stimulus regardless of the level of attention that is given to that stimulus. The stimuli involved in driving and talking switch between levels of consciousness depending on what stimulus has the person's attention, but both driving and talking are never unconscious (Augustenborg, 2010). Alternatively in Baars' Global Workspace Model, stimuli are filtered from the unconscious to the conscious workspace. In the workspace, one stimulus at a time is under the attentional spotlight resulting in conscious awareness while all other stimuli stay unconscious (Baars, 2005). The attentional spotlight can quickly shift between stimuli related to driving or talking, but in this theory, you are technically unconscious of the activity that is not given attention at that moment. While each of these theories have their own advantages and disadvantages, these two classes of theories dominate the cognitive neuroscience of consciousness discussion. These cognitive consciousness theories appear to oppose each other, however, there is a range of variability within each of these umbrella categories. Baars' and

Augustenborg's models are just two examples that exemplify the main aspects of globalists and localists, respectively (Augustenborg, 2012).

The consciousness theory that I will use to establish the current experiment is a globalist theory using Baars' Global Workspace Model. I chose this theory because Baars and other globalists clearly define consciousness by equating consciousness to attention while all other stimuli are processed unconsciously. The clear definition makes the globalist theory a beneficial method for a study of unconsciousness because it allows a greater capacity to research unconscious processes compared to the localist theories. The globalist theory defines the concept of consciousness to be equivalent to explicitness because both require attention. Both explicit and conscious will be used interchangeably, as will unconscious and implicit learning.

Learning: Conscious vs Unconscious

It may seem that learning is a cognitive skill that requires attention to be successful. However, experimentation shows consciousness is not required for learning (Watanabe, 2001). Watanabe determined that attention and visual perception are not necessary for learning during a visual task. A person constantly receives information they are not consciously aware of and much of that information influences their behavior, suggesting that unconscious learning is possible. A classic example of unconscious learning that is commonly taught in AP psychology classes across the country is classical conditioning. Classical conditioning was first demonstrated by Ivan Pavlov. He showed that dogs were able to associate ringing a bell with food and after multiple trials the dogs would salivate in response to the stimulus of the bell without the presentation of the food (Fanselow & Wassum, 2015). Other examples of classical conditioning are when you hear your alarm sound and you react, or when you develop taste aversion after having food poisoning. Classical conditioning demonstrates that implicit learning is possible in everyday life even through it occurs without our awareness.

Another form of learning not limited to consciousness is sequence learning. Previous research has shown that sequences can be acquired through implicit learning. For example, Fu et al. (2008) found that participants were able to learn a sequence without awareness. However, the capacity for unconscious short-term memory is not a highly researched area. In contrast, the capacity for conscious short-term memory, or working memory, has been examined over time and has been commonly accepted to be seven plus or minus two (Miller, 1956). Miller suggests most people can hold approximately seven items in their working memory at any given time. Research on implicit sequence learning has utilized a wide range of sequence lengths, ranging from six to fifteen trials (Destrebecqz & Cleeremans, 2001; Fu et al. 2008). Studies like these have demonstrated that sequence learning can be acquired implicitly, however the length of the sequence that should be tested in unconscious learning tasks is still unknown.

One aspect of learning that has been more fully examined by researchers is the processing of faces and facial features. It has been discovered that we holistically process faces instead of using the part-by-part system used to process other objects (Wang, 2019). Holistic processing is believed to be developed in the early stages of childhood when children learn to distinguish faces and create emotional attachments to those faces, allowing people to quickly identify faces and individuals in everyday life (Taubert et al., 2011). The ability to holistically process faces has been tested primarily through tasks that rely on conscious processing. There is currently controversy in this field as some researchers have found that humans are unable to holistically process faces unconsciously (Axelrod & Rees, 2014), while others have found that unconscious holistic processing is possible (Jin et al., 2021). A study by Axelrod and Rees created unconscious and conscious parameters using facial images that focused only on the eyes to conclude that unconscious visual perception may not involve holistic processing. However, Jin et al. ran their own similar experiment and reviewed the Axelrod and Rees study. They commented on the difference between the Axelrod and Rees study and theirs pointing to the limited sample size and the exclusive use of eyes in the older study. The Jin et al. study presented halves of faces, instead of just eyes, for the unconscious and conscious paradigms. They concluded that holistic processing is possible without consciousness because when the bottom half of a face was not consciously visible, its presence still influenced the processing of the top half of the face. The conflicting sets of results indicate that further examination is necessary to understand unconscious processing of faces and the way faces as social cues affect unconscious learning.

Goals and Hypotheses

The current study is designed to test whether the social cue of faces helps, hinders, or does not alter our ability to unconscious learn sequences compared to abstract objects. The study used sets of faces and abstract objects to create a sequence of seven repeated trials. Each trial consisted of a spot-the-difference task for the participants to complete. Learning was measured by tracking the changes in average mean reaction times for the repeated sequence over time. A post-task questionnaire indirectly asked participants if they noticed the sequence during the tasks.

My research partners and I hypothesized that unconscious learning would occur for both facial and abstract objects tasks, like previous research has shown (Destrebecqz & Cleeremans, 2001; Fu et al. 2008). We also hypothesized there would be increased learning as measured by greater average reaction times for the abstract objects compared to faces. This prediction is based on the assumed difference between processing types for faces and abstract objects. It should take more time to identify the difference in the spot-the-difference task for faces because it likely takes longer to single out one attribute with holistic processing of faces than part-by-part processing of objects (Jin et al., 2021; Wang, 2019).

The overall goal of this study is to aid in our understanding of unconsciousness and the effect it has on different types of learning. The results of the unconsciousness study may have societal, psychological, and philosophical impacts. Consciousness is one of the big questions in neuroscience and can help us comprehend topics like how our reality and perception differ, discover how identities are created, and how our intuition can be influenced. Every day we are constantly interacting with the world and reacting to our surroundings, but we are not necessarily paying conscious attention to every decision we make. Research on implicit learning and how it can be altered is important to further scientific understanding of consciousness and how it can affect our lives.

Methods

Participants

The experiment was run with 23 participants from American universities studying abroad at the Danish Institute of Study Abroad (DIS) in Copenhagen, Denmark (ages 20-21, 18 female, 4 male, and 1 nonbinary). None of the participants were in the Cognitive Neuroscience of Consciousness course, and they only knew the research was in cognitive neuroscience. All participants signed an informed consent form. None of the participants had been diagnosed with epilepsy, and all participants either had corrected or unimpaired vision. Fifteen participants (12 females, 2 males, and 1 nonbinary) completed both the faces and abstract objects tasks, while the other eight participants only completed the abstract objects task due to a programming error.

Experimental Design and Pilot Trials

The unconscious learning experiment was developed using a spot-the-difference sequence learning task with faces and abstract objects. The face and abstract object designs were created to be as similar as possible. The same eight general shapes of the same size were placed in a circle to create the face or abstract object design. The trials in each task consisted of nine designs placed in a three-by-three grid of entirely objects (Figure 1) or faces (Figure 2). Eight of the nine designs in the grid were the same and one was different which created the spot-the-difference game. In both tasks, the shape within the design that was changed was a triangle, which was replaced by a rhombus. The changed shape was placed in the center of the midline for the faces and below the center of the midline for the abstract objects, and it was this substitution that participants were asked to identify in the spot-the-difference game. The purpose of the face and abstract objects having such a similar design was to eliminate any potential variables that would make one of the sets of stimuli inherently easier to spot the change than the other.

Using the spot-the-difference trials, the tested learned sequences were created for both faces and abstract objects. Learning was measured by analyzing the average participants' mean reaction times for the spot-the-difference trials during the sequences of seven trials. Each sequence consisted of the same seven trials shown in the same order, and this sequence was repeated for a total of eight presentations during the task. There were four different rounds during the study for both the faces task and the abstract objects task. The second and fourth rounds used the repeated sequence, and the first and third rounds used a randomized set of trials. The four rounds were the initial round, the learning sequence round, the distractor round, and the final sequence round (Figure 3). The sequence was repeated five times during the learning sequence round and three times during the final sequence round. The initial round consisted of four trials and was meant for practice. The distractor round of four trials was meant to disrupt any conscious perception of learning the sequence. The four rounds together composed the task or paradigm for either the faces or abstract objects. The rounds were shown one after the other, so participants could not determine any difference between the trials of each round.

An obstacle we encountered was deciding on a sequence length. We needed the sequence to be short enough to learn with a few repetitions but long enough that the pattern was not consciously recognized. Therefore, we decided the length of the pattern would be equivalent to the conscious short-term working memory capacity because unconscious memory capacity has not been extensively studied. The maximum conscious working memory capacity has been established to be seven plus or minus two (Miller, 1956), so the length of sequence we decided to test was seven. The length of the pattern was confirmed to be sufficient through pilot trials that were run before the experimental data collection began.

Another challenge we discovered during these trials was the time it took participants to adjust to the spot-the-difference trials. The first reaction times were much longer because participants were still working to correlate the design on the screen with the correct number keys to press. This issue was eliminated by adding an initial screen before the experiment for participants to align themselves with the three-by-three number keys and the three-by-three spot-the-difference trial design. Additionally, this was when the initial round of four trials was added so participants could orient themselves to the task and the shape that changed without the data being analyzed (Figure 3). This first round was meant as a practice round to eliminate the variable of learning how to do the spot-the-difference trials.

Another important aspect of the experimental design was the distractor round, which occurred between the two rounds of sequences (Figure 3). This round consisted of four spot-the-difference trials. The goal of the distractor round was to prevent the participants from consciously recognizing the pattern by interrupting their learning of the sequence. Similarly to the seven-trial sequence, participants were not meant to consciously recognize the distractor round. Experimentation has shown that a distractor round is one way to ensure the sequence being tested is not recognized consciously as a pattern (Destrebecqz et al, 2005). To further ensure individuals were unconsciously learning, a post-task questionnaire with open-ended questions was given to all participants after the study.

The post-task questionnaire asked: 1.) Did you find the task with the faces or abstract objects to be more difficult? 2.) Did you find yourself using any tactics in order to complete the task more efficiently and if yes please explain? 3.) Do you feel like your speed changes throughout the task and if yes why?

The goal of the post-task questionnaire was to determine if participants recognized a pattern, and if they did not, we took that as evidence that their learning was implicit.

Procedure

The experiment aimed to measure implicit learning using the average mean reaction times of a repeated sequence of seven. After participants filled out demographic forms, they were brought into the test room and sat in front of a mounted computer with the program E-prime and a nine key number pad oriented three-by-three. The participants were told they were about to participate in a cognitive neuroscience experiment by playing a spot-the-difference game where they would select a number one through nine on the square number keypad that corresponded to the item in the array that was different. They were told to go at their own speed to ensure they selected the correct number. The researchers sat in the room while the experiment was run in case the participant had any questions.

The experiment began by the participant reading the instructions on the screen welcoming them and restating what the participants were told by the experimenters. Then they were shown an example paradigm of nine plain circles in a three-by-three grid that lined up with the nine number keypad. The goal of this slide was to orient the participants to how the keypad, numbers, and paradigm were related. Once the participants felt ready, they started the experimental session.

The participants were given, at random, either the abstract objects or the faces paradigm first, except for the eight participants who only did the abstract objects task due to technical difficulties. During the spot-the-difference trial, participants selected the number associated with the face or abstract object with the rhombus instead of the triangle through the four rounds: the initial round, the learning sequence round, the distractor round, and the final sequence round (Figure 3). Once the four rounds were completed for either the faces or abstract objects paradigm, the participant was given a break. Then the participants started the other paradigm when they were ready except for the eight participants who only completed the abstract objects paradigm. The total experiment took 15 to 20 minutes to complete. After the experiment was completed, participants were given the post-task questionnaire.

Statistical Analyses

The average mean reaction times for the first sequence and the last sequence, in the learning sequence round and final sequence round, respectively, were used to assess if participants learned the sequence. The distractor round and the last sequence in the learning sequence round were also used to analyze the likelihood that learning happened over general improvement in the spot-the-difference trials. Lastly, the learning rate for a given participant was compared for the faces and the abstract objects, since they completed both tasks, to see if any difference was observed.

Figure 1

A Sample Spot-the-Difference Abstract Objects Trial

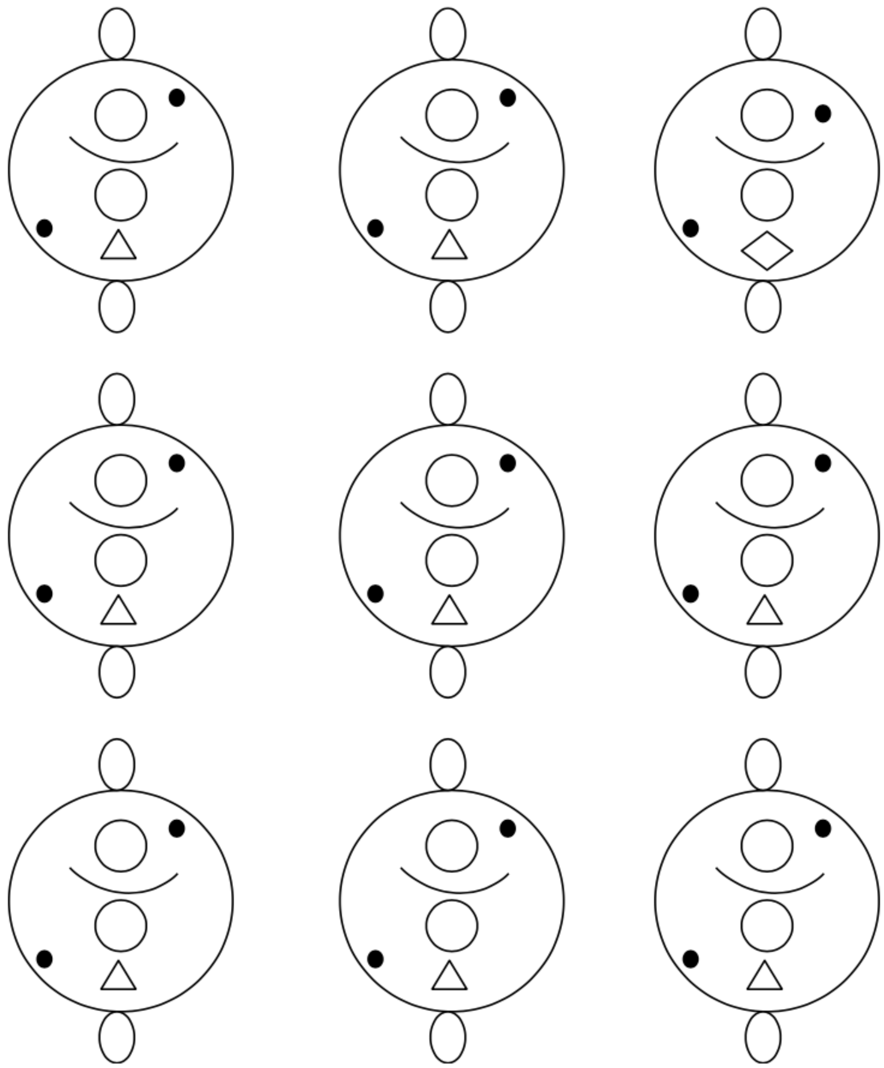


Figure 2

A Sample Spot-the-Difference Faces Trial

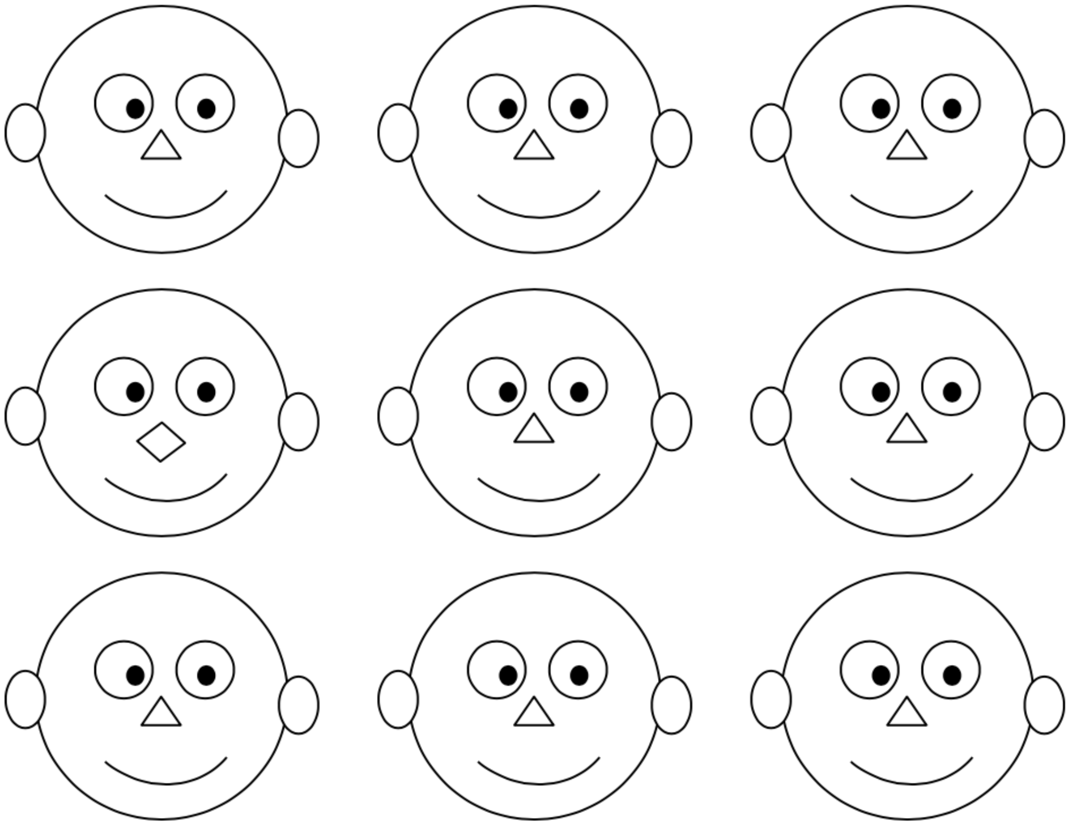
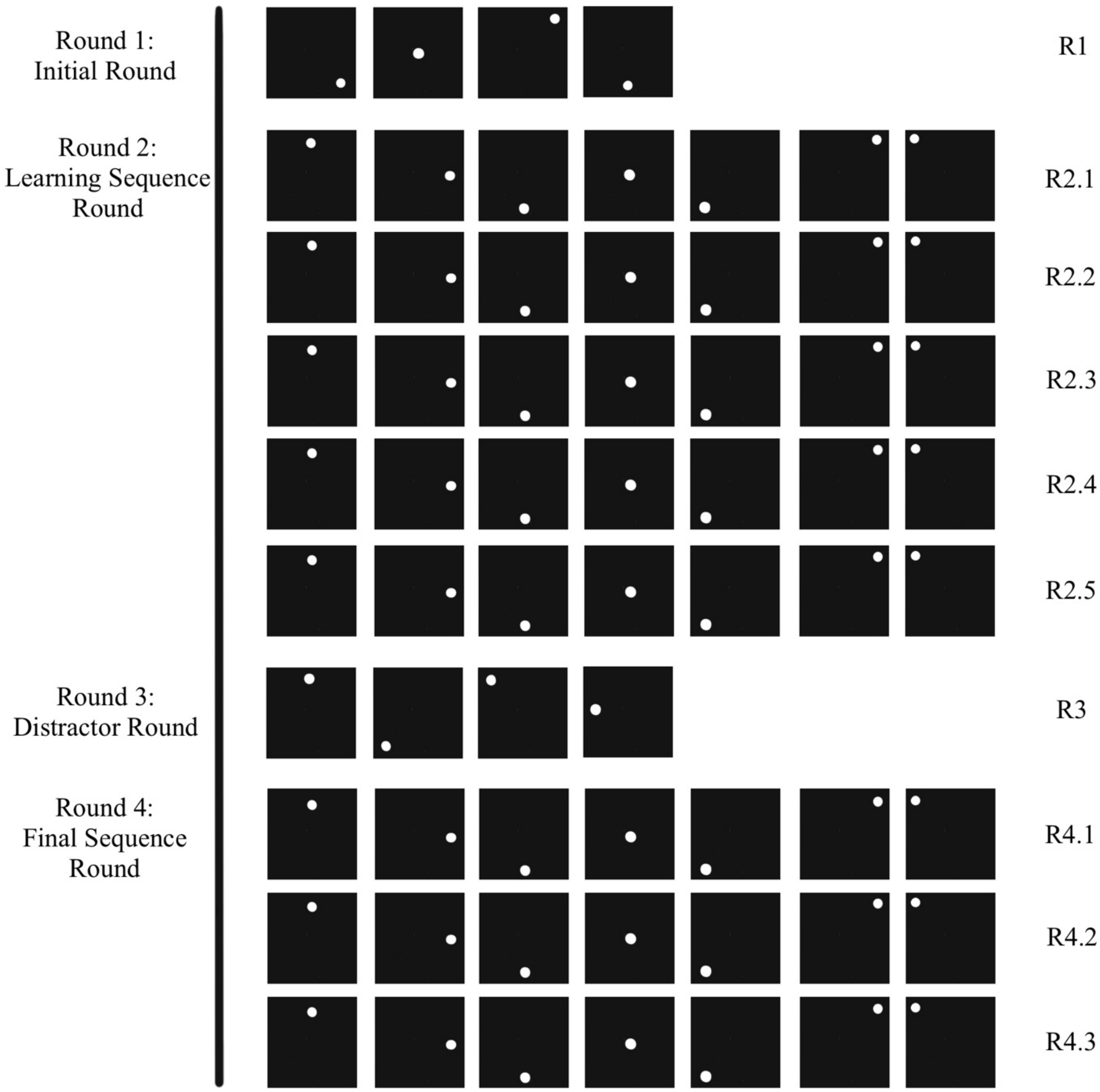


Figure 3

The Outline of a Single Task



Notes: This is an example of either task that would be entirely faces or abstract objects. Each square represents one trial. The rows with seven trials are the tested sequence that is repeated and analyzed. Each repetition of the sequence is indicated with the tenths value. The white dot represents the location of the design with the spot-the-difference change in each trial.

Results

It was hypothesized that participants would learn both the faces and the abstract object seven-trial sequence by seeing improvements in the sequence's average reaction times over the task. To address this hypothesis, a two-tailed paired-sample t-test was run to compare average mean reaction times for the first sequence of the learning sequence round with the average mean reaction times for the last sequence in the final sequence round. Learning occurred for the face sequences, with reaction times decreasing between the first sequence in learning sequence round (R2.1) (M = 2475.67 ms, SD = 474.32 ms) and the last sequence in the final round (R4.3) (M = 1941.52 ms, SD = 719.51 ms), $t(13) = 2.65$, $p = 0.02$. Similarly, learning occurred for abstract object sequences as evidenced by faster reaction times in the final round (R4.3) (M = 1717.41 ms, SD = 485.97 ms) compared with the learning sequence round (R2.1) (M = 2891.12 ms, SD = 1234.78 ms) $t(21) = 4.35$, $p < 0.001$.

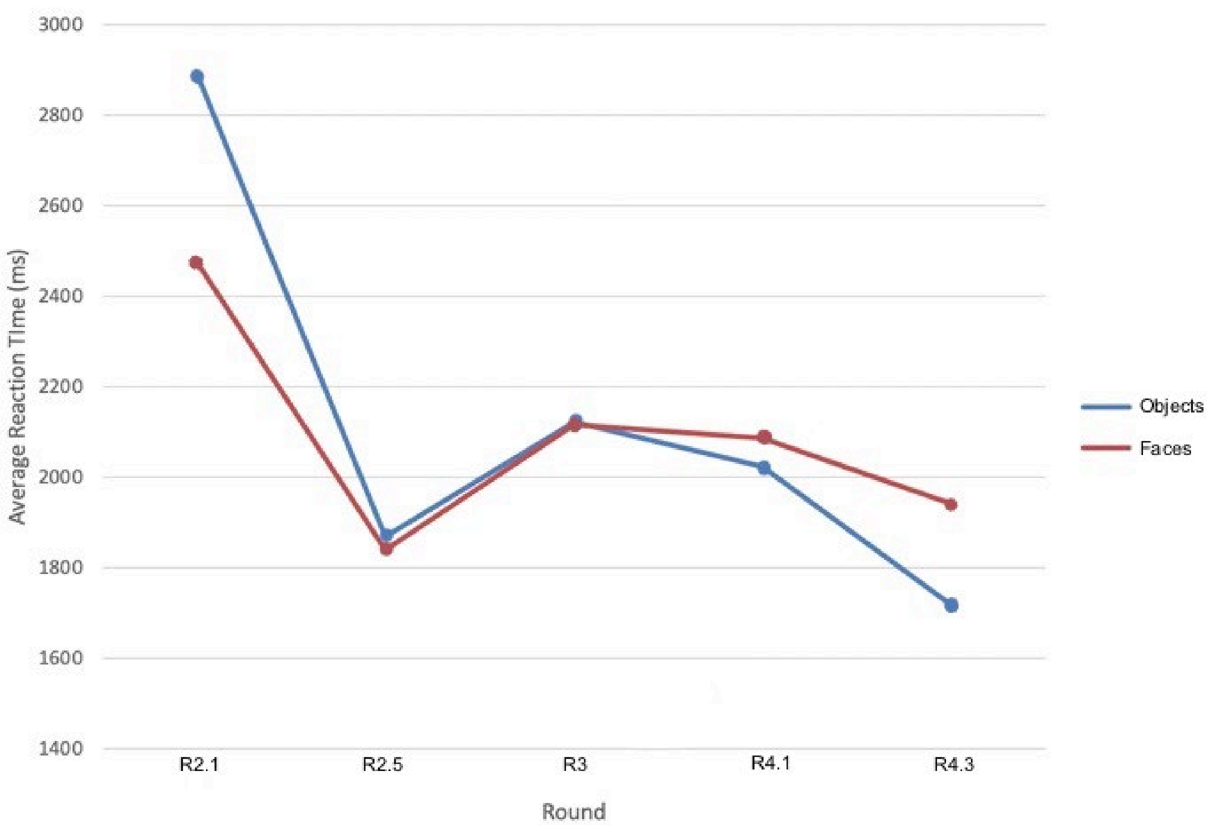
To further support the finding that sequence learning was occurring, rather than participants getting faster due to practice effects, average mean reaction times for the last sequence in the learning sequence round were compared with average mean reaction times for the subsequent distractor round with a two-tailed paired samples t-test. For the objects, although reaction times were numerically faster for the sequence round (R2.5) (M = 1868.53 ms, SD = 472.23 ms) compared with reaction times for the distractor round (R3) (M = 2122.21 ms, SD = 687.19 ms), the difference was not statistically significant, $t(21) = 1.61$, $p = 0.122$. For the faces task, there was a significant increase in reaction time during the distractor round (R3) (M = 2116.07 ms, SD = 388.66 ms) compared with the end of the preceding learning sequence round (R2.5) (M = 1838.34 ms, SD = 364.49 ms), $t(13) = 2.78$, $p = 0.016$, (Figure 4).

The second hypothesis, that the face sequence would show less improvement over time than the object sequence, was tested using a 2 x 2 repeated measures ANOVA with Round (2^{nd} vs. Last) and Stimulus Type (Faces vs. Objects) as the factors. The ANOVA revealed a main effect of learning [$F(1,13) = 15.71$, $p = 0.002$], with the reaction times decreasing between the learning sequence and final sequence rounds, but there was no main effect of object type [$F(1,13) < 1$, $p = 0.554$]. The interaction between Round and Object Type did not reach statistical significance [$F(1,13) = 3.12$, $p = 0.101$], but there was a nonsignificant difference in the learning between the faces and abstract objects tasks such that reaction times decreased to a larger extent for abstract object sequences.

The post-task questionnaire revealed the perception of difficulty by the participants and if they used any strategies to increase their reaction times. The majority of participants (69%) felt the abstract objects task was more difficult compared to the face task, 8% thought the face task was more difficult, and 23% found them equally challenging. No participants reported noticing with any confidence that there was a repeated pattern of seven during the tasks. Ten out of 13 participants reported using the consistent change of the triangle to the rhombus as a tactic to help them and believed that to be the psychological trick being testing, instead of noticing the overarching repeated pattern of seven trials. Only one participant mentioned a consistent pattern beyond the shape change. They commented "sometimes I felt like there was a pattern in the order where I looked in the right spot, but that might have not been true." This response indicates the participant had no real confidence of awareness and the learning of the sequence was likely implicit for them and the rest of the participants.

Figure 4

Average Mean Reaction Times by the Sequence in a Round During a Given Task



Note: The round and sequence numbers correspond with those depicted in Figure 3. This shows the average mean reaction time for a specific sequence in the round that was used during analysis. For example, R2.1 is the first sequence in the second or the learning sequence round.

Discussion

The current research shows that unconscious learning occurred for both the faces and abstract objects tasks. For both types of stimuli, there was a significant decrease in reaction times from the first to the last sequence of seven, demonstrating that learning had occurred. It was evident participants learned the sequence by comparing the end of the learning sequence round to the distractor round. These two sets of trials were next to each other. If learning had not occurred and the change was only due to practice effects, then the distractor round should have seen continued improvement. Instead, reaction times increased from the end of the learning sequence round to the distractor round for the abstract objects task and significantly increased for the faces task. These data suggest the overall decrease in reaction times through the paradigm was not just a general decrease in reaction times related to a practice effect, but that sequence learning had occurred during the task.

Additionally, the post-task questionnaire was meant to covertly ask participants if they noticed the sequence to assess if the sequence was unconsciously learned. No participants reported noticing the sequence with any confidence on the questionnaire. This is evidence for unconscious learning of the sequence of seven for both the faces and abstract objects. The results show that unconscious learning is possible with a sequence of seven. A sequence length of seven was used because of the well-established working memory capacity value of seven plus or minus two. The results indicate that if there is a capacity to unconscious learning it is seven or larger.

An unexpected finding from the post-task questionnaire was that the participants' perception of task difficulty differed from how the participants performed overall on the tasks. The participants showed about the same or slightly more improvement on the abstract objects task over time, yet the majority of participants reported the objects task as more difficult than the faces task. Interestingly, the initial reaction times were faster for the faces than abstract objects, but by the end of the final round their reaction times were faster for abstract objects than faces (Figure 4). The results show greater improvement and faster reaction times at the end of the objects task, however participants perceived faces as easier than abstract objects. This is likely a result of the participants being more familiar with faces than abstract objects. Our familiarity with a given stimulus, such as a face, can falsely influence our decision making to bias the more familiar stimulus, a phenomenon called the Mere Exposure Effect (Serenko & Bontis, 2010). The familiarity with faces over abstract objects gave participants a false sense of their overall ability leading them to conclude that the faces task was easier. Instead, participants should have rated the tasks with equal difficulty because they performed similarly on both. Additionally, the incorrect judgement of their own ability could be used to further suggest that unconscious learning was occurring because participants could not accurately assess their own learning ability when asked which task was harder.

I also analyzed whether the change in reaction time over time differed between the abstract objects and the faces. Sequence learning occurred for both types of stimuli, but I was interested in whether there was variation in our ability to unconsciously learn based on stimuli. The change in reaction time for the sequence of seven was smaller for the face stimuli than for the abstract objects, but this difference was not statistically significant. The data trend skewed towards the facial stimuli being harder to unconscious learn than objects. The results could have more power with more participants, so an analysis of the potential cause of these differences could help to explain this trend.

Any potential difference in unconscious learning of face and abstract object sequences could be due to how these stimuli are processed. Holistic processing, which is common for faces, would cause participants to recognize the whole abstraction more quickly as a face before breaking the components down into individual shapes. This could take longer than the part-by-part processing that is done for other shapes, like abstract objects. The abstract objects would be seen initially as parts so identifying one aspect as different might be faster for objects than faces that are processed as one whole image before being broken into identifiable parts (Jin et al., 2021). However, this assumes holistic processing occurs unconsciously which remains controversial (Axelrod & Rees, 2014). In the current experiment, this difference in processing appears to have caused some lag in reaction time over the whole paradigm for faces compared to objects but not a significant amount. The insignificant difference could suggest no difference in processing is occurring or the different processes have similar timing. Even though the value was not significant, it may be because holistically processing does take additional time, but just not a large enough amount of time to cause a significant difference. To confirm if holistic processing in unconscious learning is actually slower than part-by-part processing, a similar experiment should be run with more participants or a more diverse population of participants. A more extensive study could help to confirm the null effect or potentially demonstrate whether implicit learning occurs at a different rate for face and object stimuli.

A research study expanding on these findings could be done with another population of participants. It is predicted that the difference observed in sequence learning between face and abstract object stimuli, although not significant, is due to holistic processing of faces. To test this theory, another study should be run using participants with prosopagnosia and controls. Prosopagnosia is an impairment resulting from a brain lesion or developmental abnormalities that causes the inability to recognize faces (Albonico & Barton, 2019). The extent of brain damage can vary the degree of impairment from being unable to distinguish between faces or recognize familiar faces to not being able to recognize themselves or distinguish a face as being different from an object (NIH, 2023). A prosopagnosia case study was documented by the famous neurologist Oliver Sacks in his book *The Man Who Mistook His Wife for a Hat* (1985). The patient Dr. P could not recognize anyone, not Sacks or his wife, and would often mistake people as objects, such as hats.

Holistic processing can vary depending on the cause of a person's prosopagnosia. The lesions in acquired prosopagnosia are typically bilateral or exclusively in the right hemisphere, likely because facial processing is primarily in the right hemisphere. There are a few locations of lesions, mostly in the temporal or occipito-temporal cortex, that cause prosopagnosia, which may account for the varying degree of symptoms as well as the extent of the injury (Albonico & Barton, 2019). These lesion locations may be linked to holistic processing, according to recent research that compared acquired prosopagnosia patients to controls. The researchers noticed atypical perceptual judgement of faces, suggesting that holistic processing is affected in patients with acquired prosopagnosia (Monti et al., 2020). In contrast, other research on patients with developmental prosopagnosia concluded that holistic processing is possible. The developmental prosopagnosia participants were less able to use facial evidence when presented region-by-region compared to being shown the whole face, suggesting there is at least some holistic processing occurring (Tsantani, Gray, & Cook, 2020). Developmental prosopagnosia is present at birth (NIH, 2023), suggesting the possibility of developing alternative neural pathways to engage with holistic processing.

An experiment using facial and abstract stimuli, like the current experiment, could be important to show a potential difference between controls and acquired prosopagnosia patients' ability to unconsciously learn. The results of that study could help to explain whether holistic processing occurs during implicit learning of faces. I would hypothesize that there would be a difference in the average reaction times between groups because people with acquired prosopagnosia process faces in the same way as they do objects. So, there would be no difference between prosopagnosia patients learning of faces and abstract objects, and some difference for controls, as was seen in this experiment. An experiment of this sort could clarify holistic processing as an unconscious learning process if there is a difference between facial learning between the two groups. If there is no difference between the groups, it would suggest holistic processing is not occurring unconsciously and highlight another difference between our explicit and implicit processes.

There were some limitations in the current experiment. The E-prime program was set to move forward even if the participant selected the incorrect number. This may have affected our data by allowing participants to select a design in a trial that was wrong, resulting in falsely faster reaction times. Unfortunately, we did not collect data on participant accuracy. To improve this limitation, the E-prime program could be changed so the participant can only move forward when they choose the correct answer. This could potentially cause a longer reaction time and reveal if participants were just guessing or incorrectly assuming they knew the answer. Another option would be to record the accuracy of the responses and only looking at the reaction times for correct responses. This would also allow one to examine how accuracy improved over time.

Additionally, several participants reported in the post-task questionnaire that they blocked out the rest of the face to focus only on the nose because only one feature changed each trial. This may have reduced the holistic nature in which participants processed the faces. Changing a different facial feature each time might more effectively encourage holistic processing of the faces because people would not be able to focus on just one part of the face.

This was a similar limitation of the Axelrod and Rees study that was changed in the Jin et al study which demonstrated holistic processing to be an unconscious process. Presumably, a similar change in the current study would also increase the likelihood of unconscious holistic processing. This could cause a larger and potentially significant difference between the implicit facial and abstract stimuli learning, assuming holistic processing is causing this data trend.

Furthermore, the nature of testing unconscious learning has inherent limitations. To test unconscious learning, the data must show that there was learning and that participants were not aware of this learning. It is difficult to prove without a doubt that the learning was unconscious without making the participant aware of the goal. Despite this limitation there is vast literature demonstrating that sequence learning tasks can be used to test unconscious learning (Axelrod & Rees, 2014; Destrebecqz & Cleeremans, 2001; Fu et al. 2008; Jin et al., 2021; Watanabe, 2001).

Lastly, the number of participants and the demographics of those participants were limitations. The low number of participants was partially due to the technical difficulties that prevented eight participants from completing the faces task and the limited timeline for the experiment. More participants could make the interaction between Round and Object Type more powerful, solidifying the potential difference in sequence learning between faces and abstract objects (Journal of Neuroscience, 2020). Also, the participants were limited to students at the Danish Institute of Study Abroad (DIS). The students were primarily female, and all were American college sophomores or juniors. Limited demographics is common in cognitive psychology research. Still, it is not always possible to generalize results using college students because they can be more similar in personality and attitude than the rest of the population. Context is significant to consider when analyzing results and for replication studies. Another reason why replicating experiments is important for confirming results (Hanel & Vione, 2016).

In the future, the research could be expanded by experimenting with the length of the pattern. The true capacity of unconscious learning has not been researched comprehensively. For a future study, different lengths of patterns could be used to test the capacity of unconscious learning. The knowledge of the size of a person's ability to learn unconsciously compared to the conscious short-term memory capacity will help to highlight the difference between these processes. A better understanding of how or if these processes have different capacities would show the extent of influence these different processes have on cognitive functions, such as learning, memory, or decision making.

Unconscious learning and processing are an important part of our everyday lives. One example of our unconsciousness effecting our actions is observed through the dual processing model of decision making. This theory relates to our ability to make fast or slow decisions. Fast decisions can be made without our conscious awareness, or without explicitly working through each step in making a choice (Gronchi & Giovannelli, 2018). The features of often unconscious and fast decisions operate automatically, not voluntarily, and with little or no effort. We use this form of decision making daily, and our implicit learning can also impact how we make our fast choices. The fast decisions allow for more cognitive ease, so it is often we make decisions unconsciously before redirecting our attention to make slow decisions that cause cognitive strain (Kahneman, 2013). Our implicit learning can be revealed in these fast, unconscious decisions.

Unconscious learning can also manifest in our lives by influencing our behaviors, actions, or thoughts through intuition or gut feelings. We are often not aware of implicit learning persuading our decisions and working with our consciousness due to its nature. Implicit learning can be expressed consciously through the feelings we have when deciding if one certain choice should be made over another. Research has suggested implicit learning processes are what cause us to have intuition or gut feelings (Lieberman, 2000). The study drew a correlation between implicit learning and intuition by showing that the basal ganglia is necessary for both.

An example of a famous case study relating to this is the patient HM, who had his medial temporal lobes removed. He had anterograde amnesia, so he could not form new long-term memories. However, there were times he could not consciously recognize someone, but he had a sense that he knew them. His intuition was likely because his basal ganglia was still intact, so he was able to turn implicit learning into feelings of recognition despite not consciously remembering meeting a person.

It is important to understand the differences between unconscious processing using social stimuli such as faces compared to nonsocial stimuli. People can have varying abilities in their processing and interpretation of social behaviors. Social impairment disorders, such as autism spectrum disorder, involve decreased processing of social situations (Thom et al, 2020). Experiments examining the difference in processing social stimuli like faces can aid in our understanding of what is happening in disorders that affect unconscious learning and facial processing. In the current experiment, the slight decrease in unconscious facial learning could indicate that two separate systems exist for unconscious learning based on processing of different stimuli: holistic and part-by-part processing. This could show that even in unconscious processing there is a social component that influences our abilities. This could help expand our knowledge on the social processing components affected in disorders that involve social impairments and show that it is not limited to explicit experiences.

Conclusion

The research study showed that unconscious learning is possible using sequences of either facial or abstract object stimuli. However, there was not a significant difference between the ability to unconsciously learn face sequences compared with abstract objects sequences. Further research expanding the sample size or using an experimental group with impaired social or facial processing could determine the extent of holistic processing during unconscious learning. Unconscious processes are significant in our daily lives to help us make quick decisions and experience intuition, so it is important to better understand these processes and how they influence who we are.

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