Implicit Sequence Learning in Applied Game Design:
The Interplay of Game Mechanics and Pattern Learning

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Abstract

Background: Learning to play a game involves implicit learning, which results in tacit knowledge utilised by players to master the game. The benefits of implicit learning can serve different purposes like stealth assessment or implicit influencing of gameplay behaviour. However, implicit learning can be modulated by a variety of factors associated with the structure of the task. We examined how implicit learning in games can be affected by the game's mechanics by testing whether mechanics that draw attention to a specific feature (e.g. colour) within the game improve learning of patterns associated with that feature, while potentially impairing learning of patterns pertaining to other features.

Method: We developed a web version of the game Whac-A-Mole, where moles appeared in a repeating pattern of four screen positions and also changed into one of four colours following a different pattern. Participants (N = 112) were randomly assigned to two groups: The colour-nonsalient group was instructed to click/tap ('whack') every mole as it appeared, while the colour-salient group was instructed to 'whack' all but the red moles. We expected that the colour pattern will be learned better by the colour-salient group compared to the colour-nonsalient group, but the reverse would be true for the position pattern as the colour mechanic disrupts the consistency in position responses.

Results and Discussion: Reaction times, free pattern generation after the game, and self-reported pattern awareness confirmed that participants in the colour-salient group showed inferior learning of position information and superior learning of colour information. These findings suggest that games researchers should pay special attention to how game mechanics affect what and how much is learned. The implicit learning methods in our experiment demonstrate

promising proof of concept techniques to aid the design of game mechanics that facilitate the desired learning outcomes without producing unintended learning interference.

Keywords

applied game design, implicit learning, sequence learning, game mechanics, pattern learning

Background**Applied Game Design and Implicit Learning**

How do we learn to play a game? It is common for simpler games to be explained by a manual or a list of rules, which provides an explicit description of permitted actions and defined goals. However, in many instances, when players start a game, they learn from their direct experience with it: a new player of Super Mario Bros. (Nintendo Creative Department, 1985) will press the buttons on the game controller and observe the height of their character's jump and the acceleration of the game world's gravity, soon traversing (and learning from) the obstacles in the game's world. Subsequent learning occurs with continuous and repeated playing as the player becomes more proficient at the game and starts performing complex combinations of actions in response to game obstacles without conscious effort – a feat that might have taken them a significant amount of effort when they first started playing. The patterns, complex interactions and statistical dependencies of the game are all seemingly taken into account and exploited by the player to maximise their chances of success. How does the player learn to follow the appropriate patterns and select the

appropriate actions? Knowledge of such skill mastery is often inaccessible to conscious awareness and introspection - a type of learning that is defined as implicit, where the learner is unaware of the content and processes of learning, resulting in tacit knowledge (Reber, 1989). Many fundamental abilities develop by adapting to regularities in the environment without conscious awareness, such as language learning or motor skills (Perruchet & Pacton, 2006). Therefore, a complete understanding of complex gaming behaviour and the acquisition of gaming skills must include a comprehensive treatment of implicit learning processes within games. Moreover, implicit learning can be influenced by hidden game mechanics, as demonstrated in a controlled experiment by Ciavarro, Dobson and Goodman (2008). This not only has the potential to influence gamer behaviour to bring about more desirable actions, but also opens up entirely new horizons for educational games and games for change. By taking advantage of the potential for embedding educational content implicitly within a game, players can benefit from implicit learning without conscious effort.

Explicit knowledge is sometimes theorised to arise out of implicit knowledge (Polanyi, 1966; Frensch & Rnger, 2003), though this is not uncontroversial (Berry & Broadbent, 1984). From the point of view of game-based learning, a re-occurring problem that has plagued the literature is the problem of transfer (Girard, Ecalle & Magnan, 2013; Kuipers et al., 2017). It is argued that learning does happen in educational games, but players have difficulty explicating that knowledge and performing on tests outside of the game (ter Vrugte & de Jong, 2017; Leemkuil & De Jong, 2012). If implicit

learning is to support explicit knowledge, then understanding implicit learning processes within games could be the first step to solving the transfer problem.

Some researchers, such as Rowe, Asbell-Clarke and Baker (2015), have argued that the naturally-occurring implicit learning within educational games can be measured and assessed through software analytics which provide insights into student learning. Thus, a better understanding of implicit learning within games is important to account for the totality of knowledge, explicit and implicit, acquired by players of educational games.

Despite the promising directions outlined above, the actual process of implicit learning has been mostly ignored in the academic literature on games, and it remains unknown how this process is initiated and modulated by properties of the game mechanics. To gain a better understanding of this process, we embedded an established implicit learning paradigm in a simple game to investigate how game mechanics might modulate implicit learning.

Implicit Sequence Learning

Implicit sequence learning and the Serial Reaction Time Task. A common paradigm employed to study implicit learning is the Serial Reaction Time (SRT) task where participants are instructed to respond to stimuli on a computer screen by pressing associated keys on a keyboard. Usually participants respond to four or more positions on the screen by pressing the key associated with the position at which a symbol or object can appear. Participants are told that it is a task in which both speed and accuracy are important. Unbeknownst to the participants, the stimuli's positions follow a pre-specified, structured pattern. A robust finding from these experiments is a

reliable decrease in reaction times as participants progress through the task, which is attributed to implicit learning of regularities in the pattern of positions which allows participants to anticipate upcoming positions (Lewicki, Czyzewska & Hoffman, 1987; Lewicki, Hill & Bizot, 1988; Nissen & Bullemer, 1987). Implicit learning is indicated by speed gains compared to a control group where positions are selected at random (Nissen & Bullemer, 1987). Furthermore, after a reliable reaction time decrease has been demonstrated, switching the pattern to a random sequence leads to a sudden increase in reaction times, suggesting that speed gains were due to implicit pattern learning and not a general task familiarity/training effect (Lewicki, Czyzewska & Hoffman, 1987; Lewicki, Hill & Bizot, 1988). This effect emerges even when the random sequence matches the patterned sequence in certain structural properties, such as the frequency of positions across the sequence, (Reed & Johnson, 1994).

A significant proportion of the literature on implicit learning is trying to distinguish explicit from implicit components of learning and exploring them separately (Berry, 1997). Even with respect to the SRT task, it has been debated how much of the learning is implicit or explicit (Perruchet & Amorim, 1992; Curran & Keele, 1993; Shanks & Johnstone, 1999). One commonly used method to capture emerging explicit knowledge is the so-called generation task where participants are asked to replicate the sequence that they had seen before in the SRT task. It is assumed that this task demonstrates explicit knowledge of the sequence pattern that is available to conscious recall (Destrebecqz & Cleeremans, 2001) while changes in reaction times across structured and unstructured/random blocks are considered to be more indicative of implicit learning (particularly if the participant does not seem to be able to

recall observing patterns in the stimuli in the first place). Because the aim of designing educational games is to affect the totality of a learner's knowledge, here we are interested in capturing both implicit and potentially emerging explicit knowledge of the underlying patterns by measuring both reaction times and generation performance.

The effects of task demands. What are the factors that influence implicit sequence learning? Can the process be modulated by the presence or absence of additional task components? An often-employed method, first introduced by Nissen and Bullemer (1987), is to use a distractor task, such as playing a high tone or low tone between trials of the SRT task and instructing participants to count the number of high tones in a block of trials. This was done in order to see if sequence learning was impaired by the added attentional cost of the tone-counting task, i.e. whether dual-tasking impairs implicit sequence learning. Nissen and Bullemer's (1987) experiments showed that participants' performance in a dual-task condition with regular sequences did not differ significantly from participants in a dual-task condition with random sequences. Furthermore, practice in a dual-task with regular sequences did not help participants to learn the sequence faster compared to participants with no prior experience with the sequence. It was concluded that acquisition of new associations requires attention as dual-tasking appeared to diminish implicit learning by imposing additional cognitive load.

Subsequent experiments demonstrated that the effect of dual-task conditions on implicit learning performance can be modulated by a variety of core-task properties such as the complexity of the sequences (Cohen, Ivry & Keele, 1990), the structure of the transfer/random block (Reed & Johnson,

1994), as well as response-secondary stimulus onset asynchrony (Hsiao & Reber, 2001).

However, the nature of the distractor task plays an important role. Jimenez and Mendez (1999) demonstrated that learning was not negatively affected by a secondary counting task if that task was performed on the same stimulus as the SRT task. In another experiment, a memory load task asking participants to remember a string of letters displayed before the SRT task did not interfere with implicit learning as much as simply including random longer pauses between trials (Stadler, 1995). Furthermore, Schumacher and Schwarb's (2009) series of experiments revealed that, under dual-task conditions, sequence learning is impaired only when parallel response selection for both tasks interferes with SRT task performance. Overall, existing evidence suggests that not all distractor tasks are created equal and modifying their relationship to the SRT task or the specific cognitive processes that underpins it can have profound consequences on how much is learned.

Finally, contingencies can be learned in two different modalities simultaneously (Mayr 1996; Remillard 2017), but the way they interact with the core task needs to be taken into careful consideration. Willingham, Nissen and Bullemer (1989) conducted an SRT experiment where participants had to respond to the colour of the stimulus, which simultaneously moved between four positions on the screen between trials as well. There were three conditions: (a) positions, but not colour, followed a pattern; (b) colour, but not positions followed a pattern; and (c) a control group where neither positions nor colour followed a pattern. No difference in reaction times was found between the control group and the group learning position patterns, but the group learning

colour patterns exhibited shorter reaction times than the other two groups. This suggests that when colour was the relevant (salient) feature of the task, patterns associated with it were learned implicitly while patterns associated with a feature not directly relevant to the task (positions) were not learned. Mayr (1996) was the first to study simultaneous implicit learning of two uncorrelated sequences in different modalities. In that study, participants had to respond to shapes which changed structured positions on the screen. In all three conditions (random shape sequences with structured position sequences; structured shape sequences with random position sequences; and shapes and positions both following different structured sequences) learning of structured sequences regardless of modality was observed. This finding suggested that spatial and non-spatial sequences might be learned independently, which was again confirmed by Remillard (2017).

Game Mechanics and Implicit Learning

In sum, the experimental results on dual-modality implicit learning suggest that the relation of a task to the existing underlying structured patterns can have a modulating effect on implicit sequence learning: sequence patterns that are closely related to the main task and stimulus response are learned better as a result. In addition, multiple patterns or sequences can be learned simultaneously if they operate in different modalities. However, the properties of any distractor tasks can greatly modulate how much is learned. This leads to a question of practical importance to educational game designers seeking to harness or enhance implicit learning. As most games are governed by multiple rule-based systems, which may interact in different ways across perceptual modalities and various structured patterns of the game's environment, which

game mechanics will enhance or impede implicit learning of particular patterns? The literature suggests that multiple patterns can be learned simultaneously and independently, but it is also clear that some tasks distract from learning. This makes it unclear how learning will proceed if a game mechanic draws attention to a new pattern in a different feature, but in the process introduces an additional game task that potentially interferes with the cognitive processes facilitating learning of other patterns pertaining to other features. In games, mechanics often interact or interdepend to create interest, hence it is imperative that any resulting trade-offs in learning are accounted for (consider for example that including a shield mechanic in a game means the player no longer has to manoeuvre around all obstacles, but merely shield from some of them – possibly impacting obstacle type and trajectory learning). Game designers need to carefully consider the implications of introducing new game mechanics to the learning processes underpinning the gameplay and be aware of any potential trade-offs and modulating effects.

Method

The present study sought to initiate a more nuanced and detailed investigation of implicit learning in games by examining the consequences game mechanics can have on implicit learning of contingencies in the game by manipulating the saliency of specific features of the game environment. To this end, we employed the SRT task which can be easily implemented in a game and provides a feasible way of studying implicit learning and its relation to game mechanics. We will test if the inclusion of a game mechanic emphasising an

additional pattern within the game improves learning of that pattern. Furthermore, unlike previous studies on the SRT task, we will also test if the included game mechanic might simultaneously have a detrimental effect on learning other patterns by interfering with the consistent organisation of the relevant sequence (i.e. modifying the gameplay facilitating learning of those patterns).

Our experiment resembled the popular arcade game Whac-A-Mole (Fechter, 1976), where cartoon moles appear in specified positions and players have to “whack” the moles as they come out. We designed a web-based online version of the game, where players clicked or tapped on the digital moles to gain points. Only one mole appeared at a time and both the sequences of positions and colours of the moles followed separate structured regular patterns. Learning of these patterns is indicated by reaction times and a free generation task at the end of the game. Using a between-subjects design, we manipulated the gameplay salience and importance of the colour dimension by assigning participants to two conditions: in the colour-nonsalient condition, players were instructed to click/tap all moles regardless of colour; in the colour-salient condition, players were instructed to click/tap all moles, except moles in red colour. However, while the colour game mechanic increases the salience of colour, it also interferes with the consistent organisation of the position sequences by introducing pauses on some trials (when the player needs to resist whacking the mole), similar to Stadler’s study (1995).

This experiment tests the following two hypotheses:

1. It is expected that if a game mechanic encourages the player to pay attention to a particular feature within the game then learning of contingencies

related to that feature will be easier. Thus, implicit learning of the sequence contingencies pertaining to colour will be enhanced in the colour-salient condition.

2. At the same time, the presence of game mechanics that direct attention to one feature will make learning of contingencies pertaining to other features more difficult when the game mechanic impedes the cognitive processes facilitating learning of those contingencies. Thus, in the colour-salient condition, learning of the sequence contingencies for positions will be compromised as the colour game mechanic interferes with the consistent organisation of position responses.

Study design and analyses were pre-registered on the Open Science Framework on 3 August 2018. The OSF pre-registration form and project can be found on the following link: <https://osf.io/pzhft/>

Participants:

The experiment took the form of an online web-based game, which was disseminated through a weblink across social media channels, email lists, as well as the university's internal newsfeed. Using this method 118 participants completed the study in full. Four participants were excluded for poor response accuracy (<85%; the choice of this exclusion criterion is carefully outlined in the pre-registration document). Our recruitment stopping rule was to stop when usable data for 112 participants were obtained (as outlined in the pre-registration, as we wanted to avoid under/overrecruiting), but due to challenges with achieving balanced list sizes for each counterbalancing variable we overrecruited two participants in two lists (counterbalancing variables will be

explained in detail below) who were subsequently excluded. This left 56 participants in the colour-nonsalient group and 56 participants in the colour-salient group. Before starting the study, participants confirmed that they were above the age of 18 and gave informed consent. The study was granted ethical approval by the university's Ethics Committee.

Instruments and Materials:

The experiment was built using HTML5 and JavaScript. Participants could run the experiment on any device (desktop or mobile) using a modern web browser (the experiment was not supported by Microsoft Internet Explorer). The game used vector graphics that dynamically adapted to the browser's window size. Participants could interact with the game either through mouse clicks (on desktops and laptops) or through finger taps (on mobiles and tablets). Interactions in the game were accompanied by appropriate sound effects and animations. Reaction times between trials (or whacks) were recorded by the web browser.

On the game screen (see Figure 1) mole positions were in the top-centre, right-middle, bottom-centre and left-middle of the screen. Moles appeared only one at a time from one of the positions in one of four colours (red, blue, purple and yellow). Moles' upward animation lasted 100 ms and if the player did not react in the next 1500 ms the mole would move back down by itself. As soon as one mole disappeared, the next one began to appear after a 200 ms interval.

Figure 1. Screenshot of the game screen running on a PC.

Procedure:

Participants were randomly assigned to one of the two conditions (colour-nonsalient and colour-salient). Before beginning the game, participants in the colour-nonsalient condition were instructed to whack any moles that appear, while participants in the colour-salient condition were instructed to whack all moles, except moles in red colour. Whacking a mole resulted in a +1 point increase of the player's score, but whacking a red mole in the colour-

salient condition would decrease the player's score by 5 points (in the colour-nonsalient condition, red moles would simply award +1 point, like any other mole).

The positions and colours of the moles followed two independent repeating and predictable sequences, namely: [3, 1, 4, 2, 1, 3, 2, 4] and [1, 4, 3, 2, 1, 3, 4, 2, 3] (where numbers represent either a position or a colour value: 1 is up or red; 2 is right or purple; 3 is down or blue; 4 is left or yellow). The patterns were of length 8 and 9 items respectively and were repeated simultaneously for 72 consecutive mole appearances (trials) in each block, where one pattern pertained to the moles' colours and the other one to their positions. Patterns were of different lengths so that they would not synchronise and introduce covariation that may affect learning of the other feature. The two patterns were counterbalanced to represent either position or colour.

The sequences were non-random as they were formed by second-order conditionals (SOC), as described by Reed and Johnson (1994). This means each number in the sequence could be predicted with 100% accuracy by the previous two numbers, as any combination of two numbers was always followed by only one permissible number. SOC's provided a structure to the pattern that can potentially be learned by the participant to enhance their game performance.

There were 10 blocks of 72 trials in the game in total (not counting the free generation task), resulting in a total of 720 game trials. Blocks were labelled as 'levels' to participants to maintain the game aesthetic. The first 4 blocks, as well as blocks number 6, 8 and 10 of the experiment followed the patterns of positions and colours described above. However, block number 9

presented positions and colours of the moles in a randomised sequence so there was no structured pattern, while blocks number 5 and 7 presented randomised sequences for only one feature (either colour or positions). Order of which features' sequence was randomised in blocks number 5 and 7 was counterbalanced across participants. If there was implicit learning of the patterns facilitating participants' performance, we would expect to see increases in reaction times on these randomised blocks.

After playing the game for 10 blocks, participants were asked whether they had noticed any patterns within the game by selecting one of two options for two questions (see Table 1). These questions were used as a measure of participants' explicit awareness of the patterns.

Table 1. Awareness questions after the game.

1. Try to think about the sequence of positions the moles took in the game you just played. Do you think:

- ☐ There was a pattern to the moles' positions sequence.
- ☐ There was NOT a pattern to the moles' positions sequence.

2. Try to think about the sequence of colours the moles took in the game you just played. Do you think:

- ☐ There was a pattern to the moles' colours sequence.
 - ☐ There was NOT a pattern to the moles' colours sequence.
-

Finally, participants performed a free generation task. In this task, after being told that there were patterns to both colours and positions, they were

asked to recreate the patterns they would have seen while playing the game. This was done by clicking/tapping on a coloured mole next to one of the available positions where moles appear (see Figure 2). This advanced the generated sequence and participants were asked to do this 72 times to generate a full block. The order, positions and colours they clicked/tapped on for each generated response was recorded for later analysis of how well they had learned the contingencies contained in the sequences. Table 2 summarises the experimental procedure.

Figure 2. Screenshot of the free generation task. Participants have to select a little mole around a hole to progress the pattern.

Table 2. Experimental Procedure.

Experiment Screen	Types of Patterns
Game Block 1	Both Structured
Game Block 2	Both Structured
Game Block 3	Both Structured
Game Block 4	Both Structured
Game Block 5	Random Colour/Position + Structured Position/Colour
Game Block 6	Both Structured
Game Block 7	Random Position/Colour + Structured Colour/Position
Game Block 8	Both Structured
Game Block 9	Both Random
Game Block 10	Both Structured
Awareness Questions	
Free Generation Task	

Results

Our final data analysis includes some deviations from our original pre-registration because our original proposal required a few tweaks and clarifications that became apparent upon implementation of the study. Detailed justification for each deviation is provided on the OSF study page:

<https://osf.io/yuxgb/>

Reaction times:

For each mole the participant's click/tap reaction time in milliseconds was collected. An accuracy measure for each trial (mole) was also calculated, evaluating whether the mole was clicked in time before it disappeared or if a red mole was correctly avoided in the colour-salient condition (1), and whether a mole was not clicked in time or a red mole was incorrectly clicked in the colour-salient condition (0). The mean accuracy scores of four participants were less than 85%, which, as mentioned in the Method section, were excluded from the analysis as their data revealed insufficient engagement with the game. The rest of the participants scored above 90%, with a mean of 98.49%.

Trials with red moles were excluded from both conditions, as they would skew the reaction time data. The means of participants' median reaction times per block are shown in Figures 3, and 4. In the colour-nonsalient condition participants got progressively better at the task with performance disrupted at the position-random block and the position+colour-random block. We conducted one-sided one-sample *t*-tests on the differences between the median reaction times of the random block to its preceding block to test whether mean reaction time differences were significantly above zero, which indicated that sequence learning had taken place. For the position-random block and its preceding block the mean difference of 98.30 ms indicated a significant reaction time increase, $t(55) = 7.56$, $p < .001$ (one-sided). A positive value of 122.04 ms was also found for the mean difference between median reaction times of the position+colour-random block and its preceding block in the nonsalient condition, $t(55) = 8.65$; $p < .001$ (one-sided). In the colour-salient condition, the differences to the preceding blocks were considerably smaller with a mean difference of 12.40

ms, $t(55) = 2.08$, $p = .02$ (one-sided), for the position-random block and of 19.35 ms, $t(55) = 3.46$, $p < .001$ (one-sided), for the position+colour-random block.

In contrast, the mean difference of median reaction times of the colour-random block to its preceding block was non-significant, with means of -36.67 ms, $t(55) = -5.85$, $p = >.999$ (one-sided), and -2.03 ms, $t(55) = -0.41$, $p = .66$ (one-sided), for the colour-nonsalient and colour-salient conditions, respectively. In order to be able to interpret these null results as evidence for no change in reaction times, we conducted Bayesian one-sample t -tests in addition to all of the above t -tests (see Table 3). The effect size (δ) was assigned a default half-Cauchy prior centred on zero with a range of 0 to positive infinity, and with a scale parameter of $\sqrt{2}/2$. The choice of prior reflects the assumption that reaction times differences between random and preceding blocks are constrained to be at or above 0, with smaller effects being more likely than larger effects, and is therefore more appropriate than a uniform prior (which assumes every effect size to be equally likely) in situations where a more informed prior cannot be defined. The resulting Bayes factors quantify the relative evidence for both the alternative (H_1 : $0 < \delta < \text{Inf}$) and null (H_0 : $\delta = 0$) hypotheses. Support for the null model relative to the alternative model in the colour-random blocks was very strong ($\text{BF}_{01} = 67.42$) in the nonsalient condition and moderate ($\text{BF}_{01} = 9.18$) for the salient condition (Table 3). Bayes factors for the position-random block and the position+colour-random block in the nonsalient condition showed very strong support for the alternative hypothesis ($\text{BF}_{10} > 100$ and $\text{BF}_{10} > 100$ respectively). In contrast, in the salient condition evidence for the alternative hypothesis was very strong for the position+colour-

random block ($BF_{10} = 52.38$), but weak for the position-random block ($BF_{10} = 2.10$).

Table 3. Test results for one-sided, one-sample t-tests on reaction time differences between random blocks and preceding blocks using Null Hypothesis Significance testing (NHST) and Bayesian analysis.

Condition	Random Block	NHST t-test (true mean > 0)	BF_{10} ($0 < d < \text{Inf}$)	Cohen's d
Colour-nonsalient	Position	$p < .001$	$BF_{10} > 100$	1.05
	Colour	$p > .999$	$BF_{10} = 0.015$	-0.81
	Position+Colour	$p < .001$	$BF_{10} > 100$	1.199
Colour-salient	Position	$p = .02$	$BF_{10} = 2.10$	0.289
	Colour	$p = .66$	$BF_{10} = 0.109$	-0.057
	Position+Colour	$p < .001$	$BF_{10} = 52.38$	0.48

Figure 3. Mean of median reaction times in ms per game block in the colour-salient and colour-nonsalient condition when the colour random block was presented first (n=28). Error-bars show within-subject 95% confidence intervals (Cousineau, 2005).

Figure 4. Mean of median reaction times in ms per game block in the colour-salient and colour-nonsalient condition when the position random block was presented first ($n=28$). Error-bars show within-subject 95% confidence intervals (Cousineau, 2005).

We also compared the differences between random and preceding blocks between the salient and nonsalient condition using between-participants t -tests, to see whether learning gains differed across conditions. All of the comparisons were significant (see Table 4) indicating greater learning of position information in the non-salient group. Additionally, a Bayesian between-participants t -test was also fitted with the effect size (δ) assigned a default half-Cauchy prior centred on zero, and with a scale parameter of $\sqrt{2}/2$. Unlike the one-sample t -tests, this prior was not constrained to be at or above 0, but instead allowed for negative differences between the nonsalient and salient

groups. All Bayes factors show very strong evidence for the hypothesis of differences between groups not being equal to zero.

Table 4. Mean differences in reaction times (in ms) between random and preceding blocks in the two groups and results of between-participant tests.

Random Block	Nonsalient Group	Salient Group	t(110)	p	BF ₁₀	Cohen's <i>d</i>
Position	98.3	12.4	6.01	< .001	> 100	-1.135
Colour	-36.7	-2.0	-4.35	< .001	> 100	0.822
Position+Colour	122.0	19.4	6.76	< .001	> 100	-1.278

The free generation task

For the analysis of the free generation task, the entire block of trials for each participant was taken and subdivided into triplets (for example a sequence coded as [1-3-4-2-1] (where numbers represent either positions or colour values depending on the sequence) would be divided into: [1-3-4], [3-4-2], [4-2-1]). We counted how many of the user generated triplets were permissible and then calculated a proportion of correct responses by dividing the number of permissible triplets by the total number of triplets. These proportions represent the learning scores of the participant in regards to how well they have learned or reproduced the sequences. Mean learning scores were then calculated based on these proportions.

To determine chance performance, we used a computer simulation to produce random participant responses for the generation task, assuming that the same state within a sequence would not be produced twice in a row. Using

this method, chance performance for this task was around 21% - the mean chance performance between the two sequences of lengths 8 and 9 elements.

For position sequences, the mean generation score of 43% in the colour-nonsalient condition was significantly above chance, $t(55) = 7.12$, $p < .001$ (one-sided), as was the mean generation score of 28% in the colour-salient condition, $t(55) = 1.8$, $p = .04$ (one-sided). The difference between these two scores was also significant in a between-participants t -test, $t(110) = -3.84$, $p < .001$, $d = -0.73$. For colour sequences, the mean generation score of 18% in the colour-nonsalient condition did not differ significantly from chance, $t(55) = -2.75$, $p = .99$ (one-sided), nor did the mean generation score of 26% in the colour-salient condition, $t(55) = 1.64$, $p = .05$ (one-sided), although the difference between these two scores was significant in a between-participants t -test, $t(110) = 3.12$, $p = .002$, $d = 0.59$. Thus, learning of the position sequences was diminished as a result of including the colour-based game mechanic while learning of the colour sequences improved (see Figure 5).

Figure 5. Mean generation score for position and colour sequences for each colour-saliency condition. Dotted line (0.21) is simulated chance performance. Error bars show 95% confidence intervals.

Conscious pattern awareness

The answers to the pattern awareness questions in Table 1, presented after playing the game, are summarised in two contingency tables - one for each pattern (see Tables 5 and 6). A Fisher's Exact Test on each contingency table showed a significant difference on pattern awareness by colour saliency condition ($p < .001$ for both position awareness and colour awareness tables). The key result from these data is that self-reported awareness of the existence of a pattern in positions is very high in the colour-nonsalient condition, but substantially drops in the colour-salient condition. The reverse is seen for awareness of the colour pattern (see Figure 6).

Table 5. Self-reported awareness of position patterns by condition.

		Condition		total
		colour nonsalient	colour salient	
Position pattern awareness	unaware	10	31	41
	aware	46	25	71
	total	56	56	112

Table 6. Self-reported awareness of colour patterns by condition.

		Condition		total
		colour nonsalient	colour salient	
Colour pattern awareness	unaware	44	26	70
	aware	12	30	42
	total	56	56	112

Figure 6. Percentage of participants aware of patterns per colour-saliency condition.

Discussion

The results from this study have provided support for both of our hypotheses by showing that (i) implicit learning of the sequence contingencies pertaining to colour will be enhanced in the colour-salient condition and that (ii) in the colour-salient condition, learning of the sequence contingencies in position will be compromised, as the consistent organisation of the position sequences had been disrupted. These effects were observed in the implicit reaction time measures, the free generation task measures, and the self-reported awareness questions.

Reaction time measures showed that implicit learning took place during the designated game task, with a steady reaction time decrease over time until interrupted by a sudden change in the positional pattern. However, sudden changes in the colour pattern only did not increase reaction times suggesting that being able to predict the colour in the colour-salient condition did not confer any speed advantage. It is important to note that the reaction time curve is flatter in the colour-salient condition, despite excluding trials with red moles. This implies that while position learning still took place, it was greatly reduced due to the additional task of anticipating red moles.

Even though pattern generation at the end of the game was fairly poor, the scores demonstrated above chance performance for the position pattern. However, as predicted, success with learning of the position patterns in the colour-salient condition was substantially lower than in the colour-nonsalient condition. The opposite effect was seen in the colour sequences, where scores were better in the colour-salient condition. However, the generation scores for colour in both conditions were not significantly higher than our simulated chance

performance. It is difficult to interpret the significant difference in generation scores between conditions when scores did not exceed the simulated chance performance, but we argue that this does demonstrate better learning of colour in the colour-salient condition. Scores around chance in both cases might simply reflect substantial task difficulty. Furthermore, our computer simulation of random performance (which determined the baseline) might have overestimated human random performance more than we anticipated.

A similar result emerged when asking participants about their awareness of the patterns. The percentage of participants aware of the position pattern in the colour-nonsalient condition was very high (82%) but was substantially lower (45%) in the colour-salient condition. The reverse was observed for awareness of the colour pattern (21% when nonsalient, but 54% when salient), but the increase of awareness for colour was not as large as the decrease in awareness of position. This indicates that there is not a simple trade-off between feature saliency and awareness.

Our results showed that position was always learned better than colour. In the colour-nonsalient condition, this may reflect the fact that colour was not part of the response decision – after all, participants had to anticipate positions but not colours. However, in the colour-salient condition, this may reflect that attention was drawn not to all colours, but only to the red colour. This means that the response decision was determined by the binary choice red/non-red, so participants could safely disregard all other colours. In future, a modified version of the task could reveal if this makes a difference; for example, if players had to pick a hammer with the same colour as the mole before whacking. We predict that this would increase salience of all colours which, in turn, would result in

better learning of colour patterns. An alternative interpretation of the generally inferior learning of colour might consider the effect of reward/punishment size. For example, would the colour sequence be learned better if players lost all their points when whacking a red mole, as opposed to losing just 5 points? Would such a high punishment disrupt position learning even more? Again, simple modifications of our experiment using the same methods could reveal more about the interplay of game mechanics and implicit learning.

In line with previous research on sequence learning, we demonstrated that the specifics of the task can have significant implications on what and how much is learned (Willingham, Nissen & Bullemer, 1989; Schumacher & Schwarb, 2009). Multiple patterns can be learned within a game, but learning success is dependent on their salience within the gameplay and on how game mechanics might enhance some, but impede other, learning processes. Games researchers seeking to harness the power of implicit learning in games for stealth assessment (Rowe, Asbell-Clarke & Baker, 2015) or to influence gameplay behaviour (Ciavarro, Dobson & Goodman, 2008) need to be aware of how the relative salience of game patterns and mechanics influences what kind and how much information can be learned.

Conclusion

In summary, we proposed that game mechanics can manipulate the salience of specific features within a game and, as a result, affect player learning and performance. Our experiment has provided evidence for this effect, showing that it can have profound impact on what is learned both implicitly and explicitly as task demands in the game facilitate or impede the cognitive

processes necessary for learning. The results highlight that game mechanics do not simply confer an attentional benefit to learning contingencies pertaining to the particular features they draw attention to, but can also bear a detriment that hinders learning of contingencies pertaining to other features. It is advised that game designers carefully consider the cognitive consequences of including (or excluding) different game mechanics and that these are properly balanced to reflect a game's intended learning outcome.

In future, further research can reveal how different game mechanics interact and result in various trade-offs in learning the patterns associated with the gameplay. The proof of concept methodology employed in our research can help in understanding the cognitive mechanisms involved in learning to play games and provides a tool for investigating learning in games to guide better applied game design.

Funding statements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The Authors declare that there is no conflict of interest.

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