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Implicit working memory

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Abstract

Working Memory (WM) plays a crucial role in many high-level cognitive processes (e.g., reasoning, decision making, goal pursuit and cognitive control). The prevalent view holds that active components of WM are predominantly intentional and conscious. This conception is oftentimes expressed explicitly, but it is best reflected in the nature of major WM tasks: All of them are blatantly explicit. We developed two new WM paradigms that allow for an examination of the role of conscious awareness in WM. Results from five studies show that WM can operate unintentionally and outside of conscious awareness, thus suggesting that the current view should be expanded to include implicit WM.

Keywords

Working memory; Executive functions; Automaticity; Consciousness; Unconscious

1. Introduction

Working memory (WM) has long attracted the attention of experimental psychologists and neuroscientists who are interested in how people reason, solve problems, pursue goals, make decisions, and achieve cognitive control (Baddeley, 2003; Baddeley & Logie, 1999; Cowan, 1999; Dudai, 2004; Shah & Miyake, 1999; Smith & Jonides, 1995). The conception of WM grew out of the literature on short-term memory (STM) in the mid 1970s (Baddeley & Hitch, 1974), and soon became what Baars and Franklin (2003) described as "the most influential empirical model of cognitive functions to date" (p. 170). Alan Baddeley, one of the leading researchers of WM, wondered in a recent exploration of the WM literature "what else is needed for a theory of working memory," and he replied that, among other things, "the proposed link between working memory and conscious awareness also represents a lively and exciting interface" (2003 p. 837; cf. Miyake & Shah, 1999). The current paper addresses this issue directly. It presents five studies that examine the relation between working memory and conscious awareness, with findings strongly suggestive of nonconscious, implicit WM.

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1.1. Working memory: functions and basic processes

There seems to be a widespread consensus regarding the functions that WM serves. This consensus was nicely described by Miyake and Shah (1999) who, after having reviewed major theories of WM, concluded that “working memory is not for ‘memorizing’ per se but, rather, it is in the service of complex cognitive activities such as language processing, visuospatial thinking, reasoning and problem solving, and decision making” (p. 445; cf. Unsworth, Heitz, & Engle, 2005).

A review of the models of WM is beyond the scope of the current paper (see Baddeley, 2007 and Miyake & Shah, 1999 for overviews). However, an inspection of these models and the tasks used to examine WM (e.g., Daneman & Carpenter, 1980; O’reilly, Braver, & Cohen, 1999; Smith & Jonides, 1999; Turner & Engle, 1989) reveals that the consensus regarding the functions of WM is matched by a general agreement regarding the processes that underlie it. These include: (1) active maintenance of ordered information for relatively short periods of time; (2) context-relevant updating of information, and goal-relevant computations involving active representations; (3) rapid biasing (control) of task-relevant cognitions and behaviors, in the service of currently pursued goals (Hassin, 2005; O’reilly et al., 1999). The latter processes include attending and inhibiting, scheduling, monitoring and planning (cf. Smith & Jonides, 1999).

1.2. Conscious awareness and working memory

The consensus among WM- and consciousness researchers is that the psychological processes that underlie WM, attention and awareness are closely intertwined (e.g., Baars & Franklin, 2003; Dudai, 2004; Kintsch, Healy, Hegarety, Pennington, & Salthouse, 1999). The nature of these relations, however, is less consensual.

Some researchers adhere to what Kintsch et al. (1999) referred to as the “subset hypothesis,” which argues that a subset of the information that is actively maintained in working memory is that of which we are aware (cf. Cowan, 1999; O’reilly et al., 1999). Baddeley, who historically was reluctant about exploring the relations between working memory and consciousness (Baddeley, 1992), suggested that conscious awareness may be one of the functions of the central executive component of WM (Baddeley, 1993). In a more recent development of his model Baddeley (2000) explicated his proposal and suggested that awareness is inherent in the interaction between the executive and the episodic buffer.

Baars (1997) went one step further by postulating that conscious awareness is involved in all WM input, output, and voluntary operations, as in explicit problem solving. Similarly, in a more recent paper Baars and Franklin argued that “all active components of classical working memory are conscious: input, rehearsal, visuospatial operations, recall and report.” (Baars & Franklin, 2003, p. 170).

While divergent, these views seem to have two common themes. First, they share the idea that some components, processes or contents of WM are conscious. The contents may be the representations in the focus of attention (Cowan, 1999), or those that are involved in the interaction between the executive and the episodic buffer (Baddeley, 2000), and the processes may include input, rehearsal, and visuospatial operations (Baars & Franklin, 2003). We adopt Baars & Franklin’s terminology (2003; see above), and refer to these as active contents or processes. Second, none of these views suggests that people have conscious access to everything that goes on within WM (e.g., we may not have conscious access to the processes that underlie our ability to rehearse information, or to those that underlie our ability to update information in WM.)

The differences in opinion described above may result in a somewhat complex picture of the relations between WM and conscious awareness. The major WM tasks, however, are clearer and unequivocal on this question: In all of them participants are explicitly presented with materials that they are explicitly asked to manipulate (e.g., they are instructed to memorize, rehearse, compare, subtract, and so on). In other words, these tasks take as given that WM is conscious (see Berns, Cohen, and Mintun (1997), for a similar argument regarding novelty detection).

We suggest to view these tasks as implicit, or indirect, measures of researchers' beliefs regarding WM. As such, they clearly show that researchers adhere to the view that active components and contents of WM are conscious.

1.3. Conscious awareness and short-term memory

A notable exception to the picture portrayed above is short-term memory: Results from two very different paradigms suggest that it can operate implicitly. McKone (1995, Study 1) used a lexical decision task to assess the effects of repetition priming on words and non-words at lags of 0, 1, 2, 3, 4, 5, 9, 23, and 1050 intervening items (where lag 0 is an immediate repetition condition, in which there are no intervening items between two presentations of a stimulus). Participants in these experiments were not asked to memorize the stimuli, and were largely unaware of the repetitions. Yet, the results showed that repetition priming for words had two components. First, a short term component that led to a relatively big reduction in RTs. This component decayed pretty smoothly until lag 4 (starting from ~140 ms at lag 0, and asymptoting at approximately 50 ms at lag 4). Second, a relatively long term component, that led to a reduction of around 50 ms in RTs as a result of repetition priming. This component lasted at least until lag 23.

These two components were found in three more studies, leading Mckone (1995) to conclude that there are both short term implicit memory effects in word priming (lasting approximately 8 s in her studies), and long-term implicit memory effects (lasting at least 40 s in her studies.) The short term effects described above did not replicate with non-words. Thus, McKone's interpretation of the results focused on short-term retention within system(s) of word recognition (McKone, 1995; McKone, 1998; McKone & Dennis, 2000; cf. Cowan, 2001).

In a similar vein, Maljkovic and her colleagues (Maljkovic & Martini, 2005; Maljkovic & Nakayama, 1994; Maljkovic & Nakayama, 2000) found evidence for implicit short-term memory in a visual search task. On each trial in this task several shapes appear on a computer's screen, and participants are asked to decide whether the left or right side of one of these shapes is cut off. The target shape (i.e., the one about which the decision is made) is determined, on each trial, by popout. Thus, for example, on trial n participants may be presented with 10 stimuli, nine of which are green and one is red; in this trial response should be based on the red stimulus. On trial m, however, participants may be presented with nine red stimuli and only one green, and here response should be based on the green stimulus.

The consistent finding of Maljkovic and her colleagues is that when the popout feature is repeated (e.g., the "oddball", popout color in trial n and $n + 1$ is red), responses are speeded. This effect lasts for 15–30 s, suggesting that the short term visual memory of the popout feature improves performance. Crucially, participants were unaware of the repetition and its effect (Maljkovic & Nakayama, 1994; Maljkovic & Nakayama, 2000), and hence the researchers concluded that this short term maintenance is implicit.

Whether these lines of investigation look at two different implicit mechanisms – reminiscent of the phonological loop and the visuospatial sketchpad (Baddeley & Hitch, 1974) – or at a more general short term implicit memory system(s) is still an open question. Regardless of the answer to this question we find these findings encouraging, because they establish the existence of implicit short-term memory.

1.4. Implicit working memory

The review above indicated that there is a wide consensus regarding the role of WM in many high-order cognitive processes (e.g., reasoning, problem solving, cognitive control, goal pursuit). It also indicated that, with the possible exception of short-term memory, active components of WM are generally perceived as intimately tied to conscious awareness. Given the acknowledged capacity limitations of conscious awareness (e.g., Kahneman, 1973), these two conclusions imply that we can only engage in a very limited number of these high-order cognitive processes at any given point in time. This conclusion stands in stark contradiction to the simple intuition that there are points in time in which we seem to be advancing multiple goals, decisions and plans (etc.), so the question that arises is – how can the two be reconciled?

One option is that it only seems as if we can pursue more than a handful of these processes at any given point in time, but in actuality when they are "out of sight" (i.e., unconscious) they are also "out of mind" (i.e., inactive). In other words, it may be the case that when processes of this sort are not in our current conscious focus they are idle. They do not do any work.

Yet another option is to reconsider the view that active components of WM are conscious, and to suggest that WM can operate implicitly[1] (cf. Spelke, Hirst, & Neisser, 1976). While both options are logically possible, psychological considerations – mainly, the grave limitations on conscious resources (e.g., Kahneman, 1973) – suggest to us that the latter is more plausible.

We argue, therefore, that WM can operate outside of conscious awareness. More specifically, we suggest that the processes that were identified above as underlying (or constituting) WM can be recruited without conscious intention, and that they can then go on to operate non-consciously. These include: (1) active maintenance of ordered information for relatively short periods of time; (2) context-relevant updating of information, and goal-relevant computations involving active representations; (3) rapid biasing (control) of task-relevant cognitions and behaviors, in the service of currently pursued goals. Furthermore, we contend that this is the case even when the representations on which these processes operate are inherent to the focal task. Lastly, we argue that the content that is task-relevant and that is modified by these processes may be unconscious too.

Since existing WM tasks take as given that WM is predominantly conscious, they cannot be used to systematically address questions regarding the role of conscious awareness in WM. We therefore developed two new working memory paradigms. In the next section we describe the paradigm that was used in four out of the five studies we report, and the following section examines whether it is indeed a working memory paradigm.

1.5. Examining implicit working memory: a new paradigm

In this paradigm the computer screen is divided into cells by a 24 (columns) by 18 (rows) matrix. Small round disks (five millimeters in diameter) that are either empty (i.e., bagel-shaped), or full, appear in the different intersections of the matrix. The disks appear one at a time, and participants' task is perceptual: They are asked to indicate, using two keys on the keyboard, whether the disk is full or empty. The disk remains on the screen until participants respond, and erroneous responses are followed by a short auditory feedback. After each response the disk disappears and 150 ms later the next disk appears.

[1]There is a third option, which puts in question the assertion that WM is intimately involved in higher cognitive processes such as problem solving, goal pursuit, etc. Given the sheer volume of research that supports this assertion (for overviews see Miyake and Shah (1999)), this possibility is not considered any further.

The stimuli appear in sets of five, which are demarcated from each other by a fixation point (a small square) that appears in the center of the display for 1500 ms. There are three different kinds of sets, which define three conditions. In the Pattern sets condition the locations of all the disks in a set follow a pre-determined pattern. If one keeps in mind all of the disks in a set in their right order, and then mentally "draws the lines" between their locations, then many of these patterns are familiar (e.g., zigzags). Note, however, that the disks appear one at a time, and hence the input to the cognitive system is comprised of individual disks, not sets (for a full list of these patterns see Table 1). In the yoked Broken Pattern condition the locations of the first four disks in a set follow the same pattern (e.g., zigzag), but the location of the fifth disk does not[2], and in the yoked Control condition the locations of the first three disks are randomly determined, but the fourth and fifth follow the pattern.

If participants extract the pattern during the first four disks of a Pattern set, they can correctly anticipate the location of the last disk in that particular set. This may allow them to speed up their response to this last disk. If they extract patterns during Broken Pattern sets, though, their anticipations will err systematically, thus potentially slowing down their responses. The dependent measure of interest is thus reaction time to the last disks in Pattern, Broken Pattern and Control sets. Because of the hypothesized pattern-driven anticipations of the disks' locations, RTs to last disks in Pattern sets (where pattern-based anticipations are veridical) should be faster than RTs to the last disks in Broken Pattern sets (where pattern-based anticipations are systematically misleading), with Control sets falling somewhere in between.

Note that participants' explicit task is merely to judge whether the disks are empty or full. Hence, any extraction of the patterns that govern disks' locations is incidental. Furthermore, the nature of the disks (i.e., whether they are full or empty) is randomly determined throughout the study, and so extracting the patterns that determine disks' locations cannot help participants predict the correct responses (although it can speed them up if it allows them to predict where will the next disk appear).

Each pattern, broken pattern and control set (see illustration in Fig. 1) appears only once in a block, and the remaining sets are Random, that is – the locations of all five disks are pseudo-randomly determined, with the constraint that two consecutive disks cannot be more than four matrix-units apart from each other (the average distance between disks in the experimental sets is 3.125). In four out of the five studies we report, each block contains 10 different patterns, and their 10 yoked broken patterns and 10 yoked controls. The remaining 70 sets of each block are random.

1.6. Is this a WM paradigm?

To answer this question we adopt a functional perspective. Thus, a working memory paradigm is a paradigm that taps the functions of WM. To answer this question, then, one needs to consider the mental operations that subserve extraction and use of patterns in this paradigm. First, the goals of being fast and accurate need to be in place. Second, one must mentally rehearse and actively update a list of locations of disks (within each set). Third, the locations of the disks must be maintained in order of their appearance. Fourth, mental computations must be conducted in order to extract the pattern. Fifth, the extracted patterns must lead to anticipations regarding the locations of the last disks, anticipations that affect the speed with

[2]The fact that the fifth disk in Broken Pattern sets did not follow our intended pattern does not mean that it did not follow some other pattern. In fact, every finite set of disks follows a mathematical rule (i.e., pattern). If participants extract this other pattern, rather than the one we intended them to, then the fifth disk in pattern sets actually breaks the pattern thus transforming this set to a broken pattern set (and vice versa for the broken pattern sets). What is important for our purposes here is that this factor leads to an underestimation of the effect of patterns.

which responses are made. In other words, an extracted pattern biases other concurrent cognitive processes and thus controls behavior.[3]

A comparison of these features with the list of WM processes given above reveals that the current paradigm is indeed a WM paradigm: It requires active maintenance of ordered information for relatively short periods of time; in addition, it requires context-relevant updating of information (with incoming disks) and goal-relevant computations (i.e., pattern extraction and anticipation formation). Lastly, the information is processed in the service of current goals (of being fast and accurate), and is readily available to bias cognition and behavior (thus speeding/slowing responses).

Note that this task (like many other WM tasks; cf. Baddeley, 2003; Waugh & Norman, 1965) may involve long term memory. This involvement may occur both at the level of the individual stimulus (e.g., the stimulus may seem to be a "ring" or a "bagel") and at the level of sets, especially in those sets that may be used to create patterns that are familiar (e.g., zigzags). Recall, however, that each disk appears in isolation, separated in time and space from the previous and following disks. Thus, without active maintenance of ordered locations there are no sets of disks, only isolated ones. And without the goal-relevant computations that involve disk-related information (i.e., "connecting the dots") there are no patterns, just sets of disks. In other words, one cannot identify (or recognize) a pattern in this paradigm without rehearsing the locations of the disks in a set, in their right order, and without mentally "drawing the lines" that "connect" the disks. Without this endeavor of WM the only relevant information in long term memory would be the information provided by each trial (i.e., the information of one disk) or, at most, the unordered, unprocessed, "raw" information of multiple trials. And hence, long term memory cannot generate the hypothesized effects by itself.

We conclude, then, that WM operations are necessary for "drawing" the visual patterns created by the various sets. This means that evidence which suggests that the hypothesized effect occurred is also evidence that these WM operations had taken place. Whether the processes of "naming" the patterns, creating anticipations for future locations, and controlling cognition, are done solely by WM or, like many other WM paradigms (Baddeley, 2003; Gathercole, Pickering, Hall, & Peaker, 2001), involve the interaction of WM and long term memory, is an empirical question that we sadly leave for future research.

1.7. But still: is this an implicit learning paradigm?

To answer this question it is important to reiterate that pattern- and broken pattern sets are equally likely. It is important, because this procedure prevents more gradual implicit learning per-se. To see why this is so consider the following conditional probability: Given four disks of a pattern/broken pattern set, where would the next disk appear? Recall, that up to the fourth disk a pattern and its broken pattern set are identical in terms of disks' locations. Note, furthermore, that in each block we keep the probability of a pattern-following last move equal to the probability of a pattern breaking last move (=.5). Thus, one's learning history during the experiment should lead to chance performance on the fifth disk. As far as learning is concerned, then, no differences should emerge between pattern-following and pattern-breaking sets. We conclude, then, that evidence for pattern extraction in this paradigm cannot be merely attributed to implicit learning.

[3]By "extraction" we do not mean to rule out other theoretical alternatives such as "identification" or "recognition". It is crucial for the current purposes, though, that none of these processes can proceed without the functions and actions that are described in this paragraph. In other words, one cannot identify or recognize a "zigzag" pattern in this paradigm without rehearsing all the locations, in their right order; without "drawing" the "lines" that "connect" the disks; without putting this information to good use, etc.

1.8. Overview

This paper offers to extend our views of WM to include implicit working memory. Studies 1–3 use the paradigm that was described above with various tests of awareness (self report, immediate reconstruction, and immediate recognition). Study 4 again tests for awareness of pattern extraction, this time by contrasting the implicit version of this paradigm with an explicit version. Study 5 uses a conceptual replication of this paradigm in a non-visual domain. We conclude by discussing the current proposal in its wider context.

2. Study 1

2.1. Method

2.1.1. Participants—Twenty Hebrew University students participated in Study 1 in exchange for course credit or 15 Shekels (~$3).

2.1.2. Materials and tools—These were described above in Section 1.5. The study comprised of two blocks of 100 sets, and it included 10 different patterns (the complete list of patterns is presented in Table 1). Each block was comprised of a single presentation of each pattern-, broken pattern- and control sets, and 70 random sets. The experimental sets were pseudo-randomly distributed within the block. The only constraint on this pseudo-random distribution was the following: Each block was divided to 25 mini-blocks (e.g., sets 1–4, 5–8, etc.), and there was no more than one experimental set (either pattern, or broken pattern, or control) per mini-block.

Note, that since our hypothesis entails that pattern extraction in this paradigm does not depend on statistical learning of any kind – implicit or explicit – the effects of our manipulation should already be evident on the first block.

2.1.3. Procedure—Participants were run in individual booths. Upon entering the booth they received written instructions, which were later repeated by the experimenter. In these instructions the paradigm was described, and participants were told that their task was to determine "as quickly and as accurately as possible" whether the disks that they see are "full" or "empty". Obviously, the mere existence of patterns, and their anticipated effects, were not mentioned in the instructions. Participants engaged in 20 practice sets before they began the actual study. After having finished the experiment participants answered a long and detailed debriefing that assessed their awareness to the patterns and their extraction (see more details in the Results section below).

2.2. Results

Participants' awareness and intentions were assessed in the debriefing stage, in which they were asked open-ended questions regarding their thoughts while completing the task, whether they noticed any visual (or other) patterns in the appearances of the disks, and whether they intended to guess where will the disk appear next. The responses of four participants indicated awareness (e.g., one participant suggested that he might have seen a zigzag pattern) or intention, and their data were excluded from the analyses. Incorrect responses, as well as responses that were faster than 200 ms or slower than three SDs from the mean, were discarded from analyses (4.3%).

A 3 (Pattern: Pattern, Broken Pattern, Control) × 2 (Block) within subjects' ANOVA revealed that, as hypothesized, RTs in the Pattern condition (M = 528 ms, SD = 48) were considerably shorter than those for the Broken pattern condition (M = 565 ms, SD = 62) with RTs for control sets falling in between (M = 532 ms, SD = 48), $F(2, 30) = 5.55$, $p < .01$, MSE = 2.41, partial $\eta^2 = .27$. The main effect of block approached significance, $F(1, 15) = 2.95$, $p = .10$, suggesting that performance on the second block was a bit faster than on the first. There was also a trend towards an interaction between Block and Pattern, $F(2, 30) = 2.14$, $p = .14$, suggesting that the Pattern effect on the first block was stronger than on the second (see analyses of the first block later).

Planned comparisons revealed that the difference between the Pattern and Broken Pattern conditions was significant, $t(15) = 3.07$, $p < .01$, as was the difference between the Control and Broken Pattern conditions, $t(15) = 2.85$, $p < .02$. The difference between the Pattern and Control condition did not reach significance, $t < 1$.

It is crucial for the current argument that pattern extraction did not result from (implicit) learning. Although we argued above that the paradigm precludes statistical learning per-se, analysis of the data of the first block is an important empirical test of this assumption. And indeed, a repeated measures ANOVA on this block revealed a highly significant effect of Pattern, $F(2, 30) = 7.17$, $p < .01$, MSE = 1.55, partial $\eta^2 = .32$. Pairwise comparisons revealed a significant difference between Pattern ($M = 529$, SD = 55) and Broken Pattern ($M = 579$, SD = 63) sets, $t(15) = 3.52$, $p < .01$, and between Control ($M = 541$, SD = 56) and Broken Pattern sets $t(15) = 2.93$, $p < .02$. The difference between Pattern and Control sets did not reach significance, $t < 1$.

To sum up, the results indicate that participants non-consciously and unintentionally extracted patterns that, in turn, affected their performance on the task. Importantly, pattern extraction occurred on the first block, thus ruling out implicit learning as an alternative explanation of the results. Since the paradigm is a WM paradigm, this evidence supports our contention that active components of WM can operate without intention and outside of conscious awareness.

3. Study 2

Study 2 is a replication of Study 1 with one extension: awareness of pattern extraction was also assessed through an immediate reconstruction-probe method. Thus, the last set that participants saw was always a (randomly chosen) Pattern set. Immediately after giving their response to the last disk in this set participants were asked to reconstruct it. Awareness was determined by whether participants could do so.

3.1. Method

3.1.1. Participants—Sixteen NYU undergraduates (mean age 19.1) participated in this study in exchange for course credit.

3.1.2. Materials and procedure—Other than the procedure for assessing awareness, these were identical to the first study. Immediately after the last response, a message that appeared on the screen instructed participants to turn a page that had been placed on their desk. On this page appeared a matrix, similar to the one on the screen. Written instructions informed participants that “you are now asked to draw on the matrix the last five disks that you saw. Please number the disks in order of appearance. If you do not remember – please do your best at guessing”.

3.2. Results and discussion

Two judges (who were participants in the same subject pool) were given participants’ reconstructions of the last sets, alongside the actual patterns that participants saw. The judges were asked to assess whether participants’ reconstructions indicated that they were aware of the sets. Both judges concluded that none of the participants had been aware of the patterns.

In order to further examine awareness of the last pattern, participants' reconstructions were re-presented as eight moves: Four on the *X* axis and four on the *Y* axis. For example, if the second disk appeared two units to the right and four units below the first disk, then the first X move would be (+2) and the first *Y* move would be (–4). The actual last sets were analyzed in an identical way. These re-presentations resulted in two ordered lists of eight moves: One that was computed from the reconstructions and one that was computed from the actual last sets. We argue that the correlation between the lists is an indication of participants' awareness: If participants were aware of the sets then they should have been be able to fully reconstruct it, yielding a perfect correlation; no awareness might yield chance-based reconstructions, and hence no correlation. The individual correlations ranged from –.54 to +.49, and none of them significantly differed from zero, ps > .2. The mean correlation did not significantly deviate from zero too, $M = -.08$, SD = .33, $p = .42$. Thus, the judges' judgments and the more formal analysis agree: It seems that none of the participants could reliably reconstruct the moves of the last set.

Incorrect responses, as well as responses that were faster than 200 ms or slower than three SDs from the mean, were discarded from the analyses (3.3%).

Participants' mean RTs to the three conditions were subjected to a repeated measures ANOVA. Replicating the results of the first study, participants were faster to react to pattern sets than to broken pattern sets, with control sets falling in between ($M = 462$ ms, SD = 61, $M = 489$ ms, SD = 66, and $M = 465$ ms, SD = 78, respectively), $F(2, 30) = 4.62$, $p < .05$, MSE = .72, partial $\eta^2 = .24$. Pairwise comparisons revealed a significant difference between Pattern and Broken Pattern sets, $t(15) = 3.10$, $p < .05$ and between Control and Broken Pattern sets, $t(15) = 2.81$, $p < .05$. The difference between Pattern and Control sets did not reach significance, $t < 1$.[4]

The results of the current study replicate those of the previous one, in that participants used WM to extract patterns without intention or awareness. They extend them by using a new measure of awareness – immediate reconstruction.

4. Study 3

Study 3 is identical to the previous study, except for the method that was used to assess awareness. Like in the previous study, the last set participants saw was always a pattern-following set. Immediately following their last response to this set participants were given a recognition test.

4.1. Method

4.1.1. Participants—Thirty six participants of the Hebrew University (20 females and 16 males) took part in this study, either for course credit (15 participants) or for 15 Shekels (~$3; 21 participants). Their mean age was 21.5 years.

4.1.2. Materials and tools—Other than the procedure for assessing awareness, these were identical to Study 2. The last set presented to participants was always a pattern set, that was randomly chosen out of five possible patterns. Immediately after the last response, a message that appeared on the screen instructed participants to turn around a page that had been placed on their desk. All five patterns were visually represented on this page in the following manner (for an example see Fig. 1). Five matrices of the sort used in the study appeared on the recognition page. Five disks, that were numbered 1–5, appeared on each of the matrices. The instructions informed participants that the numbers represent order of appearance, and that one

[4]The idea to examine the effects of Patterns in the first block came pretty late in the project. Hence, we have information about blocks only in Experiments 1 and 4. Importantly, these data are very conclusive.

of these sets was identical to the set they have just seen. They were asked to choose which one of these sets is the one they have just seen, and they were encouraged to guess even if they felt that they did not know the answer.

4.2. Results

One participant did not complete the experiment, four mentioned patterns in their debriefing, and the debriefing of one participant implied that he was looking for patterns (although he did not find any). Out of the remaining 30 participants only 5, or 20%, correctly recognized the set. This proportion is exactly that expected by chance. Thus, the recognition measure corroborates the findings from the previous studies: Participants were unaware of the patterns they were exposed to. Incorrect responses, as well as responses that were faster than 200 ms or slower than three SDs from the mean, were discarded from the analyses (3.2%).

Replicating previous analyses, the data were subjected to a repeated measures ANOVA, with Pattern, Broken pattern and Control as within participant conditions. This analysis yielded a significant effect of Pattern, $F(2, 58) = 3.37$, $p < .03$, MSE = 1.21, partial $\eta^2 = .10$. Pairwise comparisons revealed a significant difference between Pattern (M = 508 ms, SD = 62) and Broken Pattern sets (M = 528 ms, SD = 70), $t(29) = 2.54$, $p < .02$, and between Control (M = 507 ms, SD = 60) and Broken Pattern sets $t(29) = 2.12$, $p < .05$. The difference between Pattern and Control sets did not reach significance, $t < 1$.

Although recognition rate is at chance level, we also conducted similar analyses only for those participants who could not recognize (or correctly guess) the last set that they have seen. These analyses yielded a similar pattern of results. The overall effect of Pattern was marginally significant, $F(2, 58) = 2.99$, $p = .06$, partial $\eta^2 = .10$. Pairwise comparisons revealed a significant difference between Pattern (M = 510 ms, SD = 64) and Broken Pattern sets (M = 532 ms, SD = 70), $t(29) = 2.67$, $p < .02$. The difference between Control (M = 518 ms, SD = 59) and Broken Pattern sets was evident yet not significant $t(29) = 1.42$, $p = .17$, and that between Pattern and Control sets did not reach significance, $t < 1$.

These results, then, lead us to conclude that even when awareness is assessed through immediate recognition, participants show evidence for non-conscious extraction of patterns in this paradigm. And thus, these results provide further evidence for implicit WM.

5. Study 4

The first three studies established that participants can non-consciously and unintentionally extract patterns in a new working memory paradigm. The studies used three different measures of awareness – post-experimental questionnaire, immediate reconstruction, and immediate recognition. The current study examines the contention that pattern extraction is non-conscious in this paradigm in yet another way: Instead of measuring awareness and intention, it manipulates them. Thus, participants in one group (the Implicit condition) received the same instructions as those of studies 1–3, while participants in the other group (the Explicit condition) were explicitly told about the existence of visual patterns and were encouraged to find them. Thus, participants in the latter condition were encouraged to examine the first few disks in each set and to try and predict the following disk.

If participants in the previous studies were intentionally and consciously looking for patterns and extracting them, then there should be no differences between the Implicit and Explicit conditions. If, however, participants in these studies were not consciously and intentionally looking for patterns and extracting them, then the two conditions might differ.

Previous findings in the long-term implicit learning literature suggest that drawing people's attention to the existence of complex structures in their environment may interfere with the extraction of these patterns (e.g., Berry & Broadbent, 1988; Brooks, 1978; Reber, 1976). One proposed explanation for these findings maintains that the conscious mind cannot apprehend complex structures of this sort, and so conscious search is bound to fail (cf. Reber, 1993). The conscious search and the conscious failure may interfere with the relevant implicit processes, resulting in an ironic effect: Conscious search for structures diminishes the probability of actually finding these structures (it is interesting to note here that Maljkovic and Nakayama (1994, Study 2) found a similar damaging effect of explicit knowledge on implicit short-term memory).

The same phenomenon may emerge in the current paradigm. Simply, 80% of all sets (the 70% random sets plus the 10% controls) are pattern-less (in the sense that we did not endow them with a pattern) and hence they are likely to be more difficult to "decipher" (see endnote 2). Put differently, it is more difficult to find a pattern in these sets. In the Explicit condition, in which participants actively search for patterns, these sets are likely to result in frequent failures. Given the literature succinctly described above, the conscious search and its prominent failures are likely to interfere with the relevant implicit processes, and to diminish successful pattern extraction.

The current study employs a 2 (Instructions: Implicit vs. Explicit; between participants) × 3 (Pattern: Pattern, Control, Broken Pattern; within participants), × 2 (Block) mixed design. We hypothesize an interaction between the first two factors, such that the results in the implicit condition replicate the results of the previous studies, whereas no evidence for pattern extraction will be found in the explicit condition.

5.1. Method

5.1.1. Participants—Fifty-four participants of the Hebrew University (36 females and 18 males) took part in this study, either for course credit or for 15 Shekels (~$3). Their mean age was 23.4 years, and they were randomly distributed to conditions.

5.1.2. Materials and tools—These were identical to Study 1, except for the instructions of the explicit group. Participants in this group were made aware of the fact that some sets follow patterns, and they were told that extracting these patterns may improve their performance.

5.2. Results

Excluded from the analyses were one participant who did not complete the study; one participant in the explicit condition who indicated that she did not attempt to anticipate locations; one participant from the implicit condition who indicated that she attempted to anticipate locations, and eight participants from the implicit condition who indicated awareness or intention.[5] Incorrect responses, as well as responses that were faster than 200 ms or slower than three SDs from the mean, were discarded from the analyses (5.8%).

Replicating the previous results, the main effect of Pattern was highly significant, $F(2, 82) = 11.65$, $p < .001$, MSE = 1.79, partial $\eta^2 = .22$, and did not differ as a function of Block ($F < 1$). Pairwise comparisons revealed that the means of all Pattern conditions significantly differed from each other: Pattern ($M = 511$ ms, SD = 70) from Broken Pattern sets ($M = 538$ ms, SD =

[5]Given the awareness data of the previous (as well as in the following) studies, there seems to be a higher-than-usual proportion of participants who became aware of the patterns. We do not know for certain what caused this effect. We speculate, though, that it may have to do with the nature of the studies that are run in our labs. Thus, Hassin's lab (where this study was conducted) runs many non-conscious goal priming studies. Towards the end of the academic year, many participants come to the lab suspecting that there is more to our experiments than meets the eye.

78), $t(42) = 3.42$, $p < .01$; Control (M = 526 ms, SD = 86) from Broken Pattern sets $t(42) = 2.06$, $p < .05$, and Control from Pattern sets, $t(42) = 2.46$, $p < .02$. The main effect of instructions, however, did not reach significance, $p > .2$

Crucially for the current concerns, a significant interaction between Instructions and Pattern emerged, $F(2, 82) = 5.32$, $p < .01$, MSE = 1.79, partial $\eta^2 = .12$. As hypothesized, the interaction consisted of a significant effect of Pattern in the Implicit condition, $F(2, 32) = 10.75$, $p < .001$, MSE = 1.12, partial $\eta^2 = .40$, and no effect of Pattern in the Explicit condition $F = 1.1$ (for means see Table 2).

Analyzing the results of the Implicit condition, with Block and Pattern as repeated measures, yields a significant effect of Pattern $F(2, 32) = 10.74$, $p < .001$, an effect of Block that approaches significance ($p = .13$), and no interaction $F < 1$. Replicating the previous results, the difference between Pattern and Broken pattern is significant $t(16) = 4.05$, $p < .002$, and the difference between Broken Pattern and Control is marginally significant, $t(16) = 1.89$, $p < .08$. Unlike the previous studies, the difference between Pattern and Control conditions reached significance, $t(16) = 3.02$, $p < .01$.

Importantly, the current design allows us to re-examine the emergence of the pattern effect in the first block, where each pattern only appears once (see Study 1). Replicating the results of the first study, the effect of Pattern in the Implicit condition was highly significant, $F(2, 32) = 9.98$, $p < .001$, MSE = 1.10, partial $\eta^2 = .39$. Pairwise comparisons revealed that mean RT in the Pattern condition (M = 523 ms, SD = 96) was significantly shorter than that in the Broken Pattern condition (M = 579 ms, SD = 100), $t(16) = 5.70$, $p < .00$ and from the mean RT in the Control condition (M = 559 ms, SD = 117), $t(16) = 2.52$, $p < .01$. The difference between the mean RTs for Control and Broken Pattern was only marginally significant, $t(16) = 1.45$, $p = .08$ (one tailed).

5.3. Discussion

The results of this study establish a dissociation between an implicit and an explicit version of the current task. While, as hypothesized, participants in the Implicit condition show a significant effect of Pattern, there is no such effect for participants in the Explicit condition. This dissociation between the two versions of this task corroborates the results of the first three studies: Participants implicitly extract patterns in this paradigm, thus providing evidence for implicit WM.

6. Study 5

The fifth study is a conceptual replication of the first four studies, in the domain of numbers. Participants saw sets of one-digit numbers that appeared, one at a time, on a computer screen. Unlike the previous studies, where the sets created visual patterns, here they create algebraic ones (e.g., 0, 2, 4, 6 for a pattern set vs. 0, 2, 4, 2 for a broken pattern set).

6.1. Method

6.1.1. Participants—Twenty-eight NYU undergraduates (mean age 19.4) participated in the study.

6.1.2. Materials and tools—Participants saw sets of one-digit numbers that appeared, sequentially, on a computer screen. Each number was composed of either little *X*'s or of little *O*'s, and participants were asked to indicate as quickly as possible, using the keyboard, whether the number they saw was composed of *X*'s or *O*'s (cf. Navon, 1977). Upon providing their answer the number disappeared from the screen, and if the answer was incorrect, participants heard a short auditory feedback. Immediately thereafter the next number appeared.

The numbers appeared in sets of four, which were demarcated from each other by a fixation point (a small black square) that appeared (randomly) either on the left or on the right side of the screen. The exact location of each number was pseudorandomly chosen out of four locations around the fixation point. This measure was taken to prevent participants from strategically narrowing their attention, thus focusing on the components of the numbers (the local dimension), rather than on the numbers themselves (the global dimension).

There were two kinds of sets: Patterns (e.g., 0, 2, 4, 6; 0, 3, 6, 9; 1, 3, 5, 7) and Broken Patterns (e.g., 0, 2, 4, 2; 0, 3, 6, 3; 1, 3, 5, 3). These sequences accounted for 25% of the trials (12.5% each), and 75% of the sets were random. The order of presentation of the Pattern and Broken Pattern sets was determined pseudo randomly, with the constraint that out of every four sequences only one was a Pattern or a Broken Pattern.

Unlike in the first four studies the patterns here were not visual. Rather, they were constituted from the relations between the numbers (e.g., $X_{n+1} = X_n + 2$). In this sense, then, the patterns are conceptual in nature. Note that as in the first four studies, participants' explicit task had nothing to do with the numbers themselves, let alone with the relations between them. Thus, pattern extraction is incidental in this paradigm too.

Following the logic of the previous studies it was hypothesized that participants will implicitly extract patterns. Moreover, it was hypothesized that if participants did indeed extract a pattern during the first three terms of a set (e.g., 0, 3, 6), then doing so should facilitate their response to a pattern-following fourth term (e.g., 9), relative to a fourth term that violates the pattern (e.g., 3). This is so because predicting the fourth term may allow participants to anticipate the shape of the stimulus, thereby facilitating the location of its components. Hence, participants should be faster to react to a fourth term that follows the pattern (Pattern condition) than to a fourth term violates the pattern (Broken Pattern condition).

6.2. Results and discussion

Participants' awareness and intentions were assessed in the debriefing stage (see Study 1). Three participants indicated either intention to extract patterns or awareness of them, and their data were excluded from the analysis. Participants made few errors (3.2%) and incorrect responses were excluded from the analysis. Responses that were faster than 200 ms, or longer than three SDs from the mean (1.1%) were excluded from the analyses.

As hypothesized, RTs for the fourth terms in the Pattern condition were significantly shorter than those in the Broken Pattern condition (M = 547 ms, SD = 84 vs. M = 561 ms, SD = 82) $t(25) = 2.35$, $p < .05$. These results, then, replicate those of the first four studies, in a paradigm that examines patterns that are conceptual in nature.

To summarize, the results of five studies, which use two different paradigms, suggest that active processes of WM can be unintentionally (incidentally) activated, and that they can then operate outside of conscious awareness. The evidence for implicitness and unintentionality comes not only from thorough debriefings, but also from immediate probe last-trial reconstructions and from recognition tests. Furthermore, we established a dissociation between an implicit and an explicit version of this task.

7. General discussion

The results of five studies show that the online extraction and application of patterns, a task that meets the requirements for a WM task, occurred in the absence of intention and conscious awareness. These data suggest, then, that WM can operate unintentionally and outside of conscious awareness, and hence – that current theorizing of WM should be expanded to include implicit working memory.

7.1. Implicit processes in WM

Previous research by McKone, Maljkovic and their colleagues provided evidence for an implicit mode of short-term memory (e.g., Maljkovic & Nakayama, 1994; McKone, 1995; see pp. 6–7 above). McKone's paradigm is verbal in nature whereas Maljkovic's paradigm is visual in nature; the results of the current studies replicate both findings in new paradigms. The main paradigm we used was visual in nature, thus corroborating Maljkovic's data in a new task. Study 5, however, used conceptual stimuli, and could be interpreted as corroborating McKone's data.

The current results offer a significant extension to the pervious findings by suggesting that other processes that are considered central to WM can occur implicitly (see p. 4). These include – above and beyond active maintenance of ordered information – context-relevant updating of information (with incoming disks) and goal-relevant computations (e.g., grouping of the disks in a set and extracting the underlying pattern). They also include the formation of anticipations that are based on these computations (i.e., expectations regarding disks' locations), and the quick biasing (control) of cognition and behavior (that resulted in different RTs for pattern vs. broken pattern sets). As can be expected from the nature of WM, all of these functions serve currently held goals.

Interestingly, recently Engell, Hassin, Bargh, and McCulloch (in preparation) began to explore the brain mechanisms that underlie the pattern effects in our visual paradigm using fMRI. Since Broken Pattern sets uniquely involve processes such as disconfirmation, inconsistency detection, surprise and possibly correction, only a Pattern minus Control contrast should give us clean activation of WM related areas. What areas should they activate? Previous studies have demonstrated right hemispheric lateralization within PFC for spatial WM (Smith & Jonides, 1999). Furthermore, right PFC, IFS, and FEF have been repeatedly identified in neuroimaging investigations of both spatial WM (Haxby, Petit, Ungerleider, & Courtney, 2000) and covert shifting of spatial attention (Corbetta & Shulman, 2002).

As hypothesized, fMRI analyses revealed increased activation in the right PFC during the Pattern sets relative to the Control sets. Specifically, regions within the right inferior frontal sulcus (IFS), the right cingulate sulcus, and the right frontal eye field (FEF, in the precentral sulcus) were selectively active during sets from which a pattern could be extracted and applied.

Before we go on we would like to dwell on two points that are central to our argument: the nature of the task and the issue of awareness.

7.2. The nature of the task revisited

So is the effect we report here a working memory effect, which implies implicit working memory, or a mere long term memory (LTM) effect, which implies (the well established) implicit long term memory? Imagine, then, how would LTM deal with this task. As input, it would have single disks, separated in time and space. How would LTM extract the patterns from this information? Logically, to even get to a pattern it would have to somehow actively maintain the information of all of the disks, in their right order. But this would not be enough. It would have to "freeze time", "look" at all the relevant disks, and "connect the dots" (metaphorically speaking, of course). But these types of cognitive functions are usually attributed to WM (see Section 1.1), and parsimony suggests that we continue attributing them to WM, and not to LTM.

All of this does not mean, of course, that LTM is not involved in this task altogether (see Section 1.6). It does mean, however, that working memory operations are necessary for the effect that we report here, and hence that the effect in itself provides evidence that these WM operations took place.

7.3. The issue of awareness revisited

We would like to re-evaluate our claim that the basic effect reported in this MS is non-conscious. Across the studies we used various techniques to verify that this is indeed the case. First, participants were asked explicit questions regarding the existence of patterns (self report). Second, they were asked to report whether they intended to extract patterns (self report). Third, participants were asked to immediately reconstruct the last set that they saw (free recall). Fourth, participants were asked to immediately recognize the last set that they saw (5-alternative forced choice). All of the participants who indicated either intention or awareness were excluded from the reported analyses (see more on these subjects in the next paragraph). Fifth, in Study 4 we contrasted an explicit version of this task (in which participants were encouraged to look for patterns and use them) with the regular, implicit version of it. There was no significant evidence for pattern extraction in the conscious, intentional condition.

Additional evidence regarding the nature of the effect may come from analyzing the data of the participants who were excluded from the analyses. Since Studies 1–4 are very similar in nature, we report an analysis that includes participants from all of them (except for those in the Explicit condition of Study 4). Twenty participants were excluded from analyses in these experiments (henceforth Excluded condition) and 79 were included (Included condition). Given these huge differences in numbers we cannot directly compare the effects using an ANOVA. Hence, we use as heuristics the actual size of the effect in milliseconds and effect sizes.

The basic idea of this analysis is that if the effect of patterns depends on awareness then it should be stronger for the participants in the Excluded condition, who were conscious of (at least some of) the patterns. Yet, the data does not support this suggestion. First, whereas the difference between broken pattern and pattern RTs was 31 ms in the Included condition, it was only 17 ms in the Excluded (similar differences between the Excluded and Included conditions are obtained when one compares the broken patterns and the control ones). Secondly, the effect size in the Included condition was 50% bigger than that in the Excluded condition (partial η^2 = .20 and .14, respectively). Assuming that participants in the Excluded condition consciously searched for patterns, these results replicate those of Study 4: Consciously looking for patterns seems to diminish their effects.

We acknowledge that these analyses are heuristical in nature. Yet, like the rest of the measures we report herein they suggest that it is not awareness that drives the effects we report. Concluding that a process or a phenomenon is non-conscious is always a very difficult challenge. Yet, the various measures we used paint a relatively clear picture: Pattern extraction in this paradigm seems to occur outside of conscious awareness.

7.4. Speedup vs. slowdown

The hypothesis developed in Section 1 suggested that RTs to pattern sets should be faster than those to control sets, and that the latter should be faster than RTs to broken pattern sets. Alas, the results of the first four experiments (there was no control condition in Study 5) suggest that the effects are not symmetrical. The differences between Broken Pattern and Control sets were significant in three studies (1, 2, & 3), and marginally significant in one (4). The difference between Pattern and control sets, however, was significant in one study (4) and insignificant in the rest. Furthermore, when the data of all first four studies is pulled together (see above) the difference between broken pattern and control sets is highly significant ($p < .001$), whereas the difference between pattern and control sets only approaches significance ($p < .09$, one tailed).

It is important to note here that in all studies, and in all of the analyses we report here, average RTs to pattern sets are faster than those to Control sets. This result is unlikely in a world in which there are no differences between Pattern and Control sets. Coupled with the analyses described above this suggests to us that there are both speedup and slowdown, but the latter is stronger than the former.

Why is this the case is not immediately clear. One possibility that comes to mind is that maybe there is an inherent slowdown upon the discovery of a pattern, as if the system takes a few milliseconds to develop an implicit "aha" experience. Thus, while the extraction of the pattern and the prediction of the location speed performance, the implicit "aha" experience slows it down a bit. Admittedly, this idea is speculative. Regrettably, we leave the resolution of this issue to future research.

7.5. Explicit and implicit working memory

What are the relations between explicit and implicit WM? Broadly speaking there are two alternatives. First, that the two are similar to the extent that there are no interesting functional differences between them (i.e., they differ only in phenomenology: We are aware of active processes in the former, but not the latter). If this is the case, then parsimony suggests that we view implicit working memory as a mode of operation of WM, at least until new data suggest otherwise. The second alternative is that there are important and interesting functional differences between them. Once these differences are mapped, one would have a better idea of whether one should view implicit working memory as a separate system or, again, as a mode of WM.

Our strategy in this paper was to focus on similarities between implicit- and explicit working memory, and hence it should not come as a surprise that this paper mainly documented resemblances. It also demonstrated one difference, though: Study 4 established that the Pattern condition did not exert its typical effect on participants in the explicit condition.

We speculate that more differences of this kind exist. Thus, for example, given that implicit working memory operates non-consciously, it may be less sensitive to conscious capacity limitations. The putative differences between explicit and implicit WM, as well as other intriguing questions such as whether they belong to the same system or to two separate systems (cf. Keren & Schul, in press), and what are their respective roles in higher order cognitive processes, are topics for future research.

7.6. Non-conscious controlled processes

WM plays an important role in controlled processes in general, and in high-order cognitive processes such as problem solving, decision making, reasoning and goal pursuit in particular (cf. Miyake & Shah, 1999). Traditionally, these processes were considered to be intentional and conscious. Yet, recent research in social cognition has established that high-order cognitive processes in general, and goal pursuit in particular, can occur non-consciously (for recent overviews of this literature see Bargh (2006) and Hassin, Uleman, and Bargh (2005)).

Existing models of high order non-conscious processes do not involve WM, a fact that should not come as a surprise given the traditional equation of WM with conscious awareness. The current findings suggest, however, that models of this sort can be expanded to include implicit WM and implicit executive functions (cf. Hassin, 2005; Hassin, Aarts, Eitam, Custers, &

Kleiman, 2009; Hassin, Bargh, & Zimerman, 2009). This move may open the way for new lines of research regarding automatic, non-conscious high-order cognitive processes.

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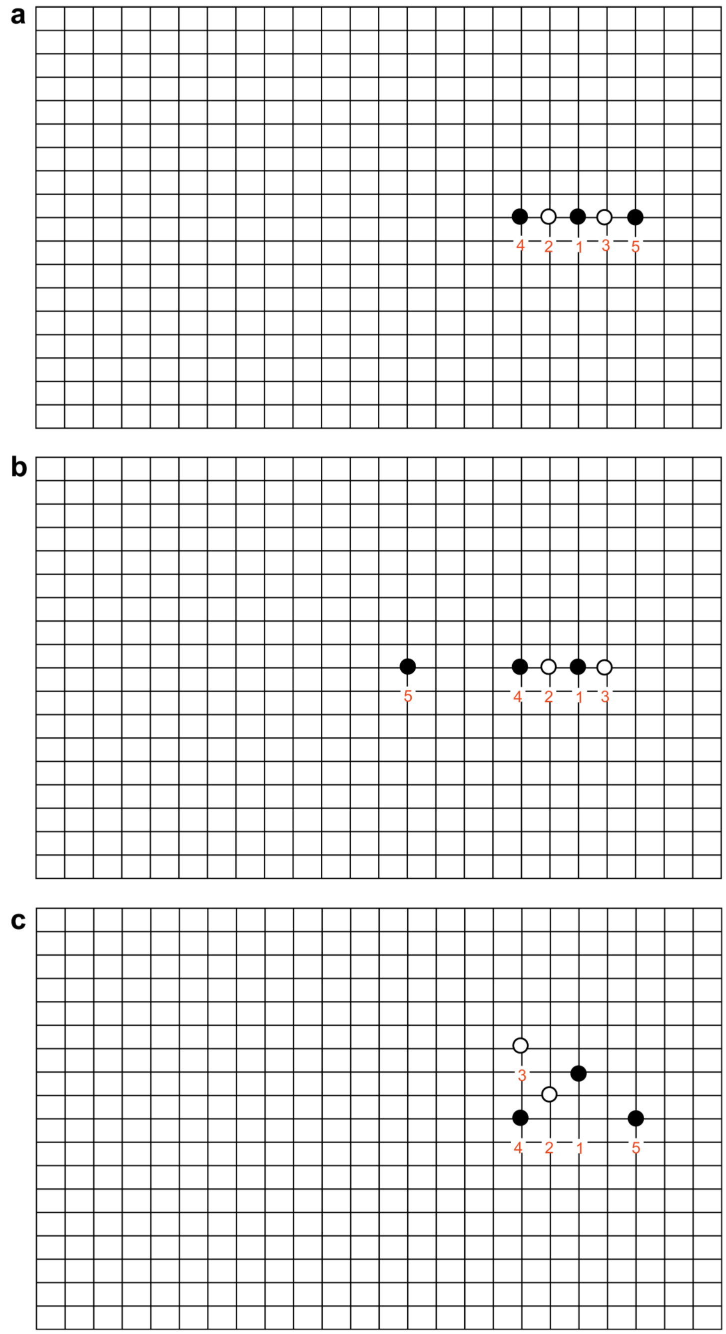

Fig. 1.
An illustration of a pattern set (a) its yoked broken pattern set (b) and control set (c). The numbers appearing below the locations indicate order of appearance, and did not appear in the actual study. The disks in the actual study appeared sequentially, such that participants saw only one at a time.

Table 1

The patterns used in studies 1–4 and their interpretation as "moves" on the screen.

	***X* axis**		***Y* axis**	
	Pattern	**"Moves"**	**Pattern**	**"Moves"**
Pattern #				
1	$X_{n+1} = X_n +2$	+2, +2, +2	$Y_{n+1} = Y_n$	0, 0, 0
2	$X_{n+1} = X_n +3$	+ 3, +3, +3	$Y_{n+1} = Y_n$	0, 0, 0
3	$X_{n+1} = X_n$	0, 0, 0	$Y_{n+1} = Y_n - 2$	–2, –2, –2
4	$X_{n+1} = X_n$	0, 0, 0	$Y_{n+1} = Y_n - 3$	–3, –3, –3
5	$X_{n+1} = 8X_n + 2$	+2, +2, +2	$Y_{n+1} = Y_n + 2 \times (-1)^n$	+2, –2, +2
6	$X_{n+1} = X_n + 4$	+4, +4, +4	$Y_{n+1} = Y_n + 4 \times (-1)^n$	+4, –4, +4
7	$X_{n+1} = X_n + 4 \times \mathrm{Mod}(n + 1, 2)$	0, –4, 0	$Y_{n+1} = Y_n + 4 \times \mathrm{Mod}(n, 2)$	+4, 0, +4
8	$X_{n+1} = X_n + 2^{n-1}$	+1, +2, +4	$Y_{n+1} = Y_n$	0, 0, 0
9	$X_{n+1} = X_n + 2^{n-1} \times (-1)^{n+1}$	+1, –2, +4	$Y_{n+1} = Y_n$	0, 0, 0
10	$X_{n+1} = X_n + n$	+1, +2, +3	$Y_{n+1} = \mathrm{Y}_\mathrm{n} + (n) \times (-1)^n$	–1, +2, –3

Note: Numbers represent matrix units (i.e., 1 equals one cell). The + sign represents a rightward "move" on the *X* axis and an upward "move" on the *Y* axis. There are three "moves" in each set before pattern extraction is examined, and they appear 74 in order from left to right.

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Table 2

Means and SDs of RTs (in milliseconds) for the different conditions in Study 4.

		MEAN	**SD**
Implicit	Pattern	514	83
	Control	547	101
	Broken pattern	566	86
Explicit	Pattern	508	62
	Control	511	72
	Broken pattern	519	69