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Implicit Learning: A Demonstration and a Revision of a Novel SRT Paradigm

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Abstract

Yeates, Jones, Wills, Aitken, McLaren and McLaren (2012) devised a serial reaction time (SRT) task that provided evidence for human learning without awareness. Adapting the SRT paradigm usually employed to investigate implicit learning, participants responded to two simple white circle fills on either side of a screen. Instead of these following a sequence that participants were unaware of (e.g. Willingham, Nissen & Bullemer, 1989) this task involved a separate stimulus, which was sometimes predictive of one of the circle fills. A square in the center of the screen would fill with one of eight colors before each circle fill: one of these colors predicted a right circle fill and the other a left on 80% of trials on which those colors occurred. When pressing the key that followed the consistent response trained with these two colors, participants were both faster and more accurate than when responding to either the inconsistent response or control colors. Participants demonstrated a lack of contingency awareness, performing at chance in identifying the predictive colors and on a suitably sensitive prediction task. On reanalyzing this result, this paper shows that it was confounded with a sequential artifact produced by the experimental design itself. Pilot studies demonstrated weak learning of color contingencies when the artifact was removed, thus we sought to improve learning by both increasing the amount of training and placing the predictive color cue on the circle fills. Without the sequential artifact, we can produce the same result, although we concede the effect is less robust than we first indicated. Thus, we are able to reiterate our original conclusion: that this task can demonstrate learning of color contingencies in the absence of awareness and can be used to investigate implicit learning in humans.

Keywords: Associative learning; implicit learning; SRT task

Introduction

At the 34th Annual Conference of the Cognitive Science Society Yeates, Jones, Wills, Aitken, McLaren and McLaren (2012) presented a novel serial reaction time (SRT) task, arguing that it produced convincing evidence for implicit learning in humans. The current paper tempers these claims, by first pointing to a subtle artifact in the experimental design, and then running experiments in which this artifact has been removed.

The criticisms leveled at research exploring implicit learning are extensive and well documented (e.g. Lovibond and Shanks, 2002; Mitchell, De Houwer and Lovibond, 2009; Shanks and Lovibond, 2002; Shanks & St. John, 1994). One enduring research paradigm, however, that remains popular is the SRT task. These studies typically require participants to perform a task in which they respond quickly and accurately to stimuli presented to them in a fast-paced series. In the version developed to investigate implicit learning by Willingham, Nissen and Bullemer (1989), unknown to participants these stimuli are presented in a particular sequence. Faster performance on these sequences, compared to participants who had been trained on random control sequences, provided Willingham et al. (1989) with evidence of learning in the absence of the ability to verbally report or explicitly predict those sequences.

Yeates et al. (2012) aimed to devise a paradigm with which one could both demonstrate implicit learning and investigate implicit processes. Reasoning from a dual-process account of human learning, with both Cognitive (conscious, controlled, rule-based and symbolic) and Associative (automatic, statistical) systems (McLaren, Green and Mackintosh, 1994) assumed to be available, led Yeates et al. (2012) to develop an experimental design that attempted to circumnavigate rule-based, conscious processing of the stimuli. The intention of the study was to provide an experimental setting in which associative processing would be encouraged to underpin learning of relationships present in the SRT task.

To this end, a two-choice SRT task based on Jones and McLaren's (2009) and Aitken's (1996) previous work was devised. Participants were required to respond with two different, spatially compatible key presses to a white circle fill: either on the left or right hand side of the screen. On each trial, prior to the circle fill, a square (outlined in white in the center of the screen) would fill with one of eight colors; which participants were told functioned as a simple, central fixation to optimize their performance and avoid bias to either of the circle locations. They were therefore instructed to attend to the square but not told of its true value, which was (on certain trials) as a predictor of which circle would fill. Hence, this SRT task did not train participants to predict their next response from the sequence of previous responses; it used a separate stimulus to predict at which location the response stimuli would next occur.

A within-subject control was employed, so that only two of the eight possible colors correlated with one of the response stimuli locations. The other six colors occurred with equal likelihood before a right or left circle fill and therefore bore no predictive relation to the response participants were making. The two predictive colors were themselves only partially (80%, following Posner & Synder, 1975) predictive of a right or left circle fill. Hence one color would predict a right circle fill 80% of the time and a left circle fill 20% of the time. The other predictive color would precede a left circle fill 80% and a right circle fill 20% of the time. The prediction rate over the experiment works out at 57.5%, thus conscious detection of the presence of contingencies within the experiment would be very difficult. In conjunction with the rapid pace of the task, which involved short inter-trial intervals (ITIs: 250 msecs between response and square color fill, 250-500 msecs between square color fill and circle fill) and responses from participants (*M*=298.4 msecs, *SD*=27.7), it is a design that does not encourage nor benefit participants to try and "work it out".

Two of the non-predictive colors were presented alongside the predictive colors in experimental blocks, which made up half of the 20 total blocks in the experiment and were alternated with control blocks (containing the remaining four control colors), the order of which was counterbalanced across participants. To avoid issues due to the sequence of lefts and rights, we designed the experiment so that each control block comprised the same sequence of circle fills as the experimental block it preceded/followed (dependent on counterbalancing). Thus, when comparing the difference between experimental predictive color performance with control performance, we could be confident this was not the product of the sequence of responses performed.

The final design feature of the paradigm employed to encourage participants away from attempting to consciously discover underlying relationships between the stimuli was to prohibit repetitions of the same color on consecutive trials. If participants were exposed to random sequences, we hypothesized that consecutive trials that involved repetitions of the same, predictive color would increase the salience of that color being particularly related to one circle fill, and thus one response. Thus, the experience of randomly being presented with a string such as: red-right-red-right-red-right…etc. was prohibited.

This, however, introduced the artifact this paper is concerned with, as the consequence of introducing such a restriction on the trial sequences increased the number of alternations between right and left responses and decreased the number of repeating response trials in our experiment. For example, in an experimental block if you have just received the color that predicts a right response, you have a four in five chance of a right circle fill and thus a right response. Following this trial, on the next trial you can only be presented with: one of the two non-predictive colors (which are equally likely to be a right or a left); or the color that predicts left (80% of the time). Therefore, you have a (roughly) two in five chance of another right trial and a three in five chance of a left trial. The confound occurs in that such alternations are more likely to occur on predictive trials that follow the contingency within the experiment, and least likely to occur on the 20% of predictive color trials that don't follow the trained contingency, and are equally likely on control trials. This, rather worryingly, neatly explains our original findings, if we assume that people either naturally prefer to alternate responses, or learn to do so. The result would be better performance on consistent predictive color trials, worse performance on the inconsistent predictive color trials, and intermediate performance on control color trials.

We sought to investigate this possible confound, with both a re-analysis of the original data and further experiments to ascertain the extent to which our previous claims – that we had demonstrated implicit learning using a novel, neat and robust paradigm – would survive when removing this potential artifact. The exact nature of the sequential artifact itself is interesting as, if indeed the observed results of the original experiment were concerned not with the relationship between color and circle but the statistical regularity of alternations versus repeats, was this learnt or is it simply a behavioral preference?

Original Experiment

The full details of the experiment can be found in Yeates et al. (2012). A brief description of the method follows here, with the further analyses run on the original data, which corrects the original analysis by including a comparison between control and experimental blocks to investigate sequential effects.

Method

Participants. The study involved 32 participants from the University of Exeter who each performed a two-choice serial reaction time over one session lasting roughly an hour.

Materials. The experiment involved the on-screen presentation of two white circle outlines and a white square outline, all 1.9cm in width. The square was presented in the center of the screen, with the circles 2.2cm either side to the right and left. The stimuli were one of eight possible colors: red, green, blue, yellow, pink, orange, brown and teal; that appeared within the square outline. The circle outlines would only fill white.

Design. Half of the colors were presented in experimental blocks and the other half in control blocks. There were 10 of each type of block, which alternated throughout the experiment and comprised of 120 trials each. In each block, each of the four colors were equally likely to occur. In control blocks, half of the time a color would precede a right circle fill and half the time a left circle fill. In experimental blocks two of the colors acted as controls, with the same number of right and left circle fills after these two colors. One of the two predictive colors in an experimental block preceded a right circle fill on 24 out of 30 trials, with the other color preceding a left circle fill on 80% of trials. Therefore we classified trials as: Predictive-Consistent (the 24 of 30 trials that followed the predictive relationship); Predictive-Inconsistent (the 6 of 30 trials where the circle fill following a color was not the target trained circle fill);

Experimental Non-Predictive (control color trials in experimental blocks); and Control Non-Predictive (control color trials in control blocks). The same color could not occur on consecutive trials. All blocks involved an equal number of right and left circle fills, and control block right and left circle fill sequences followed the same sequence of right and left circle fills as the experimental block adjacent to it (either preceding or following depending on the counterbalancing).

Procedure. On each trial the square would fill with one of eight possible colors and, after a variable interval of between 250 and 500 msecs one of the two circles would fill in white. This was the cue for participants to respond with spatially compatible keys of either “x” or “>” on a standard QWERTY keyboard for the left and right circle, respectively. A 250 msec ITI followed, during which the circle and square outlines were again presented on screen. Errors were signaled with a beep and each block was followed by a 30 sec break.

Participants were instructed to fixate on the colored square to avoid a bias toward either of the circle flashes, and were told that the experiment was concerned with responding quickly to simple stimuli. No mention was made of the predictive nature of the colors, or of any relationships in the experiment to learn about. A verbal interview and prediction task followed the experiment. The structured interview aimed to assess knowledge of the experimental contingencies and asked participants to describe anything that they had noticed and to identify two colors that may have been predictive. The prediction task involved the same stimuli as in the previous experimental and control blocks, with two blocks of 16 trials each – one with experimental and one with control colors. These colors were randomly presented an equal amount of times to participants within the square in the center of the screen. Instead of this stimulus preceding a circle fill that prompted a response, the display remained the same until participants made a prediction about where they thought the circle would have filled in the experiment using the same response keys (“x” or “>”). Participants were informed that pressing either of the response keys would not be considered an error and no feedback was given.

Results

In the original paper, Yeates et al. (2012) analyzed both reaction times (RTs) and error rates across the four Trial Types mentioned previously. An analysis of variance (ANOVA) was conducted comparing Trial Types across Blocks. We found a significant effect of Trial Type in both RTs and errors, both following the same ordinal pattern – with slower and less accurate responding to Predictive-Inconsistent, followed by Experimental Non-Predictive and Control Non-Predictive colors, with Predictive-Consistent colors resulting in faster and more accurate responding.

To ascertain whether these results were due to learning of the contingencies present between predictive colors and responding across the experiment, here we report the results of a corrected ANOVA with Block Type as a two level within-subject variable enabling us to compare experimental and control blocks. We categorized Trial Types in experimental blocks as before (Predictive-Consistent, Predictive-Inconsistent and Experimental Non-Predictive). However, in the corresponding control block that is paired with the experimental block (dependent on participant counterbalancing, either the block preceding or following the experimental block) we did not collapse all trials into Control Non-Predictive. Instead, each of the 120 trials in each control block were labeled with the same Trial Type as the corresponding trial from the paired experimental block. As a brief illustration: if the first trial of the first experimental block was a Predictive-Consistent trial, we would give the first trial of the first control block a Predictive-Consistent dummy label. Thus, instead of collapsing all control block trials to compare for general sequential effects, we can assign them these dummy labels. This will enable us to examine whether the sequential artifact of more alternations than repeats was what produced the pattern of results previously reported. If the control block pattern of responding across the three dummy Trial Types follows the experimental pattern, then we have evidence that sequential effects may have produced any differences in responding rather than learning about color contingencies.

ANOVAs comparing both RT and errors across Block, Block Type and the three level Trial Type revealed a significant effect of Trial Type in both RTs, $F(2,62) = 23.6$, $p < .001$, and errors, $F(2,62) = 5.67$, $p = .006$. There was no significant effect of Block Type in either RTs, $F(1,31) = 1.55$, $p = .2$, nor errors, $F(1,31) = .908$, $p = .3$. However, it is the interaction between Trial Type and Block Type that we are interested in, which was not significant in either RTs, $F(2,62) = 1.11$, $p = .3$, nor errors, $F(2,62) = .166$, $p = .8$. This is due to both experimental and control Block Types following the same pattern, as is seen clearly in Figures 1 and 2. Thus, we found no difference in the observed pattern of responding to Trial Types between Block Types.

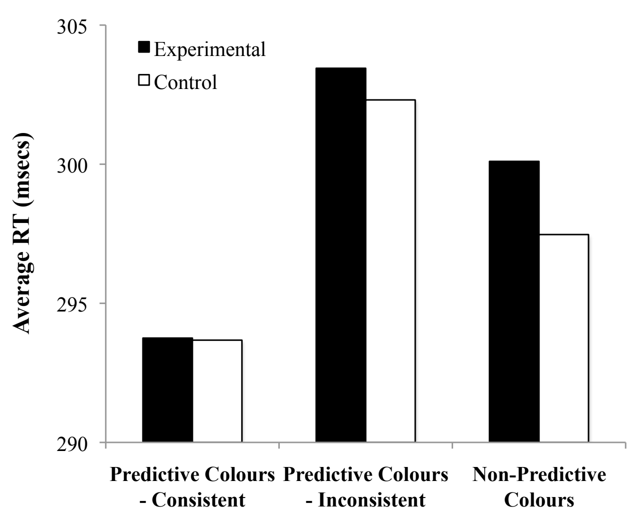

Figure 1. Mean RT for each Trial Type for experimental (solid bars) and control (open bars) Block Types.

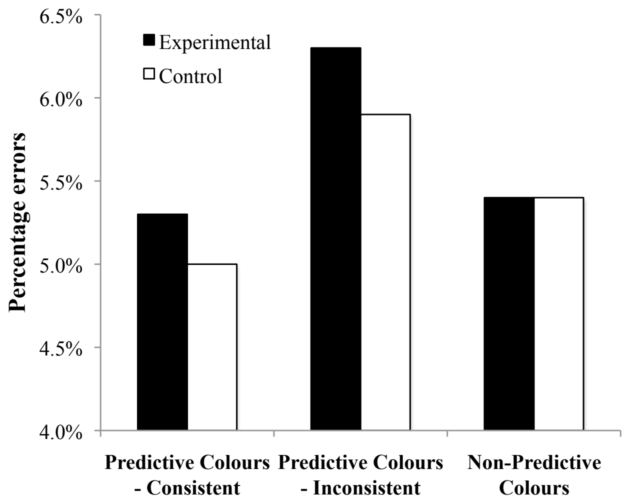

Figure 2. Mean % error for each Trial Type for experimental (solid bars) and control (open bars) Block Types.

Discussion

The absence of a difference between the Block Types, and the lack of a significant Block Type by Trial Type interaction demonstrates quite clearly that the sequential artifact could have produced most of, if not the entire effect of Trial Type. Given this, it becomes vital to demonstrate that color learning can be obtained without the presence of this sequential artifact if the paradigm is to be of any use. The next experiment does just this.

Experiment 1

In pilot work for this experiment, 16 participants formed two groups: eight participants who received the same, constrained sequences as in the original experiment (i.e. a color would never repeat) and eight who were trained on random sequences with no constraint (i.e. color repeats were permitted). Training lasted sixteen blocks (half experimental and half control), as the final four blocks were altered to act as test. In these the same colors were used as in the training, except contingencies were all set to the same, equal probability (50%) of preceding either circle fill. This introduced a section of the experiment free from trained contingencies, meaning results could be compared across colors when matched. The results of this pilot study encouraged us to develop a design that encouraged more learning, as without the sequential artifact the Trial Type effect began to emerge at test in RTs and across training in errors for the group without the sequential artifact, but very weakly.

In an attempt to develop the original procedure to encourage learning whilst maintaining the original design elements, we first decided to increase the length of training. Instead of extending the experiment, which lasts around one hour, we chose to remove the control blocks and replace them with experimental blocks. Without the constraint on color repetitions and with the introduction of a set of test blocks, possible sequential confounds should be avoided. Thus, control blocks for comparative purposes become surplus to the task's requirements, hence 15 blocks of experimental, training blocks preceded five blocks of test. This gave us one and one half times the amount of training in the original experiment. The training followed the form of the earlier described experimental blocks, so the experiment now contained only four possible colors in total, two Predictive and two Non-Predictive.

To further increase the possibility of learning, we ensured that participants were attending to the cue (the color of the square fill) when both processing and performing their response. When the circle fill occurs during the experiment, the colored square cue is still on screen and remains there until a response is made. However, attention will have shifted from the center of the screen and the color filled square onto the circle that has filled. Thus, if participants were attending to the circle fill when making their response the contingency between color and response would be strengthened if the color was represented in the location of the response cue itself. Consequently the circle in this version of the experiment did not fill white, but the color of the square color cue preceding it.

Method

Participants. 16 University of Exeter undergraduate students (4 male, 12 female) aged between 18 and 24 (M=19.25) participated in the experiment for course credit.

Materials. As detailed in the original experiment, but with two differences. Firstly, the color of the circle fills was no longer white but the circle would fill with the color of the preceding square fill. Secondly, the blocks in training were exclusively experimental blocks. The experiment therefore consisted of only four colors in total (two Predictive and two Non-Predictive), presented across 15 training blocks and in 5 test blocks. The sequences were constructed randomly with no color repeat constraint.

Design and Procedure. The experiment again comprised of 20 blocks of 120 trials. All blocks were made up of a sequence of rights and lefts constructed as previously described, with the constraint that no color could follow itself on consecutive trials. The first 15 blocks acted as training, involving the same four colors in each Block Type as detailed in the original experiment. The final five blocks were test blocks involving the same four colors in each. For these blocks all colors were equally likely to be followed by a right or left circle fill. The procedure was as detailed in the aforementioned original experiment.

Results

The data for both RTs and error rates were analyzed as in the original experiment, however, the variable of Block Type was no longer needed as all blocks involved the same four colors, two Predictive (split into Consistent and Inconsistent) and two Non-Predictive. Thus Trial Type and Block were the variables of interest in our ANOVAs. The results for RTs can be seen in Figure 3 and errors in Figure 4.

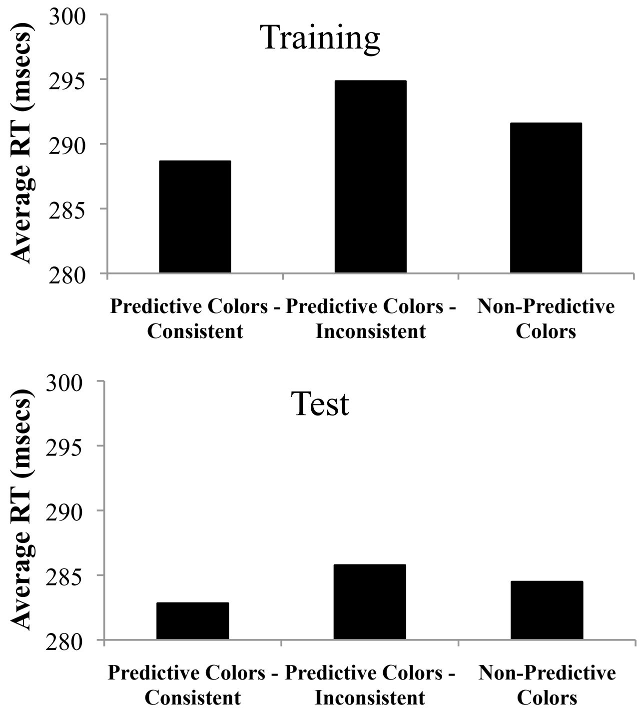

Figure 3. Average RT in msecs for each Trial Type over training (top panel) and test (bottom panel).

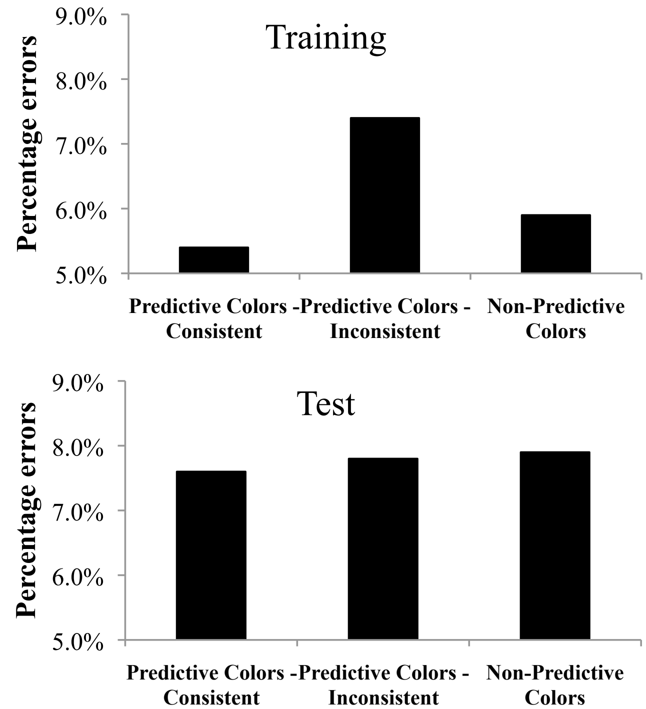

Figure 4. Mean % errors for each Trial Type over training (top panel) and test (bottom panel).

Training data demonstrated a significant effect of Trial Type in RTs, $F(2,30) = 11.23$, $p < .001$, and errors, $F(2,30) = 9.68$, $p = .001$. Predictive-Consistent trials are responded to more quickly and accurately than Non-Predictive trials, and these more quickly and accurately again than Predictive-Inconsistent trials, which can be seen in both the top panels of Figures 3 and 4. This is further expressed by significant planned contrasts between Predictive-Consistent and Predictive-Inconsistent trials in both RTs, $F(1,15) = 18.98$, $p = .001$, and errors, $F(1,15) = 14.44$, $p = .002$ showing that participants responded faster and more accurately to trials that followed those contingencies they were trained on than those trials that were not consistent with these trained contingencies. Both lower RTs and fewer errors were present in Predictive-Consistent trials opposed to Non-Predictive trials as well, shown in the planned contrast between the two in RTs, $F(1,15) = 5.65$, $p = .03$, and with a non-significant trend in same direction for errors, $F(1,15) = 1.24$, $p = .3$.

At test the RT data demonstrate no significant main effect of Trial Type, $F(2,30) = .86$, $p = .4$, yet follow the same ordinal pattern as in training. The error data at test also show no significant main effect of Trial Type, $F(2,30) = .077$ $p = .9$, with Predictive-Consistent trials resulting in faster and more accurate responding than Predictive-Inconsistent trials. However, this is not entirely the pattern observed in training, as the control Non-Predictive stimuli produce more errors at test.

The structured questionnaire revealed that twelve of the sixteen participants indicated surprise that the experiment did indeed involve color contingencies. This is further supported by the colors identified by participants as predictive. Given two choices each to name the two colors, participants selected the correct color on 16 out of the total 32 responses (exactly what one would expect by chance). They were asked also which of these two colors predicted which circle fill, which resulted in 9 accurate responses out of 32 (again this is close to the 8 expected by chance).

The prediction task itself involved two blocks of 16 trials, with all four colors occurring equally in each block – resulting in eight trials where participants could predict Color 1 (which predicted the right circle fill) and eight trials for Color 2 (which predicted the left circle fill), see Figure 5. Of these 16 trials involving the Predictive Colors we can expect 8 correct responses by chance, which is near to the observed mean correct responses of 8.25. This is not significantly different from chance and, when taking the colors separately, is not the result of learning about one color alone with mean correct responses of 3.94 and 4.31 for Color 1 and 2, respectively.

Discussion

The results in training clearly demonstrate a pattern that provides evidence that learning about the contingencies between color and response has occurred. This is further supported the ordinal pattern in RTs and errors at test, which lessens the possibility that the effect is due to a speed-accuracy tradeoff.

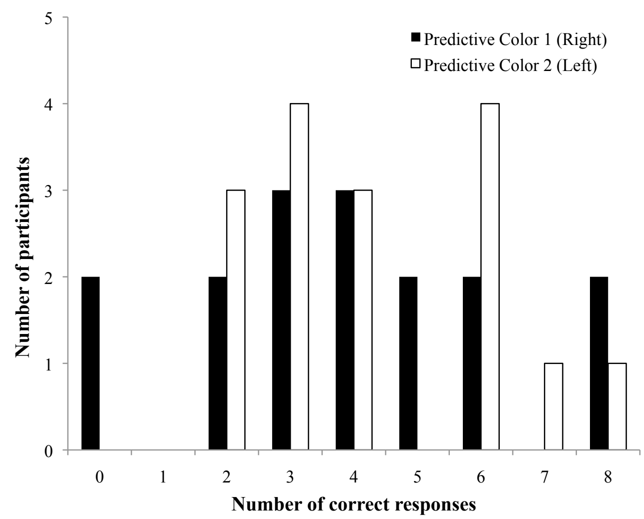

Figure 5. The number of correct responses participants gave for Predictive Color 1 (filled bars) and Predictive Color 2 (open bars).

The structured interview responses and prediction task results provide evidence that this learning occurred outside of awareness, as not only were most participants surprised to learn that contingencies were present, they could not identify these colors, what the colors predicted, or use them to predict the correct, trained response above the level expected by chance.

Thus, we would conclude that across training we clearly demonstrated learning, in the absence of awareness, of color-response contingencies similar to those we believed to have found in our original paper's claim (Yeates et al., 2012). Furthermore, we have demonstrated that this effect somewhat remains when transferred to a test phase. The lack of significance may be attributed to extinction of the trained contingencies. Indeed when considering the first two blocks of test the ordinal pattern of RTs and errors are the same as during training and a post-hoc contrast test demonstrates a significant difference between Predictive-Consistent and Predictive-Inconsistent trials, $F(2,15) = 13.23$, $p < .01$.

General Discussion

We can conclude, as in the original paper, that this paradigm can still be used to demonstrate implicit learning in humans. However, this effect is clearly not as robust or easily obtained as we first imagined. When increasing the number of training trials and placing the predictive cue (color) on the response stimuli to ensure participants attended to them while processing or executing their responses we obtained effects comparable to those we previously reported.

We concede that whilst the prediction task demonstrates little evidence of conscious awareness that the result could be made more convincing if we could produce a non-null result (Z. Dienes, personal communication, 3 August 2012). A comparison between participants trained under intentional instructions or indeed a Bayesian analysis (for which we would require an 'aware' prior from participants with explicit knowledge) of these data could strengthen our claims regarding the implicit nature of this learning.

It is not the intention of this paper to be entirely concerned with methodological issues. Our original paper suggested this paradigm as a method for studying implicit learning in humans and thus a refinement of the paradigm is of importance to the research questions that it enables us to investigate. We proposed that the process by which this occurs is associative in nature and aimed to produce variants of the task to investigate this behaviorally, alongside associative, computational modeling. It remains our intention to do so and we encourage the use of this paradigm in its re-designed form. We also accept that the prediction test in this version of the design is not maximally sensitive, as the test block (during which no contingencies are in play) separates training from this test of awareness. We intend to run other experiments using this paradigm without a test phase to address this issue.

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