Timing Precision in Circle Drawing Does Not Depend on Spatial Precision of the Timing Target

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ABSTRACT. The authors manipulated the width of a timing target in continuous circle drawing to determine whether a more stringent spatial-timing criterion would produce an increase in participants’ \( N = 30 \) temporal variability. They also examined the effect of the computational method of determining cycle duration. There was no effect of spatial precision on temporal variability in circle drawing, and tapping and circle drawing were found to use the same criterion. Those findings lend strong support to the earlier view of R. B. Ivry, R. M. Spencer, H. N. Zelaznik, and J. Diedrichsen (2002), who argued that continuous tasks such as circle drawing are timed differently from discrete-like tasks such as tapping. Therefore, the results of the present study provide support for the event and emergent timing frameworks.

Key words: emergent timing, event timing, motor control, timing

Investigators have studied repetitive timing tasks to understand the nature of timing control in general (Michon, 1967). Repetitive tapping, in particular, has been the preparation of choice in those studies (Rosenbaum & Collyer, 1998; Wing & Kristofferson, 1973a, 1973b). The tapping task is very easy to instrument. Performers do not require much practice to reach a stable level of performance (Wing, 1980). Finally, it allows for very nice comparisons across experiments done in different laboratories. The unstated reason why tapping has been so well studied concerns the belief that timing processes, to a great extent, can be shared by a variety of motor tasks. In other words, timing can be viewed as an elementary process; timing is sometimes referred to as a timing ability (Keele & Hawkins, 1982). Thus, when a researcher is studying timing processes in tapping, he or she is, in fact, examining timing in general.

Several lines of evidence support such a view. First, Keele and Hawkins (1982; Keele & Ivry, 1987) have clearly shown that individual differences in several timing tasks are correlated with tapping. Individual differences in timing precision on a tapping task predict individual differences in timing perception as well as individual differences in timing precision when tapping is performed with different effectors than the index finger. Franz, Zelaznik, and Smith (1992) have extended those findings. They found that individual differences in timing precision in finger tapping and jaw timing were correlated.

A different approach is to examine whether the relationship between the timed interval and the variance of that timed interval—a Weber fraction—is equivalent for different tasks. Ivry and Hazeltine (1995) and Ivry and Corcos (1993) have termed that approach the slope analysis. Ivry and Hazeltine demonstrated that the Weber slopes for tapping and for temporal perception precision were equivalent. Green, Ivry, and Woodruff-Pak (1999) demonstrated that the Weber slopes for timing in eye-blink conditioning were equal to that of tapping. Equivalent Weber slope values have been interpreted as an indication that those tasks share a common duration-dependent timing process.

Recently, Zelaznik and colleagues have challenged the ubiquity of general-purpose timing. Robertson et al. (1999) used an individual difference approach along with a Weber slope approach. Across three studies, they demonstrated that individual differences in timing precision in tapping and in circle drawing were not correlated. Furthermore, in Experiment 3, the Weber slopes for tapping and circle drawing were examined and were found to be different for the two tasks. Robertson et al., on the basis of the converging evidence of those three experiments, proposed that the timing processes in tapping capture a timing process that differs from those in continuous circle drawing.
Spencer, Zelaznik, Diedrichsen, and Ivry (2003) provided neurological evidence in support of the behavioral work. In those experiments, they found that patients with unilateral cerebellar lesions were impaired in the tapping task when they performed with their impaired hand, but the unimpaired hand, which was controlled by the unaffected cerebellar hemisphere, was timed normally. When those participants performed the circle-drawing task, however, each hand performed equally well and was unimpaired. Given the substantial evidence that the cerebellum acts as a timer (for a review, see Ivry, Spencer, Zelaznik, & Diedrichsen, 2002), the dissociation discovered by Spencer et al. provided strong evidence for separable timing systems.

Ivry et al. (2002), Spencer et al. (2003), and Zelaznik, Spencer, and Ivry (2002) have proposed that tasks with salient events, such as tapping, require a temporal representation, with a strong cerebellar involvement. That type of salient events, such as tapping, require a temporal representation, with a strong cerebellar involvement. That type of timing is called *event timing*. Event timing is not used for timing in the continuous circle-drawing task; it is believed instead that timing is not controlled directly in that task. Rather, timing is a by-product of the control of the dynamical aspects of the circle-drawing task. Borrowing from the seminal article of Turvey (1977), such timing is called *emergent timing*.

Although the corpus of work generated by our group has produced a very consistent set of results, we wanted to examine a rather straightforward concern that potentially can weaken support for the idea that timing in tapping and in circle drawing use those different timing processes. The concern has to do with the actual nature of the timing goals and with the method of scoring a cycle in the two tasks.

In the repetitive tapping task, the participant attempts to touch the tabletop coincident with the appearance of the metronome beat and to then continue at that rate when the metronome beat disengages during the continuation portion of the trial. In other words, the repetitive tapping task involves timing to a spatial location. In the repetitive circle-drawing task developed by our group, the participant is provided with a circle that is normally 5 to 10 cm in diameter. At the top (farthest away from participants in the anteroposterior dimension), a target circle is centered along the circumference of the drawn circle. The target circle is often 1 cm in diameter. Participants are instructed that being on time means that their drawing pencil is “inside” the target timing circle coincident with the metronome beat. In the circle-drawing task, participants appear to have a less stringent spatial-precision requirement on timing than they do in the tapping task. Thus, variability in timing in tapping may result from participants’ making adjustments on the basis of the very precise spatial demand of timing to a particular place, whereas in circle drawing, participants have to time to a particular area. One of the findings of our work has been that circle-drawing timing exhibits a smaller variance than that of tapping timing. Perhaps that effect is a consequence of the relaxed spatial demands on timing in the circle-drawing task.

It is well known that spatial-precision demands will affect temporal precision, and vice versa. Zelaznik, Mone, McCabe, and Thaman (1988) showed that temporal precision requirements in aimed hand movements affect the nature of the movement speed–accuracy tradeoff. Hancock and Newell (1985) have argued that spatial and temporal accuracy are different sides of the same process and that their effects are interactive. Thus, it is reasonable to evaluate whether the different spatial demands in circle drawing compared with tapping may be the driving force behind the timing differences observed over many experiments conducted in our laboratory.

In addition to that theoretical issue, there is an additional data-scoring issue that has theoretical importance. In previous tapping experiments, Spencer and Zelaznik (2003) and Zelaznik et al. (2002) used a criterion for determining the beginning and the end of the cycle that was based on when the finger movement had approached zero velocity in the z dimension. That criterion seems appropriate because the finger slows down considerably upon touching the tabletop. We used the same type of criterion in the present study to determine cycle onsets in circle drawing. We used the motion of the pencil in the anteroposterior dimension (what has been called the y motion in the previously mentioned articles) to determine when the pencil was about to reverse direction; the same low-velocity criterion was used. Therefore, the circle-timing criterion was independent from the location of the timing target. It is quite possible that in circle drawing, a participant could in fact reverse direction when the pencil is outside of the timing target. In other words, Spencer and Zelaznik’s previously used definition of a cycle in circle drawing did not capture participants’ instructed goal because they had not determined the time that the pencil was in the timing target zone. In tapping, the measure of cycle duration captures participants’ timing goal. Given the strong claims that have been made about the comparison between timing processes in discrete and in continuous drawing tasks (see Robertson et al., 1999; Spencer et al.; Zelaznik et al.), it is important to evaluate whether the differences in timing behavior between tapping and circle drawing depend on differences in cycle definition and in spatial-timing requirements.

Thus, in the present experiment, we examined the two aforementioned issues. First, what is the effect of the size of the timing target on temporal precision in circle drawing? Second, what is the comparison between the effects of (a) scoring the circle-drawing task by defining a cycle on the basis of when the pencil reaches a particular location and (b) scoring it on the basis of a movement reversal in the anteroposterior dimension? Although it is also of interest whether event-timing tasks such as tapping are influenced by spatial-precision demands, at this point we were more interested in whether timing in circle drawing would be immune to spatial effects. Spencer and Zelaznik (2003) have previously demonstrated that temporal precision in circle drawing was equivalent for cycle duration, as
defined by the time of peak velocity and the time of zero velocity (reversal point). However, the effects of spatial-precision demands on timing accuracy have not yet been examined. If the timing variabilities of circle-drawing tasks to narrow targets and to wide targets exhibit different temporal variability (with the same overall circle radius for the drawing tasks), then the ideas about event and emergent timing would be seriously questioned. Therefore, we first tackled the role of spatial precision in an emergent-timing task: circle drawing.

Participants performed a repetitive tapping task with a 500-ms temporal goal. The same participants also performed three different circle-drawing tasks with a 5-cm-diameter circle. The diameter of the circle did not change, but in each version of the circle-drawing task, the timing target was a rectangle 1 cm in length. We manipulated the width of the rectangle; the widths were 1.0, 0.5, and 0.2 cm. The manipulation is similar to maintaining movement distance but changing target width in a Fitts’s law task. If, in fact, the spatial-timing target affects timing variability in circle drawing, we would expect that timing variability would increase in the narrow-target condition compared with that in the wide-target condition. Furthermore, we scored the circle-drawing task by using two methods. First, we used Spencer and Zelaznik’s (2003) technique of finding the reversal (based on the low-velocity criterion) in the anteroposterior dimension. Second, we determined when the pencil crossed the center of the width of the timing target.

Therefore, this experiment allowed us to examine (a) whether spatial precision matters for temporal precision in circle drawing and (b) whether adopting a scoring criterion based on location produces the same timing variance as in tapping. We decided at this time not to manipulate spatial precision in tapping. Tapping has been the traditional task used in studying timing. We have challenged the ubiquity of that idea. Thus, we first wanted to determine whether circle-drawing timing precision is volatile and is influenced by task manipulations. Such a finding would seriously weaken our theoretical stance concerning event and emergent timing. That concern was the driving reason for this study.

Method

Participants

Thirty undergraduate students, all right-handed, served as research participants. All received course credit in introductory psychology. The procedures used in this experiment as well as all informed consent requirements were approved by the Purdue University Institutional Review Board.

Apparatus

The apparatus for finger tapping involved an Ascension Technologies (Burlington, VT) miniBIRD marker affixed to the nail of the index finger of the right hand. The apparatus for circle drawing consisted of a Mars-Staedtler 2H wooden drawing pencil, with the graphite exposed. The graphite was unsharpened. A miniBIRD marker was affixed to the pencil about 1 cm from the tip. Participants sat on a wooden chair, 47 cm from the floor. The tapping and drawing took place on a 79-cm-high wooden desk. Centered on the desk was a 21.5- × 13.5-cm section of a 3M transparency sheet in which the 5-cm circle and the timing target along the circumference of the 5-cm circle were printed. The timing target was placed at the top of the circle (at 12 o’clock), farthest away from participants. The timing target was rectangular. The rectangle, depending on the condition, was 1.0, 0.5, or 0.2 cm in width. The height of the rectangle always was 1.0 cm. Regardless of the size of the timing target, the diameter of the circle in the circle-drawing task was 5 cm. In Figure 1, the orientation of the circle-drawing task relative to participants is displayed.

The metronome signal (1600 Hz, 10-ms-duration tone) was presented through a set of Sennheiser HDC 451 noise-canceling headphones.

FIGURE 1. Schematic depiction of circle-drawing task. The stick figure arm shows where participants attempted to pass the pencil through coincident with the metronome beat. All circles were 5 cm in diameter.
Tasks

Repetitive tapping with the index finger and continuous circle drawing were the two tasks. In the tapping task, participants, while seated throughout the study, rested the heel of the hand on the desktop; formed a bridge with their thumb, middle, ring, and little fingers; and stretched out the index finger so that it was parallel to the tabletop. The task required that the tip of the index finger touch the tabletop coincident with the beat of the metronome. After synchronization, participants attempted to maintain the metronome rate by tapping as accurately and as consistently as possible.

Three versions of continuous circle drawing were used. In the wide circle condition, we used the 1-cm-timing target width; in medium circle drawing, the 0.5-cm target width; and in narrow circle drawing, the 0.2-cm target width. In each of those versions, participants attempted to have their pencil point within the timing target when the metronome beat sounded and to continue that behavior when the metronome disengaged during the continuation portion of the trial. The circle-drawing movement consisted of a multijoint movement of the elbow and shoulder. We instructed participants to fix the wrist so that they would not use finger rotation and wrist rotation to draw the circle. We have used those instructions in our previous circle-drawing timing studies.

A trial consisted of a synchronization phase of 13 metronome beats followed by a continuation phase that allowed for an additional 34 cycles. The metronome period was 500 ms, which included a 10-ms-duration 1600-Hz tone followed by a 490-ms dead interval.

Procedure

After participants received instructions and provided informed consent, testing began. For tapping, a trial began when participants placed their index finger parallel to the desktop. Two seconds later, the metronome engaged. Participants began to tap in synchrony with the metronome. They continued to tap when the metronome disengaged until we presented a long duration (500-ms-duration 3200-Hz) tone. Participants held the index finger in the parallel position for about 500 ms, and we then instructed them to relax their hand during the 20-s intertrial interval and to let the hand rest on the tabletop.

For circle drawing, a trial began when participants placed the pencil tip in the timing target area. Two seconds later, the metronome engaged, and participants began to draw circles continuously so that the pencil tip was in the timing target. Participants continued to draw circles when the metronome disengaged. On hearing the end-of-trial tone, participants were instructed they should end their last circle within the timing target and hold it there for about one-half second.

The laboratory computer running the miniBIRD kinematic system computed the average cycle duration for that trial. If the average cycle duration was less than 450 ms or greater than 550 ms, we informed participants and reminded them to speed up or slow down as necessary. For all participants, that information was not required after the first trial of any task was completed.

Each task was performed for a set of 12 trials. We randomized the order of tasks for each participant. There was a 1- to 2-min break between each task.

Data Collection and Reduction

We sampled three-dimensional kinematic data from the miniBIRD marker on the pencil and on the right index finger at 140 Hz. Offline, we up-sampled those signals by a factor of 7, using the Interp routine in MATLAB (The MathWorks, Natick, MA), thus producing an effective sampling rate of 980 Hz (almost 1-ms precision). We filtered the resampled data forward and backward with a 30-Hz low-pass Butterworth filter. We recalculated cycle duration offline for analysis.

We defined a cycle in circle drawing by two different criteria. For the first criterion, we used numerical routines that were used in other studies from our laboratory. First, on a cycle-by-cycle basis, we determined the maximum velocity of the pencil in the anteroposterior axis, moving toward the timing target. We then determined the first point that was 3% of that value or less. Thus, we defined a cycle as the interval of time between successive 3% determined points. We used the same algorithm for tapping. We determined the maximum downward velocity, and we then found the first point that was 3% of that value. We used the same method for determining cycle duration in tapping and circle drawing so that measurement error in the Ascension Technologies Flock of Birds system (on the order of 1 mm) would not differentially affect our computations. We chose the 3% criterion to simulate when the finger touched down on the tabletop. The Flock of Birds receiver sits on the nail of the index finger; therefore, we could not use an absolute location criterion because the small changes in finger orientation and in fingertip compression make the use of a location criterion problematic. The 3% of maximum velocity criterion, we have found, is an excellent substitution for a fixed location.

We used an additional algorithm for circle drawing based on the pencil’s being at a particular location. The center of the timing target lies along the y-axis of the circle template. Thus, we searched for the two kinematic samples that straddled that point and took the sample right after (or on the line, in a rare case) as the definition of a cycle. That measure allows the circle-drawing task to mimic the tapping task. Because participants are not constrained to touch a particular location along the tabletop, the 3% criterion described in the previous paragraph is really a substitute for the point of reversal. However, the critical issue was whether the circle-drawing task, when measured with a criterion similar to that used in tapping (timing to a location), would produce evidence that circle drawing and tapping use similar, and thus shareable, timing processes.
Results

We blocked the 12 trials in each task into two sets of 6 trials. We computed the intervals that were used in determining average cycle duration, as well as the coefficient of variation (within-trial standard deviation in interval duration divided by the mean interval and converted to a percentage scale) on the continuation intervals two cycles after the metronome disengaged.

The average cycle duration is presented in Table 1. As can be seen, participants, on average, produced the required interval duration for each of the tasks and in each block. Statistical analyses showed no effects of block or task and no interaction between the two (all $F$s < 1).

<table>
<thead>
<tr>
<th>Task</th>
<th>Trials 1–6</th>
<th>Trials 7–12</th>
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</thead>
<tbody>
<tr>
<td>Tapping</td>
<td>503.9</td>
<td>504.4</td>
</tr>
<tr>
<td>Circle drawing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrow</td>
<td>504.7</td>
<td>506.6</td>
</tr>
<tr>
<td>Medium</td>
<td>501.0</td>
<td>504.5</td>
</tr>
<tr>
<td>Wide</td>
<td>502.8</td>
<td>504.0</td>
</tr>
</tbody>
</table>

The coefficient of variation results for tapping and the two different cycle criteria methods are depicted for the first six trials (left panel) and the last six trials (right panel) in Figure 2. We conducted two analyses: In the first analysis, we used the velocity criterion method; in the second, we compared the low-velocity and the location methods only for the circle-drawing tasks.

Examination of Figure 2 shows that tapping produced a greater coefficient of variation than circle drawing did. The effect of task was significant, $F(3, 87) = 32.10, p < .001$. Post hoc analyses (Scheffé) revealed that variability was greater in tapping than in each of the three circle-drawing conditions. There was no effect of the size of the timing target on the coefficient of variation. The values were 3.5%, 3.5%, and 3.4% for the narrow-, medium-, and wide-target conditions, respectively. There was no effect of trial block, $F(1, 29) < 1$, and no interaction between task and trial block, $F(3, 87) < 1$.

The dashed line in each of the panels depicts the coefficient of variation for the three circle-drawing tasks for the timing-to-a-location measure. For circle drawing, we compared the two methods of scoring. First, it is clear that there were no effects of temporal target width, no effect of block, and no interactions between any of those factors. The triple interaction between task, block, and method of scoring did not approach significance, $F(2, 58) = 1.51, p = .23$. There was a clear effect of method of scoring, $F(1, 29) = 38.09, p < .001$. The velocity criterion for determining a cycle had a coefficient of variation value of 3.5%, and the timing-to-a-location method exhibited a coefficient of variation value of 3.9%.

Individual Difference Correlations

On the basis of the coefficient of variation computed by the low-velocity method for each participant within each of the four conditions, we used the best six trials. Reliability for each of the tasks was greater than .88. The correlations for the individual differences in coefficient of variation for tapping and for the three circle-drawing tasks are presented in Table 2. Please note that for the circle-drawing tasks, the coefficient of variation computed with each method has been included in the correlation matrix.

First, it is very clear that tapping variability and circle-drawing variability were not correlated. With 30 participants, the critical value of $r$ at the $p < .05$ level was .37. Thus, regardless of the method of scoring, tapping and circle-drawing temporal variabilities were not correlated. Second, within circle drawing, the correlations generally were significant, suggesting a common timing strategy that influences temporal variability.

Discussion

It has been hypothesized and demonstrated that in circle drawing, performers do not have to privilege their timing to any particular place in the circle (Spencer & Zelaznik, 2003). Even though there is a target timing area along the circle’s circumference, performers accomplish the task by timing the entire circle trajectory equally well (Spencer & Zelaznik). The results of the current experiment, along with that of Spencer and Zelaznik, further support the idea that in circle drawing, participants are not timing to any particular place in the trajectory. In other words, circle drawing does not have any salient events that a representational timing system could use. That notion is consistent with Ivry...
and Corcos’s (1993) views of emergent timing for circle-drawing tasks: The spatial width of the temporal timing target should have no effect on timing variability. Such was the case here. That finding adds important converging evidence to the event versus emergent distinction proposed by Ivry and colleagues (Ivry et al., 2002; Spencer et al., 2003; Zelaznik et al., 2002). On the other hand, the place where the finger touches down (captured by the 3% velocity method) in the tapping task possesses the smallest variability relative to other aspects of the tapping cycle (Spencer & Zelaznik). The variability there is less because touching down on the tabletop provides a salient event that participants can use as a temporal representation to time.

The 3% criterion that we used to determine cycle duration is very similar to searching for reversal of direction along the dimension of motion in question. Of course, participants can, in fact, reverse direction when they are not in the timing target. Thus, it was possible that the reason for the difference in timing variability between circle drawing and tapping stemmed from the different criteria for determining temporal precision. Because the finger-tapping task occurs primarily in one dimension, the time of touch down is virtually the same as when the finger has slowed down to the 3% criterion.

The timing-to-a-location criterion for circle drawing also showed no effect of the timing target’s width. That finding supports the hypothesis that it does not matter how, or when, a cycle is defined. There was a small increase in the coefficient of variation for the timing-to-a-location measure. The increase is easily explained. The performer is not drawing a circle with a fixed diameter and, more important, with a fixed center. There is clear variability in the center of circles during circle drawing (Zelaznik & Lantero, 1996). Therefore, given that the timing to a fixed location is being measured, if the center shifts away from the timing target, then the duration for that circle will increase; of course, if the center shifts toward the timing target, then the duration will decrease. Thus, the very small increase in the coefficient of variation was the result of a small degree of variability in the center of the circle during the circle-drawing task; the 3% criterion was not affected by that fact.

Finally, the lack of correlated individual differences in timing precision between tapping and circle drawing for each method of scoring cycle duration in circle drawing removes a potential criticism of the earlier work of Zelaznik, Spencer, Ivry, and their colleagues (Robertson et al., 1999; Spencer & Zelaznik, 2003; Spencer et al., 2003; Zelaznik et al., 2002). The absence of correlation between tapping and circle drawing resulted from the fundamental difference that tapping possesses salient events that use a temporal representation, whereas circle drawing does not.

In summary, this very simple experiment clearly provides support for our idea that tapping and circle drawing draw on different timing processes. Circle-drawing timing was unaffected by the spatial demands on timing and was unaffected (to a great extent) by the method of scoring.

NOTES

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REFERENCES


TABLE 2. Individual Difference Correlations for Coefficient of Variation for the Best Six Trials (Least Coefficient of Variation): Comparison Between Velocity and Location Methods for Computing Cycle Duration

<table>
<thead>
<tr>
<th></th>
<th>Circle drawing</th>
<th>Location method</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Velocity method</td>
<td>Location method</td>
</tr>
<tr>
<td>CIR narrow</td>
<td>.11</td>
<td>.59</td>
</tr>
<tr>
<td>CIR medium</td>
<td>.21</td>
<td>.46</td>
</tr>
<tr>
<td>CIR wide</td>
<td>−.01</td>
<td>.49</td>
</tr>
<tr>
<td>Tapping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIR narrow</td>
<td>.70</td>
<td>.59</td>
</tr>
<tr>
<td>CIR medium</td>
<td>.43</td>
<td>.46</td>
</tr>
<tr>
<td>CIR wide</td>
<td>.38</td>
<td>.49</td>
</tr>
</tbody>
</table>

Note: CIR narrow, medium, and wide refer, respectively, to the narrow, medium, and wide circle-drawing tasks.

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