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Is Learning in SRT Tasks Robust Across Procedural Variations?

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Abstract

The Serial Reaction Time (SRT) task has served as a privileged paradigm to study implicit learning processes. In contrast to other paradigms of implicit learning, this task has been commonly used without major variation since its introduction by Nissen and Bullemer (1987), and this raises the issue of the generality and robustness of the conclusions drawn from its exploitation in the face of procedural variations. In the three reported experiments, we show that performance improvement persists when (1) the repeated sequence is surrounded by random sequences, hence making the repeated sequence less salient than in the procedures used to date, (2) the task is performed with a computer mouse rather than with keypresses, hence breaking the one-to-one matching between stimuli and responses and (3), the number of possible locations of the target is extended from 4 to 8 and the possible location of the target is no longer displayed on screen. These results contrast with those of a prior study (Chambaron, Ginhac, Ferrel-Chapus & Perruchet, 2006), in which we showed that learning did not occur in a tracking task involving the continuous movement of a target on screen. We conclude that learning in SRT tasks is robust in the face of important procedural changes, and that further studies are needed to determine the reasons accounting for the learning failure observed in Chambaron et al.

Introduction

The Serial Reaction Time (SRT) task has been heavily used in studies investigating implicit learning. This prominence can be justified by a variety of reasons. For instance, the SRT task is more likely than other tasks to keep learning implicit, due to the fact that participants are never informed about the presence of regularities in the task they perform. Another advantage is that the reliability of the measures collected in SRT tasks is seemingly better than in other implicit learning tasks such as artificial grammars (Salthouse, McGuthry & Hambrick, 1999), and this feature is obviously crucial for studies investigating the preservation of implicit learning abilities in elderly people or in neurologically impaired patients.

However, grounding a large part of a research field on a single task, irrespective of its intrinsic qualities, is also endowed with potential shortcomings. The issue of concern is the generality and the robustness of the conclusions drawn from this task. Regarding the SRT task, the problem is all the more critical as the task has received no major modification since its introduction by Nissen and Bullemer (1987). A target appears in one of four possible locations on a computer screen, and the participants are asked to react to the appearance of the target by pressing as fast as possible a key that spatially matches the location of the target. The next trial is displayed a short interval (around 200 ms) after the participants' response. Unknown to the participants, the same sequence (typically a 12-trial sequence) is continually cycled.

Admittedly, some variants have been explored, such as the introduction of a secondary task (e.g., Stadler, 1995) or the use of probabilistic sequences (e.g., Schvaneveldt & Gomez, 1998). Also, some changes have been incorporated to the original Nissen and Bullemer procedure to improve the control procedures. Nissen and Bullemer compared performances in the repeated sequence to performances in random sequences of trials. It has been noted that this procedure does not allow to assess precisely what participants learn from the repeated sequence. In most recent studies, after several blocks of training a "transfer block" is inserted in which the regular sequence is switched to another sequence, the nature of which is carefully controlled. If RTs are longer for the transfer sequences than for the preceding sequences of training, it can be inferred that participants learned the features on which the training and the transfer sequences differed. However, overall, the variations introduced in the original task appear quite limited. For instance, they are much more restricted than in artificial grammar learning studies, in which different grammars (e.g. finite state vs. biconditional grammars) and different stimuli (consonant letters, tones, target locations, and so on) have been used extensively.

Starting from this observation, our question is the following: Is the frequent claim that SRT tasks are prototypical of a large sample of natural situations involving sequential materials actually warranted? What about the possibility that the conclusions issued from SRT tasks are in fact tightly linked to a very specific experimental setting?

A prior study of our own (Chambaron, Ginhac, Ferrel-Chapus & Perruchet, 2006) indeed suggests that benefiting from the repetition of events may not be as easy as SRT research leads us to believe. In this study, we attempted to replicate prior results in continuous tracking tasks. In Wulf and Schmidt (1997; see also Shea, Wulf, Whitacre, and Park, 2001), participants were asked to track a moving target by acting on a hand-driven lever. The target moved along a horizontal axis, according to the y-value of a polynomial function. The experimental sessions consisted of a succession of trials, with each trial divided into three segments. Typically, the first and the third segment were generated by a function in which the coefficients were randomly drawn on each occasion, hence generating pseudo-random target displacements. The same function served to generate the second segment, but the coefficients were now fixed, and hence, the movement described by the target around the middle of each trial was the same across the whole training session. The tracking accuracy of participants improved only on the repeated segment.

On the face of it, these results suggest that the conclusions drawn from SRT tasks can be easily generalized to fairly different experimental settings. However, Chambaron et al. (2006) found that participants failed to learn the repeated segment in several experiments in which the design of the studies by Wulf and collaborators was followed, except that a different repeated segment was used for each subject in order to ensure a sound control over the idiosyncratic properties of this segment. A plausible explanation for the discrepancy between our results and those of Wulf and collaborators is that most of the experiments by Wulf and collaborators used the same repeated segment, and that the speed of displacement and the acceleration of the target in this segment were found to be lower than in the random segments used to assess the baseline. In support of this hypothesis, we obtained positive results when using this same repeated segment for all participants. Overall, this analysis suggests that much of the evidence for implicit learning in a continuous tracking task could be due to the selection of a repeated segment that is especially easy to track. The consequences for our concern are straightforward: Learning from event repetitions may not be as easy as studies involving SRT tasks seem to suggest.

The present set of experiments is aimed at introducing a few selected variations in an otherwise standard SRT task, in order to circumscribe the conditions which allow learning to occur. In Experiment 1, the salience of the repeated sequence is lowered by introducing a large number of random trials within the training phase. In Experiment 2, a mouse is used instead of the keyboard to break the usual one-to-one correspondence between stimuli and responses and, in Experiment 3, the number of targets is increased. These variations make the procedure closer to that of the continuous tracking tasks. Note also that by increasing the overall complexity of the task, the variations we introduce make it closer to the natural situations of sequential learning, which the SRT paradigm is intended to reproduce.

Experiment 1

In the standard SRT task, the repeated sequence is continuously cycled. Some random trials have been occasionally introduced, either between the repeated sequences (Stadler, 1993; Meulemans, Van Der Linden & Perruchet, 1998) or within the repeated sequence in studies exploring probabilistic learning (Shanks, Channon, Wilkinson, & Curran, in press). However, in these studies, the proportion of random trials is greatly reduced compared to continuous tracking studies, where the ratio of random segments is twice more important than the proportion of repeated segments. It appears important to assess the importance of this feature. Indeed, cycling over the sequence certainly makes the repetition especially easy to discover. If learning turns out to be impossible or even deeply impaired when the signal/noise ratio is lowered, this would be damaging for the generalizability of the conclusions issued from SRT research, because the signal/noise ratio in real world settings is certainly much lower than in SRT studies. In Experiment 1, the repeated sequence is surrounded by random sequences of equal length, as in continuous tracking studies.

Method

Participants Participants were 17 undergraduate students from the University of Burgundy, 15 females and 2 males. All had normal vision and were right-handed. They had no prior experience with the task and were not informed about the purpose of the experiment.

Apparatus and stimuli Stimulus presentation, RT measurement and response recording were all implemented on a PC laptop equipped with a 14 inch-TFT color monitor of 1024 x 768 pixels resolution. Four square boxes (200 pixels x 200 pixels) each indicating a potential stimulus location, were located in a horizontal line in the middle of the computer screen and remained on the screen throughout the session. The target (a blue circle of 100 pixels diameter) appeared in the centre of each square.

Procedure

The participants sat in front of the computer. They were asked to respond as fast as possible to the stimulus appearing at one of four locations on the screen, by pressing the corresponding key ("W", "C", "B" and ",", were the four target locations in the left-to-right order) on a French AZERTY keyboard (which would be "Z", "C", "B", and "M" on a QWERTY keyboard) with the index and middle finger.

The experiment consisted of 8 training blocks, separated by a subject-paced pause. Each block comprised seven 36-trial series. Each series started with a 12-trial random sequence, followed by the 12-trial repeated sequence, after which a new 12-trial random sequence was again presented. On each trial, the target was erased immediately after subject's correct keypress, and the next stimulus was displayed after a response stimulus interval of 200 ms. If the participant made an error, the target remained on the screen until the subject pressed the correct key.

Each 12-trial sequence, whether repeated or random, respected the following criteria: (1) two stimuli never appeared consecutively in the same position, (2) the stimuli occurred an equal number of times in each of the four positions (i.e., each stimulus occurred three times in each of the four locations in a 12-trial sequence). In addition, there was no repetition at the junction between sequences, so that no salient cue marked the change from the random to the repeated sequences and vice-versa. Different random sequences were generated for each block and each subject, and a different repeated sequence was randomly selected for each subject. The total duration of the session was about 30 minutes.

Results

The mean of the RTs for correct responses was computed separately for both the repeated sequences and the random sequences of each block. An analysis of variance (ANOVA) with blocks (8) and sequence (repeated *vs*. random) as repeated measures was performed on these values. There was a main effect of block ($F(7,112)=6.78$; $p<.001$), which reflects the fact that RTs decreased significantly during the training phase. RTs were significantly shorter for the repeated sequence than for the random sequence ($F(1,16)=22.49$; $p<.001$), and there was a significant interaction between block and sequence ($F(7,112)=5.08$; $p<.001$). As shown in Figure 1, this interaction was due to the fact that the difference between repeated and random sequences increased across blocks.

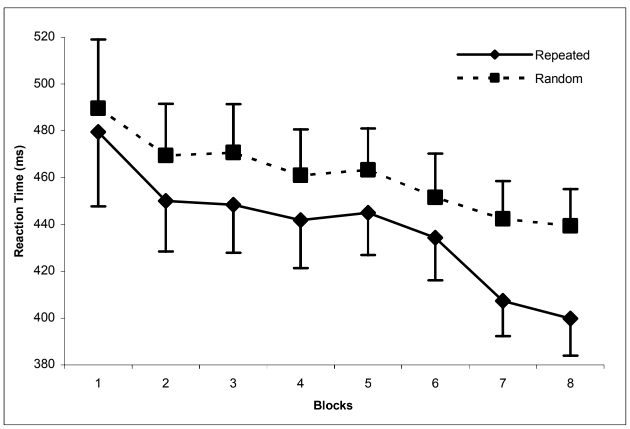

Figure 1: Reaction Time across Training Blocks for repeated and random sequences in Experiment 1. Error bars represent standard deviations.

Furthermore, block-by-block comparisons revealed a significant difference from block 2 onwards between the repeated and the random sequences ($Fs(1,16) = 21.63$; $ps<.000266$). For block 1, the difference was only marginally significant ($F(1,16)= 3.68$, $p= 0.07$. This analysis confirms that learning in SRT tasks appears after a very small amount of practice (Perruchet & Amorim, 1997; Perruchet et al., 1997).

Experiment 2

In SRT tasks, there is a one-to-one correspondence between the location of the target on the screen and the key that participants are asked to press. Thus, it is possible that learning simply proceeds through the formation of a stimulus-response link between the occurrences of the target in a given location and, say, moving the index finger of the left hand. This again may constitute a very specific situation, without any or very few analogs in real-world settings. In Experiment 2, one half of the participants performed the SRT task in this way. However, the other half was asked to move a cursor with a computer mouse, then to click with the mouse when the cursor overlapped the target. This no longer allowed the formation of simple stimulus-response links, since the movement required to reach a given target was a function of the location of the prior target in the sequence. The hypothesis that this change could be detrimental for the occurrence of learning stems from our negative results in continuous tracking tasks (Chambaron et al., 2006), in which there was no direct matching between the location of the target and a specific motor action.

Except for the use of a computer mouse in one group of participants, the sequences and the general design of Experiment 2 were borrowed from Shanks (2003). A 12-trial sequence was repeated through 11 blocks of training. Then participants were shown a block composed of a transfer sequence in which the prior regularities were broken, and the training sequence was again displayed over two additional blocks. Learning was assessed as the difference between the RTs collected in the transfer block and the RTs collected in the surroundings blocks.

Method

Participants Twenty first-year psychology students at the University of Bourgogne (15 females and 5 males) served as participants. All of them were right-hand dominant and had normal vision or vision that had been corrected to normal. They had no prior experience with the task and were not informed about the purpose of the experiment. They were randomly assigned in two groups: "keyboard group" (n=10) and "mouse group" (n=10).

Apparatus and stimuli The material and the stimulus presentation were identical to those of Experiment 1. However, the repeated sequence was now cycled without intervening random trials. The general design of the experiment, including the sequences, was borrowed from Shanks (2003). Specifically, two different sequences, called SOC A and SOC B, were used (SOC A = 1-2-1-3-4-2-3-1-4-3-2-4 and SOC B = 4-2-4-3-1-2-3-4-1-3-2-1). These sequences are structurally similar and are related by the transformation 1↔ 4. In each sequence, each location (1, 2, 3, 4) occurs three times and each possible first-order transition (e.g., 1-2, 1-3, 1-4) occurs once. The sequences differ by the second-order transition rules, hence the acronym SOC, which stands for "Second-Order Conditionals" (Reed & Johnson, 1994).

Procedure

The procedure was the same as the one used by Shanks (2003). The experiment was composed of 14 blocks of 96 trials (i.e., 8*12-trial sequence) during which all participants were exposed to a four-choice serial RT task. The repeated sequence was displayed on Blocks 1-11. On Block 12, the transfer sequence was introduced, then the training sequence was displayed again on Blocks 13-14. For half of the participants, SOC A was the training sequence and SOC B the transfer sequence, and this allocation was reversed for the other half of the participants. On each trial, the target appeared in the centre of one of the four boxes displayed on the screen, and all participants were asked to react as quickly and as accurately as possible. The "keyboard group" received the same instructions as in Experiment 1. The "mouse group" was asked to move the mouse cursor from its current location towards the target, and to click on the mouse when the cursor was inside the box displaying the target. Once the correct response was given, the target was removed and the next stimulus appeared after a 200-ms delay. Response latencies were measured from the onset of the target to the completion of responses (keypress or mouse click).

Results

The dependant variable was the reaction times for the correct responses in both groups. The results are shown in Figure 2. An analysis of variance (ANOVA) was performed on RTs with Group (keyboard *vs.* mouse) and Sequence (SOC A *vs*. SOC B) as between-subject factors, and Blocks as a repeated measures factor. Considering first the main effects, RTs were shorter for the "keyboard group" than for the "mouse group", although this effect was only marginally significant ($F(1,16) = 3.53$; $p=0.073$). The difference can be explained by the fact that the participants assigned to the "mouse group" had to move the mouse to reach the target before clicking on it. There was no significant difference as a function of the allocation of SOC A or SOC B to the study phase and the transfer phase, respectively ($F(1,16) = .79$; $p=.391$). Finally, a significant effect of Blocks was obtained ($F(13,208)=16.38$, $p<.001$): RTs decreased across the training phase (Blocks 1-11), increased on the transfer sequences (Block 12) and decreased again across the last two blocks (Blocks 13-14).

The only significant interaction was between Groups (keyboard *vs.* mouse) and Blocks ($F(13, 208) =2.19$, $p<0.011$). Visual inspection of Figure 2 suggests that this interaction is mainly due to the fact that RTs decreased more quickly in the mouse group than in the keyboard group during the training phase. It is worth stressing that this difference does *not* directly attest for a different exploitation of the repeated sequence. Indeed, the better performance improvement observed in the mouse group may be due to the fact that non specific learning effects were stronger than in the keyboard group (e.g., the mouse gain may have been different from the one participants were familiarized with, and the quick decrease in RTs observed for the mouse group may simply reflect some familiarization with the mouse device).

In order to capture the genuine effect of sequence repetition, we performed a second ANOVA with Group (keyboard *vs.* mouse) as a between-subjects factor and Block as a within-subjects factor. However, the Block factor now contrasted the RTs collected on the transfer block (Block 12) with the RTs averaged over Blocks 10, 11, 13, and 14. The effect of Group again approached the conventional significance criterion $F(1, 18) =4.40$, $p<0.051$. There was also a main effect of Blocks $F(1, 18) =40.75$, $p<0.001$. RTs were significantly higher during the transfer phase, indicating that participants had learned the training sequence. Most importantly, the performances of the two groups evolved in parallel, as attested by the lack of interaction between Groups and Blocks $F(1,18)=0.64$, $p=.434$).

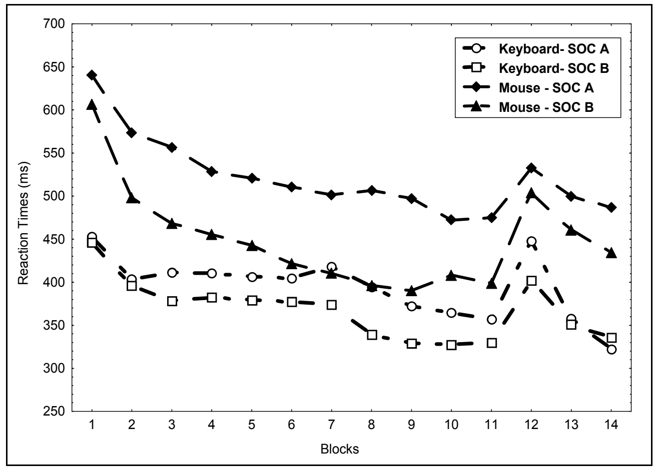

Figure 2: Reaction Time across Training Blocks and Test Block for input devices (keyboard / mouse) and different sequences (SOC A / SOC B) in Experiment 2.

To sum up, participants learned the regularities in the sequence to the same extent when they used the keyboard (with a one-to-one mapping of stimulus location to response selection) and when they used a computer mouse, in which this kind of mapping was no longer possible.

Experiment 3

In most studies using a SRT task, the target can move across four possible locations. This limitation has a straightforward reason: Extending the number of possible positions makes keypressing quite difficult to perform, at least on a standard computer keyboard. However, this limitation also has damaging consequences with regard to the generalizability of the conclusions drawn from SRT studies, because the number of possible events in a world-sized environment is usually much greater. Worthy to note, the possibility of responding with a computer mouse instead of with the keyboard, as attested in the prior experiment, relaxes us from this constraint. The main objective of Experiment 3 was to explore a situation in which the target could move across eight locations instead of four.

This main change was accompanied by several other ones, the general objective of which was to make the task increasingly similar to the continuous tracking task in which we failed to obtain evidence of learning (Chambaron et al., 2006). The target skipped only between adjacent locations, as if it was actually moving throughout an horizontal axis across the screen, and the possible locations of the target were no longer indicated on the screen. Overall, these changes made the task subjectively very different from the standard SRT task. For instance, they prevented the use of a strategy consisting in ascribing a verbal label (e.g., 1, 2, 3, 4, from the left to the right) to the different locations, hence favoring the explicit coding of the repeated sequence. Finally, participants no longer had to click on the computer mouse. They were simply asked to locate the cursor within the target as long as possible. The successive targets appeared at a regular pace, independent from the participants' success at the task. Performances were assessed through the Time on Target instead of reaction times.

Method

Participants Undergraduate students of Psychology (N=20, 16 females and 4 males) participated in this experiment. They had no prior experience with the experimental task and were not aware of the specific purpose of the study. All of them were right-hand dominant and had a normal or corrected vision.

Apparatus and Stimuli The apparatus was identical to the one used in the previous experiments. However, the repeated sequence now comprised 16 trials, and it fulfilled several constraints. First, a target could only appear just on the right or just on the left of the preceding target (i.e. the position 4 was always followed by the positions 3 or 5). This property made the generated sequence more "continuous" than in previous experiments in which a target location could be followed by any of the three other ones. Second, the choice of one among the two possible subsequent locations was random, but a probability of .7 was arbitrarily chosen to privilege the continuity of the target displacement (i.e the sequence 2-3-4 was followed by 5 in 70% of the cases, and by 3 in 30% of the cases). This constraint avoided to cause too large a number of small movements. Thirdly, among the sequences generated according to the previous two criteria, only those in which 6 locations from the 8 possible ones occurred at least once were used in the experiment.

For instance, the sequence S = 3- 4- 5- 6- 5- 4- 3- 2- 3- 2- 1- 2- 1- 2- 3- 4 respects the three preceding criteria. Note that this sequence is not balanced for location frequency, unlike the SOC sequences used in Experiment 2. For example, Location 2 occurs four times, Location 5 occurs two times and Location 8 never occurs in the sequence above. If the transfer sequence used to assess learning covered different locations, an eventual difference in performance between the two sequences could be attributed to the learning of frequency distribution, instead of reflecting sequential knowledge. To avoid this shortcoming, the transfer sequence was generated by permutating the training sequence. For instance, the transfer sequence corresponding to the training sequence above is T = 1- 2- 3- 4- 5- 6- 5- 4- 3- 2- 1- 2- 3- 4- 2- 3. Note that, as a consequence of its generation mode, transfer sequences also met the three criteria used to build the training sequences. However, it remains possible that a transfer sequence was easier (or harder) to track than the training sequence from which it was derived. To prevent any bias, a different couple of sequences was generated for each participant.

Procedure

Participants were presented with 14 blocks comprising 88 trials each. Within each block, a 16-trial sequence was repeated five times, and four random targets were added at the beginning and at the end of the block in order to make repetition less salient. During Blocks 1-11, the target followed the repeating sequence. The transfer sequence was displayed in Block 12, and the training sequence was displayed again in Blocks 13-14, as in Experiment 2.

The procedure differed from that of Experiment 2 by the following aspects: (1) The target could appear at one of eight locations on the screen instead of four locations; (2) the possible locations were no longer displayed on the screen throughout the session and, (3) the target remained displayed on the screen for 600 ms before the appearance of the next target, irrespective of the participants' responses. Participants were asked to locate the cursor within the target as long as possible.

Results

As shown in Figure 3, the mean Times on target (TOTs) for the training blocks (Blocks 1-11) increased, and performance dropped on the transfer block (Block 12), before increasing again when the training sequence was reintroduced (Blocks 13-14). An ANOVA performed with Blocks (14) as a repeated measures factor revealed a main effect of Blocks ($F(13, 247) = 17.91$, $p<0.001$).

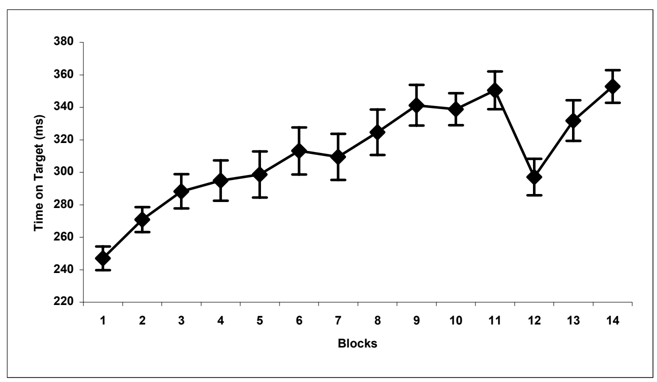

Figure 3: Time on Target across Training Blocks and Test Block in Experiment 3. Error bars represent standard deviations.

A second ANOVA was aimed at comparing the TOTs collected on the transfer sequences (Block 12) and the TOTs collected on the four surrounding blocks (Blocks 10, 11, 13 and 14). The main effect of Blocks was significant ($F(1, 19) = 42.52$, $p<0.001$), hence indicating that participants learned the regularities in the repeated sequences.

Conclusion

The three reported experiments show that learning in SRT tasks is remarkably robust in the face of important procedural changes. In Experiment 1, learning occurred despite the fact that the repeated sequence was surrounded by two random sequences, making the signal / noise ratio much lower than in the standard SRT task. In Experiment 2, the SRT task was performed either with a keyboard, as usually, or with a computer mouse. Using a computer mouse breaks the one-to-one matching between stimuli and responses that exists with the keypressing method. The results showed that learning did not differ as a function of the input devices. In experiment 3, the number of possible locations was extended from 4 to 8, and other changes were introduced regarding the nature and the presentation of the sequences. As with the standard procedure, we observed a significant impairment in performance on a final transfer block, indicating that participants have learned at least some regularities embedded in the repeated sequence.

As indicated in the introduction, this series of studies was mainly motivated by the striking contrast between on the one hand, the claim that the SRT paradigm is representative of a large sample of natural situations involving sequential material, and on the other hand, the high level of standardization of the paradigm. Inserting a large amount of noise in Exp. 1, breaking the one-to-one correspondence between stimuli and responses in Exp. 2 and increasing the number of possible events in Exp. 3, lead us to make the experimental situations more similar to real world tasks involving sequential behavior, such as learning to drive a car, learning to play a musical instrument, and more generally, operating a device. Our results are clearcut: the precise experimental conditions and parameters involved in the standard task are in no way a necessary prerequisite for learning to occur. This conclusion allows us to be optimistic regarding the generalizability of the huge number of past studies that relied on the standard SRT paradigm. Note, however, that this conclusion needs to be somewhat toned down by our prior failure to get evidence of learning in continuous tracking situations (Chambaron et al., 2006). Discovering the reasons for this failure requires further investigations.

Beyond their implication for past studies, the reported experiments also provide a source of new ideas for future research. For instance, the methodology used in our first experiment offers the opportunity to measure learning across the whole training phase, whereas learning is only measured at the end of training in the standard paradigm. Our results reveal that learning appears after a very small amount of practice and confirm prior results (Perruchet & Amorim, 1992; Perruchet, Bigand & Benoit-Gonnin, 1997).

Moreover, the possibility of using a computer mouse instead of keypresses (Experiment 2), which makes it feasible to increase the number of possible events (Experiment 3), should make it possible to explore a number of issues that stood out of reach with the standard procedure. For instance, the target may be located anywhere in a two-dimensional space. Overall, these possibilities open to a large array of manipulations regarding the statistical structure of the repeated sequence.

Acknowledgments

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