Running title: Implicit learning in continuous tracking

Refining the continuous tracking paradigm to investigate implicit motor learning

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Abstract

In two experiments we investigated factors that undermine conclusions about implicit motor learning in the continuous tracking paradigm. In Experiment 1, we constructed a practice phase in which all three segments of the waveform pattern were random, in order to examine whether tracking performance decreased as a consequence of time spent on task. Tracking error was lower in the first segment than in the middle segment and lower in the middle segment than in the final segment, indicating that tracking performance decreased as a function of increasing time-on-task. In Experiment 2, the waveform pattern presented in the middle segment was identical in each trial of practice. In a retention test, tracking performance on the repeated segment was superior to tracking performance on the random segments of the waveform. Furthermore, substitution of the repeated pattern with a random pattern (in a transfer test) resulted in significantly increased tracking error. These findings imply that characteristics of the repeated pattern were learned. Crucially, tests of pattern recognition implied that participants were not explicitly aware of the presence of a recurring segment of waveform. Recommendations for refining the continuous tracking paradigm for implicit learning research are proposed.

Keywords: Implicit learning; Continuous tracking task; Complexity control; Time-on-task effect;

Introduction

Implicit learning is defined as "the acquisition of knowledge that takes place largely independently of conscious attempts to learn and largely in the absence of explicit knowledge about what was acquired" (Reber, 1967, p.5). The continuous tracking task paradigm has been used to investigate implicit learning of motor tasks (e.g., Pew, 1974; Wulf & Schmidt, 1997). In a typical continuous tracking task, participants use a hand-driven device to track a target moving horizontally in a waveform pattern across a computer screen. The target waveform in each trial consists of three segments of equal duration generated by a sine-cosine series function. Participants are unaware that while the coefficients of the function for the first and the third segments are randomly generated and different in each tracking trial (random segments), the coefficients of the function for the second (middle) segment remain constant throughout practice (repeated segment). Increases in tracking performance with practice are normally evident for all segments of the waveform pattern, suggesting that generalized motor components of the tracking task are learned; however, compared to performance on the random segments, tracking performance on the repeated segment is improved, suggesting that characteristics of the waveform pattern are learned. Typically, participants are unaware that a segment of the waveform repeats and are unable to identify the repeated pattern when asked, causing researchers to conclude that learning is implicit (e.g., Pew, 1974; Wulf & Schmidt, 1997).

Claims that the continuous tracking task paradigm can cause implicit learning have recently been questioned, however, on the grounds that improved tracking of the repeated pattern may have occurred because the repeated segment was less complex than the random segments. Chambaron, Ginhac, Ferrel-Chapus, and Perruchet (2006) argued that the repeated segment originally used by Wulf and Schmidt (1997), and subsequently by others (e.g., Boyd & Winstein, 2004; Shea, Wulf, Whitacre, & Park, 2001), may have been easier to track than the random segments. Wulf and Schmidt (1997) tried to control for complexity by randomly selecting coefficients for their waveform pattern from a sine-cosine series function within a specified value range. They then ensured that the coefficients for the non-repeated random waveform patterns were within the same value range. Participants demonstrated better tracking performance for the repeated waveform pattern. However, Chambaron et al (2006) computed the mean velocity and the mean acceleration of 10,000 randomly generated segments using the constraints imposed by Wulf and Schmidt and showed that more than 80% of the randomly generated segments were harder to track than the repeated segment. Inadvertently, Wulf and Schmidt may have selected a repeated waveform pattern that was easier to track than most randomly generated waveform patterns. To substantiate whether learning a repeated waveform pattern could still occur when the between-segment tracking complexity was controlled for, Chambaron et al. replicated Wulf and Schmidt (1997), but had each participant track a different repeated waveform pattern. They found that tracking of the repeated pattern was no more accurate than for the random patterns (see also van Ooteghem, Frank, Allard, Buchanan, Oates, & Horak, 2008). It was only when Chambaron et al. reintroduced

Wulf and Schmidt's original repeated waveform pattern that tracking performance became superior. These findings led Chambaron et al. to question whether repeated tracking of a waveform pattern results in implicit learning of that pattern. However, Chambaron et al. did not examine whether tracking of the repeated pattern was more accurate than tracking of the random patterns in a delayed retention test.

A second methodological issue associated with the continuous tracking task paradigm was observed by Sekiya (2006), who found that participants consistently displayed better tracking performance on the first random segment of the waveform than on the second random segment. Sekiya postulated that degraded concentration across a tracking trial might explain this finding. Pew (1974) also noted poorer tracking of the second random segment, but could not fully account for the differences. Since both Pew (1974) and Sekiya (2006) did not provide evidence that between-segment tracking complexity was controlled in their studies, it is possible that any performance difference between the two random segments was caused by between-segment differences in tracking complexity.

In two experiments, we attempt to confirm and resolve methodological issues associated with the continuous tracking task paradigm and evaluate the feasibility of using the paradigm to investigate implicit learning.

EXPERIMENT 1

In the first experiment we sought to verify whether tracking performance declines during the course of a tracking trial. A standard continuous tracking paradigm was used, but a random segment was inserted in place of the repeated waveform pattern (i.e., a different series of three random waveform patterns was followed on every tracking trial). Furthermore, we implemented measures to control for between-segment complexity of the waveform patterns. A stepwise decrease in tracking performance on each segment would be consistent with previous findings (Pew, 1974; Sekiya, 2006) and suggest that time-on-task warrants consideration when employing the continuous tracking paradigm.

Method

Participants

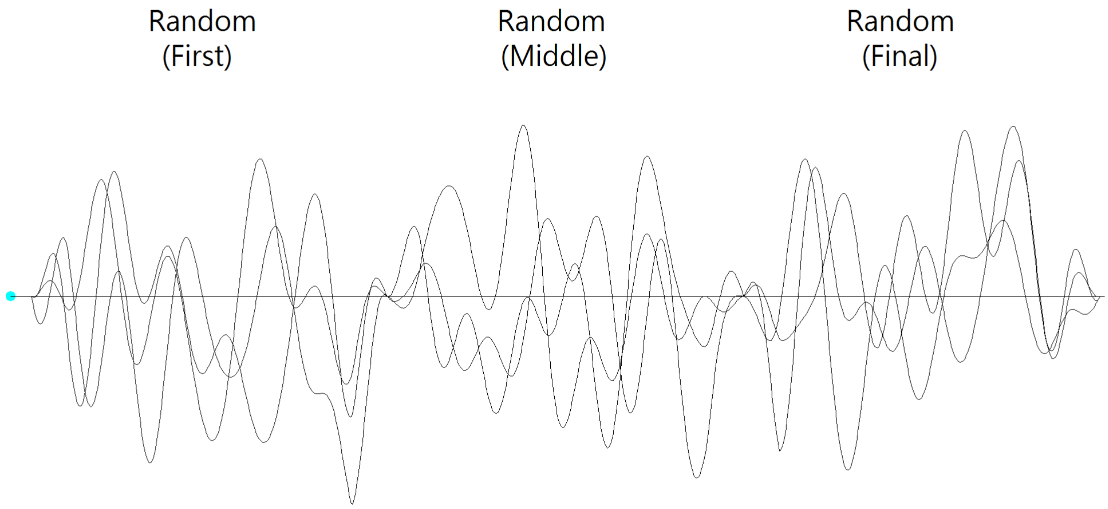
Twenty-eight right-handed university students (*M* age = 21.1, *SD* = 1.94, 11 male and 17 female) with normal or corrected-to-normal vision volunteered to participate. No participant had prior experience of the task. All participants provided their informed consent and were paid an honorarium for participation (approximately US$10). Additionally, in order to maintain motivation, participants received a bonus payment (approximately US$15) for performances that ranked in the top 20%.

Task

Participants sat in front of a 17-in. LCD monitor with 1280 x 1024 pixel resolution at a viewing distance of about 1 meter. In their right hand, participants held a pen that by use of an Intuos3 pen tablet (Wacom, JP) controlled the position of a cross-haired white cursor displayed on the monitor. The pen tablet was calibrated so that the ratio of pen movement on the tablet to cursor movement on the monitor was exactly 1:1. The task was to track a target (a red dot) moving horizontally in a sinusoidal pattern.

A custom Java program (Sun Microsystems, USA) was designed to generate the waveform, control the segment complexity, present the target, and record both the target and cursor locations at a sampling rate of 32 Hz for analysis.

Figure 1



The target waveform consisted of three segments of equal duration generated by a sine-cosine series of the general form:

$$\alpha_i = b_0 + a_1 \sin\theta_i + b_1 \cos\theta_i + a_2 \sin2\theta_i + b_2 \cos2\theta_i + a_3 \sin3\theta_i + b_3 \cos3\theta_i$$

$$+ a_4 \sin4\theta_i + b_4 \cos4\theta_i + a_5 \sin5\theta_i + b_5 \cos5\theta_i + a_6 \sin6\theta_i + b_6 \cos6\theta_i$$

where $\theta_i = i * 2.14\pi / (time * freq)$, with *time* representing the segment duration (i.e., 17.14 sec) and *freq* representing the sampling rate (i.e., 32 Hz). A smooth transition between segments was created by transforming the first 15% and last 15% of each segment so that each segment started and ended at ‘0’. Thus, waveform complexity and tracking performance were evaluated on only the middle 70% of each segment (i.e., 12 sec duration and 1.5π period). The coefficients for the three random waveform pattern segments were randomly generated and different for every participant on each trial, but followed two criteria in order to attempt to control for complexity: (a) coefficients were numbers within the range of ± 5, and (b) there was no more than 1% difference between the mean velocity of the waveform patterns of the three segments when the coefficients were run through our experimental set-up[1].

Procedure

Participants were informed that they would see a red dot (the target) moving horizontally from left to right across the monitor and that their task was to track the dot with the cursor using a tablet-pen. Participants were instructed to track the dot as accurately as possible and were informed of the importance of task improvement. In order to familiarize participants with the task, 4 warm-up trials were completed, in which all three segments were random patterns. Practice consisted of 8 blocks of 4 trials (i.e., 32 trials). A 1 minute rest interval was provided between blocks.

Dependent measures

Participants' ability to track the target waveform with the movement of the cursor was calculated for each of the three segments as root mean square error (*RMSE*) in screen pixels, which was averaged across trials per block as the dependent measure of tracking performance. Two-way ANOVA with repeated measures was used in the statistical analysis of dependent measures. Greenhouse-Geisser adjustments were applied if Mauchley's test showed that assumptions of sphericity failed. Bonferroni

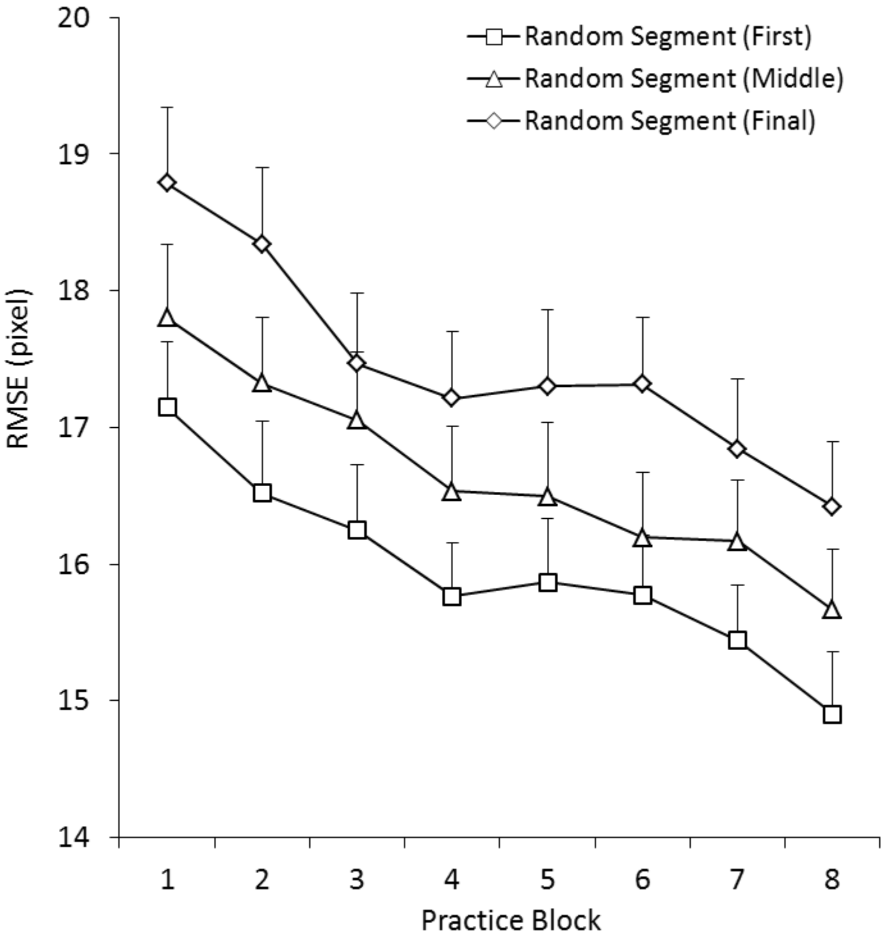
[1] Post-hoc analyses of mean segment velocity and of mean segment acceleration showed no significant between-segment effects, suggesting that complexity among the three random segments was appropriately controlled for.

adjustments were made to *p* values for multiple comparisons.

Results

Tracking performance (*RMSE*) during practice was assessed by computing a 3 (Segment) x 8 (Block) ANOVA with repeated measures. A main effect of Block was evident, $F(3.70, 99.83) = 19.76$, $p < .001$. As illustrated in Figure 2, *RMSE* in all three segments decreased across the practice phase, suggesting a general improvement in tracking with practice. A main effect of Segment was also evident, $F(2, 54) = 54.50$, $p < .001$, with *RMSE* in Segment 1 significantly lower than in Segment 2 ($p < .001$), and *RMSE* in Segment 2 significantly lower than in Segment 3 ($p < .001$). No Segment x Block interaction was shown, $F(14, 378) = .74$, $p = .730$.

Figure 2



Observation of Figure 2 suggests that the time-on-task effect was roughly linear (i.e., performance on the second segment is approximately halfway between the first and final segments). To confirm this observation, we conducted an analysis to compare tracking performance on the middle segment (M = 16.654, SE = .451) to a computed average of tracking performance on the first and final segments (M = 16.709, SE = .444). A 2 (Segment) x 8 (Block) ANOVA with repeated measures of performance during practice showed no significant effect of Segment, $F(1, 27) = .30$, $p = .586$, and no Segment x Block interaction, $F(7, 189) = .841$, $p = .555$. This analysis suggests that the time-on-task effect is more or less linear.

Discussion

Previous findings have reported that tracking performance declines across a continuous tracking task trial (Pew, 1974; Sekiya, 2006). This experiment provides clear evidence to support this observation. Participants tracked a waveform pattern comprised of 3 different (random) segments on every trial. A learning effect was evident, suggesting that a general improvement in participants' tracking capabilities occurred. More significantly, tracking performance was consistently poorer on the final segment of the waveform compared to the middle segment and in turn on the middle segment compared to the first segment. This stepwise decrease in tracking performance as the tracking trial progressed was evident from the very onset of practice (see Figure 2).

The major implication of this finding is that between-segment comparisons to verify learning of a repeated waveform pattern, commonly employed in the literature (e.g., Chambaron et al., 2006; Wulf & Schmidt, 1997), may be confounded by a time-on-task effect. Researchers must be careful, therefore, to design continuous tracking paradigms that guard against such an effect. The standard method of assessing learning of the repeated waveform pattern is to compare tracking performance on the repeated segment (i.e., middle segment) with averaged tracking performance of two random segments (i.e., first and final segments, e.g., Chambaron et al., 2006; Wulf & Schmidt, 1997). Averaging tracking performance on the first and final segments seemingly controls for performance degradation across a trial, but this assumes that this degradation is linearly related to time on task. The findings of Experiment 1 add a degree of support to this assertion, and the use of this approach. To be certain that the time-on-task effect is negated, however, one solution is to construct a waveform pattern with just two segments, one repeated and one random, and counterbalance the order of presentation of the segments across practice trials (e.g., Vidoni & Boyd, 2008 & 2009; Vidoni, McCarley, Edwards, & Boyd, 2009). Another solution is to verify learning not by conducting within-trial performance comparisons, but by introducing a transfer test in which the repeated pattern embedded in the middle segment of the waveform throughout practice is replaced by a random pattern (such that the trial comprises three random segments) and conducting between-trial performance comparisons. Poorer tracking performance on the middle segment in the transfer test would provide evidence that characteristics of the repeated waveform pattern have been learned. Since the repeated pattern tracked throughout practice and the random pattern tracked only in the transfer test are presented in the same time window of the trial (i.e., middle segment), this approach overcomes the possible confound of a time-on-task effect. Such an approach is analogous to that used in the serial reaction time task paradigm to assess (implicit) learning of finger tapping sequences (e.g., Destrebecqz & Cleeremans, 2001; Reed & Johnson, 1994; Shanks & Johnstone, 1999).

EXPERIMENT 2

In Experiment 2, we sought to clarify whether implicit learning of a repeated waveform pattern can occur using the continuous tracking paradigm. Rather than all participants tracking a common waveform pattern throughout practice, we selected 15 waveform patterns from the pool of 3108 random waveform patterns generated for Experiment 1[2], and randomly assigned a different pattern to each participant. This approach guarded against the possibility of selecting a pattern for all participants to learn, which contained a quirk that made more identifiable or easier to track. Following practice, we introduced a test phase on a second day that comprised a retention test, which included the repeated pattern, and a transfer test, which did not (as we recommended in Experiment 1). Superior tracking performance in the retention test of the repeated segment compared to the mean tracking performance on the first and final random segments, and decreased tracking performance on the middle (random) segment of the transfer test compared to the middle (repeated) segment of the retention test, were both taken as evidence of learning. To indicate whether learning of the repeated waveform pattern was implicit, awareness of the existence and configuration of the repeated pattern was examined by a series of recognition tests (see Wulf & Schmidt, 1997).

Method

Participants

Fifteen right-handed university students (*M* age = 22.73, *SD* = 3.67, 7 male and 8 female) with normal or corrected-to-normal vision volunteered to participate. No

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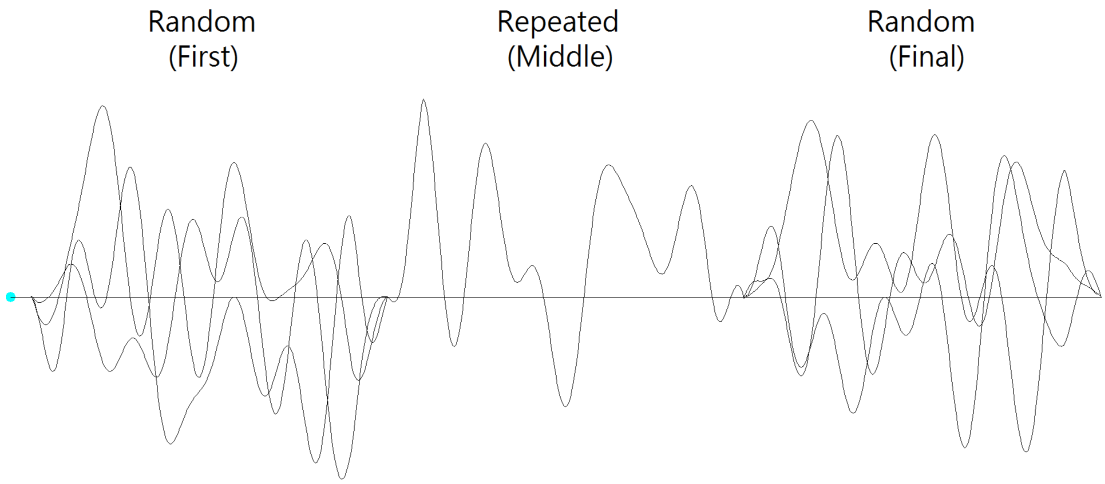
[2] Both the mean velocity and the mean acceleration of the 15 waveform patterns selected were within 0.1x standard deviations of both the averaged mean velocity and the averaged mean acceleration of the 3108 random waveform patterns generated for Experiment 1.

participant had prior experience of the task. Payment and the manipulation to maintain motivation were identical to Experiment 1. All participants provided informed consent.

Task, procedure, and dependent measures

Figure 3



The task and procedure were identical to Experiment 1 with three exceptions. First, the middle segment of the waveform was a pattern that repeated on each trial of practice and it differed for each participant[3]. Second, to guard against the performance degradation across a trial (as revealed in Experiment 1), we compared tracking performance on the middle segment with averaged tracking performance on the first and final segments. Third, tracking performance following practice was examined in both a delayed retention test and a delayed transfer test on a second day, the order of

[3] Again, post-hoc analyses of mean segment velocity and of mean segment acceleration showed no significant between-segment effects, suggesting that complexity among the three random segments was appropriately controlled for.

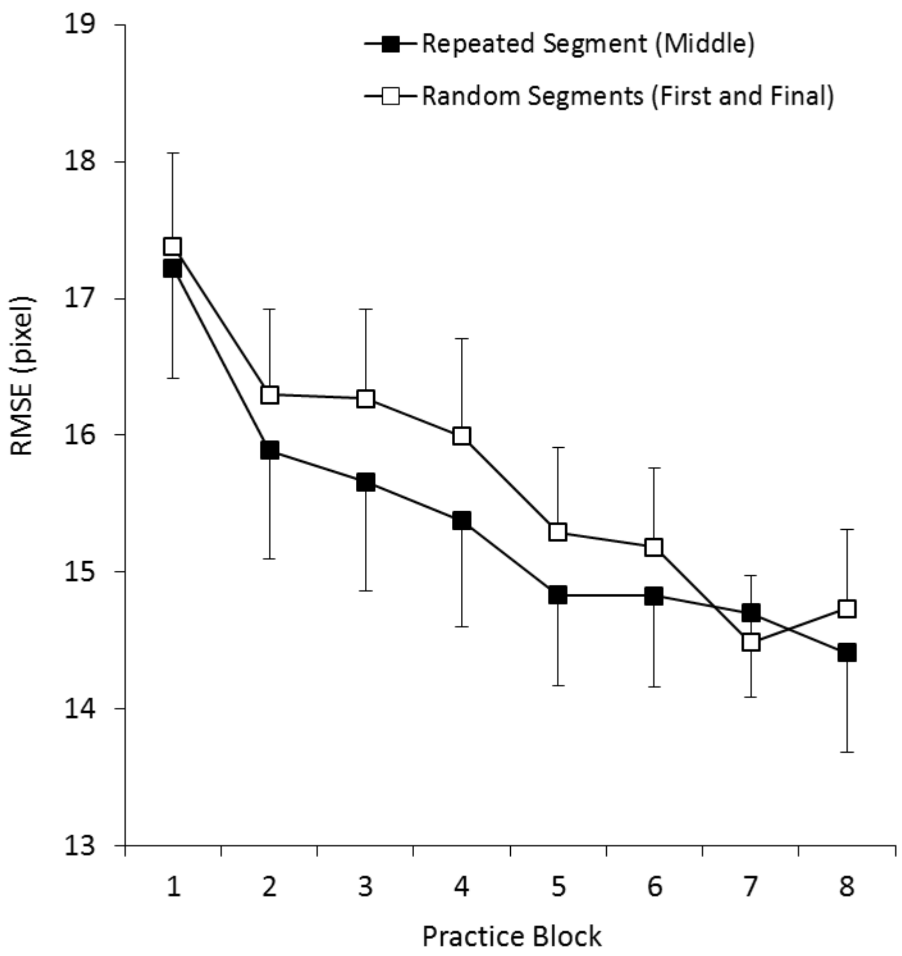
which was counterbalanced. In the transfer test, the repeated waveform pattern was replaced by a previously unpracticed random waveform pattern, such that each segment of the four transfer-test trials was random. Fourth, after the experiment, participants completed a series of recognition tests to ascertain whether the repeated segment had been detected and whether characteristics of the repeated waveform could be identified. Participants were first asked if they had noticed anything in particular about the tracking pattern and then if they had noticed repetition of any part of the waveform pattern. Participants were informed that one third of the waveform was in fact repeated on every trial and were asked to try to identify the pattern by selecting a segment of waveform from a selection of six printed on a sheet of paper. One segment represented the repeated pattern, whereas the other five segments were generated randomly and had not appeared in previous trials. Finally, in a second forced-choice recognition test, participants watched one trial of the tracking task. The location of the repeated waveform (e.g., first, middle or final segment) was random for each participant. Participants were asked to indicate the position of the repeated waveform following the trial. Dependent measures were identical to Experiment 1.

Results

Performance

Tracking performance (*RMSE)* on the middle repeated segment and the averaged tracking performance of the two random segments during practice were analyzed by a 2 (Segment) x 8 (Block) ANOVA with repeated measures. A main effect of Block was evident, $F(3.38, 47.27) = 23.45$, $p < .001$. As illustrated in Figure 4, *RMSE* on both repeated and random segments decreased across the practice phase, suggesting general improvements in tracking. However, neither a main effect of Segment, $F(1, 14) = 1.97$, $p = .182$, nor a Segment x Block interaction, $F(7, 98) = 1.23$, $p = .291$, was evident.

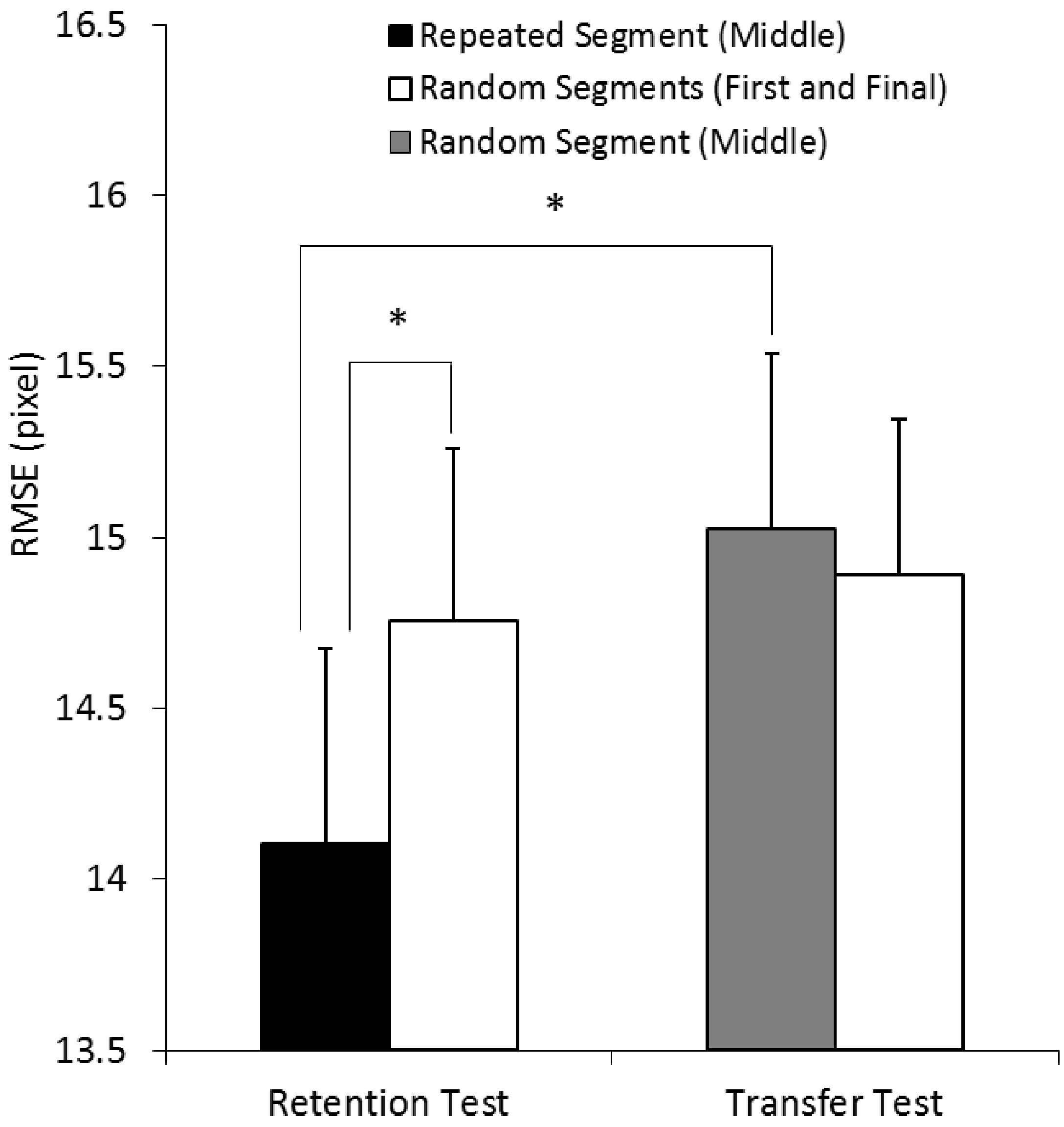
Figure 4



Tracking performance (*RMSE)* in the retention test and the transfer test for each segment was analyzed by a 2 (Segment) x 2 (Test) ANOVA with repeated measures. A main effect of Test, $F(1, 14) = 14.34$, $p < .01$, was evident and the main effect of

Segment, $F(1, 14) = 3.86$, $p = .07$, approached significance. Crucially, a significant Segment x Test interaction effect, $F(1, 14) = 4.75$, $p < .05$, was evident. Further analysis confirmed that the increase in *RMSE* when the repeated waveform pattern in the retention test was replaced by a random waveform pattern in the transfer-test (see Figure 5) was significant ($p < .01$). In contrast, *RMSE* associated with the random segments in the retention test and the (first and final) random segments in the transfer test was not significantly different ($p = .314$). Furthermore, in the retention test the *RMSE* of the repeated (middle) segment was significantly lower than the *RMSE* of the random segments ($p < .05$), whereas, in the transfer test *RMSE* of the now random middle segment was not significantly different from the mean *RMSE* of the other two random segments ($p = .524$).

Figure 5



Recognition Tests

No participant commented on a particular aspect of the tracking pattern or reported awareness of a repeated waveform pattern within a tracking trial. In the first forced-choice recognition test, only 1 of the 15 participants correctly selected the repeated waveform from the six waveforms printed on the sheet. In the second forced-choice recognition test, 5 of the 15 participants correctly identified the segment position of the repeated waveform, consistent with chance level performance. None of these five had correctly identified the repeated segment in the first forced-choice recognition test.

Discussion

The continuous tracking task paradigm was investigated to determine whether characteristics of a waveform pattern that, unbeknown to participants, repeated on every trial of practice, could be learned and whether the learning was implicit. To overcome the confounding step-wise influence of the time-on-task effect shown in Experiment 1, tracking performance on the first and final segments of the waveform was averaged for comparison to the repeated middle segment of the waveform and a transfer test was introduced, in which a previously unseen segment of waveform was inserted in place of the repeated waveform. In the retention test, tracking performance on the repeated segment was superior to tracking performance on the random segments. Furthermore, substitution of the repeated pattern with a random pattern in the transfer test increased tracking error on the middle segment. These findings imply that characteristics of the reported pattern were learned. Analysis of both the mean velocity and the mean acceleration of the waveforms suggested that between-segment complexity was appropriately controlled for.

In keeping with notions that sleep consolidates motor learning (Siengsukon & Boyd, 2009a; Siengsukon & Boyd, 2009b), trends towards superior tracking performance on the repeated segment during the practice phase did not become significant until the delayed retention test on a second day. This highlights the methodological importance of delayed retention tests to quantify the true extent of motor learning. Finally, tests of pattern recognition suggested that participants were not consciously aware of the presence of a repeated waveform pattern and could not reliably identify characteristics of the pattern.

GENERAL DISCUSSION

In two experiments, we examined the validity of the continuous tracking task paradigm for investigating implicit learning. The reliability of findings from previous work that has used the paradigm have been questioned due to uncertainties about the control of complexity across the repeated waveform pattern and the random patterns with which tracking performance is compared (Chambaron et al., 2006). In this study, the generation of waveform patterns was controlled by stipulating a tighter range of coefficient values and of mean velocity, which in turn controlled for acceleration. Furthermore, in Experiment 2 each participant was assigned a different, strictly controlled, waveform pattern to guard against the possibility of participants learning a pattern with idiosyncrasies that made it easier (or harder) to track, or more recognizable.

A second issue associated with the paradigm is that tracking performance decreases as a function of time on task (e.g., Pew, 1974; Sekiya, 2006), which may contribute to discrepancies in findings reported in the literature. Experiment 1 provides clear evidence of a time-on-task effect. Two possible explanations for the effect are mental fatigue or boredom; however, one would expect these factors to have a cumulative effect that results in larger between-segment discrepancies towards the end of apractice session. This was not the case. An alternative explanation, proposed by Sekiya (2006), is that concentration degrades as each trial progresses. It is beyond the scope of the current study to verify whether concentration or attention changes as a consequence of time-on-task. Electroencephalography (EEG) methodology has identified theta power at the frontal cortex region as a marker of attention control and has increasingly been used as a means to evaluate temporal changes in cortical activity in motor control tasks (e.g., Baumeister, Reinecke, Schubert, Schade, & Weiss, 2012; Doppelmayr, Finkenzeller, & Sauseng, 2008; Zhu, Maxwell, Hu et al., 2010). Zhu, Poolton, Wilson, Hu, Maxwell, and Masters (2011a) employed EEG methodology in a three segment continuous tracking task, but unfortunately did not specifically analyze theta power at the frontal region. Future use of EEG may help unpick the cortical activity changes that underlie the time-on-task effect. A different explanation for the time-on-task effect is that blink rate increased across a trial, causing participants to miss information that was necessary for accurate tracking. In this experiment, participants were required to track the target for 51 seconds in each trial. Blinking may have become more frequent in the second and third parts of each trail as a consequence of drying of the ocular surface (e.g., Acosta, Gallar, & Belmonte, 1999). If this was the case, a simple measure of blink rate should positively correlate with tracking error.

Although the underlying cause of the time-on-task effect is unclear, it should be considered when designing experiments using the continuous tracking task paradigm. Experiment 1 suggested that the time-on-task effect was linear across segments, so in Experiment 2 we adopted the method of averaging the tracking performance of the first and final (random) segments (see Chambaron et al., 2006; Wulf & Schmidt, 1997) to control for performance degradation across a trial. The ensuing comparison of tracking performance on the repeated segment with that on the random segments in the retention test showed superior tracking performance on the repeated segment; suggesting that elements of the repeated waveform had been learned. To further control for the time-on-task effect, we took the additional step of including a transfer test alongside the retention test, in which the repeated segment was replaced by a previously unseen (random) segment of waveform. This manipulation resulted in lower tracking performance, providing further support for the notion that the continuous tracking paradigm allows specific characteristics of a repeated waveform pattern to be learned.

As a gauge of participants' explicit knowledge about the repeated waveform, a protocol of generic questioning and forced-choice recognition tests was included, in keeping with previous work (e.g., Wulf & Schmidt, 1997). Overall, there was minimal explicit awareness of the existence of a repeated waveform or of the configuration of the pattern. There has been much debate about the credibility of such recognition tests when evaluating the implicit or explicit make-up of the knowledge supporting improvements in tracking performance (Perruchet, Chambaron, & Ferrel-Chapus, 2003; Shanks & Johnstone, 1999). Informed identification of the repeated pattern may require explicit knowledge of the entire segment of waveform (Perruchet et al., 2003); however, increased tracking performance may only require explicit knowledge of distinct characteristics or certain chunks of the waveform pattern. Whether explicit knowledge of these characteristics was available to participants cannot be ascertained fully from the recognition tests that were used. Future work using the continuous tracking task paradigm should find alternative means by which to verify the processes that underlie learning of waveform characteristics.

The measure of cortical activity by EEG methodology may provide insight in this regard. As an informative index of the involvement of explicit processes in motor control and learning, Hatfield and his colleagues recommend an analysis of the degree of linear relatedness or 'co-activation' between the left temporal brain region (T3), associated with verbal-analytical activity (Haufler, Spalding, Santa Maria, & Hatfield, 2000; Kerick, McDowell, Hung, Santa Maria, Spalding, & Hatfiled, 2001), and the frontal midline region (Fz), associated with motor planning, in the alpha frequency bandwidth. Low T3-Fz coherence is thought to reflect less dependence on explicit processes for motor performance (see Deeny, Hillman, Janelle, & Hatfield, 2003; Zhu, Poolton, Wilson, Maxwell, & Masters, 2011b). As such, expert marksmen displayed lower EEG T3-Fz coherence than less skilled shooters (Deeny et al., 2003) and novice golfers who used an implicit motor learning paradigm (Masters, 1992; Maxwell, Masters, Kerr, & Weedon, 2001) displayed lower EEG T3-Fz coherence than more explicit learners (Zhu et al., 2011b). In a recent study that modified the continuous tracking task paradigm for laparoscopic surgical skills training, T3-Fz alpha power coherence was greater when participants were made aware of the repeated waveform pattern compared to when participants were not, suggesting that T3-Fz alpha power coherence reflects the use of explicit knowledge of characteristics of the pattern to support tracking performance (Zhu et al., 2011a). In the current study, higher T3-Fz coherence in the repeated middle segment compared to previously unseen random segments would be expected if explicit knowledge about the pattern of the waveform was used.

This study of the continuous tracking task for implicit learning research leads to a number of recommendations for the appropriate use of the paradigm. First, measures should be taken to control between-segment waveform complexity, particularly segment velocity and acceleration. Having each participant track a different repeated waveform pattern, as suggested by Chambaron et al. (2006), can further reduce the chance that the repeated segment is less complex than random segments due to some idiosyncratic characteristic of the selected pattern. Second, the time-on-task effect should be taken into account when searching for evidence of learning. One solution is to compare the tracking performance on the repeated segment with the averaged tracking performance of the two random segments. Another is to include a transfer test in which the repeated segment is replaced by a random segment. Third, the retention test should be conducted on a second day to allow offline consolidation of learning to occur. Last, better ways of evaluating the knowledge that underlies learning of characteristics of the repeated waveform pattern need to be implemented. Neurophysiological measures may provide objective insight in this regard. Adherence to these recommendations should increase the reliability of findings from the continuous tracking task paradigm and will enhance confidence in the paradigm's use as a tool with which to investigate implicit learning.

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