BRIEF REPORT

Chronometry of Mentally Versus Physically Practiced Tasks in People With Stroke

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KEY WORDS
- imagery (psychotherapy)
- practice (psychology)
- stroke
- task performance and analysis
- time and motion studies

OBJECTIVE. The purpose of this study was to determine whether chronometry is appropriate for monitoring engagement in mental practice by comparing the time taken for people with chronic stroke to mentally and physically practice five tasks.

METHOD. Eighteen stroke participants mentally and physically rehearsed each task. Time was recorded for each of the three trials per task.

RESULTS. Participants required significantly more time to physically practice than to mentally practice tasks (all \( p < .05 \)). A significantly greater amount of time for mental practice of the more-affected arm than for the less-affected arm was also observed (\( p < .01 \)).

CONCLUSION. Because there was no agreement between the time taken to mentally and physically practice the tasks, chronometry does not appear to be valid for monitoring mental practice in this population.


Mental practice (MP) is a noninvasive technique in which physical tasks, scenarios, or both are cognitively rehearsed, usually without voluntary physical movements. The same musculature is activated during MP as during physical practice (PP) of the same task (Bakker, Boschker, & Chung, 1996; Hale, 1982; Livesay & Samaras, 1998; Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998). Neuroimaging studies have also revealed that identical neural structures subserve physical and imagined movements (Lacourse, Turner, Randolph-Orr, Schandler, & Cohen, 2004; Lafleur et al., 2002; Mellet et al., 1998). Because muscular and neural activations are observed during MP, repeated MP can allow for a practice effect to occur. Consequently, MP has been effectively applied as an adjunct practice strategy to PP in exercise and sport settings (for a review, see Martin, Moritz, & Hall, 1999) and in a variety of rehabilitative settings (Fairweather & Sidaway, 1993; Fansler, Poff, & Shepard, 1985; Linden, Uhley, Smith, & Bush, 1989; Sidaway & Trzaska, 2005; Williams, Odley, & Callaghan, 2004).

MP has also been used as an adjunctive strategy to PP after stroke. Its addition to PP causes increased affected arm use (Page, Levine, & Leonard, 2005), kinematics (Hewett, Ford, Levine, & Page, 2007), and function in patients with stroke (Crosbie, McDonough, Gilmore, & Wiggam, 2004; Dijkerman, Ietswaart, Johnston, & MacWalter, 2004; Page, 2000; Page, Levine, Sisto, & Johnston, 2001a, 2001b), including those in a randomized controlled trial (Page, Levine, & Leonard, 2007). However, a barrier to MP clinical implementation is assurance that patients are actually engaged in MP of the intended activities. Neuroimaging (Lacourse et al., 2004) and autonomic monitoring (Guillot & Collet, 2005a) offer scientifically validated solutions to this challenge but are impractical in most clinical environments.

An easily implemented method of monitoring MP engagement is mental chronometry, in which the time taken to...
plan for and execute movements is determined. Specifically, the time taken to imagine a movement is compared with the time taken to physically perform the same movement. Constraints such as task complexity and time can alter the duration of mental imagery, leading to under- or overestimation. Given that durations of highly automatic movements are comparable in healthy participants (Papaxanthis, Pozzo, Skoura, & Schieppati, 2002; Papaxanthis, Schieppati, Gentili, & Pozzo, 2002) and that the speed-accuracy trade-off (i.e., Fitt’s Law) is maintained during MP (Decety & Jeannerod, 1995), chronometry presents a plausible monitoring strategy in clinical situations with people who have had a stroke. Studies enrolling participants without disability have shown that the time that participants take to mentally practice movements is similar to that taken to physically perform the same movements (Decety, Jeannerod, & Prablanc, 1989). Mental chronometry has also been applied to stroke, but the small number of patients limits potential inferences (Malouin, Richards, Desrosiers, & Doyon, 2004; Sirigu et al., 1995, 1996). In this study, we examined whether this effect also holds true for participants with stroke who mentally and physically practice movements with their arms.

To our knowledge, MP chronometry has not been applied to examine the timing of imagined versus actual arm movements in people with stroke. In this study, we determined the degree of agreement between times taken for people with chronic stroke to mentally and physically practice a set of five tasks. We proposed three hypotheses: (1) Participants would take less time to complete tasks in the MP trial; (2) participants would be more likely to succeed in completing the tasks in the MP trial; and (3) the efficacy (in terms of time taken) of MP intervention might be varied by different types of stroke.

**Method**

We used a cross-sectional study design to investigate the association between mentally and physically practiced tasks in people with stroke.

**Participant Selection**

Participants were recruited using advertisements placed in therapy clinics and given to therapists. A research team member screened volunteers using the following inclusion criteria, which were based on previous studies (Crosbie et al., 2004; Dijkerman et al., 2004; Page, 2000; Page et al., 2001a, 2001b, 2007), prompting our decision to use it as a baseline measure of motor impairment in this study.

**Procedures**

MP is more efficacious when participants rehearse movements with which they have previous experience (Mulder, Zijlstra, Zijlstra, & Hochstenbach, 2004; Mutsaarts, Steenbergen, & Bekkering, 2006). To control for prior experience, all participants received identical amounts and sequencing of the following five tasks as part of their participation in PP and MP trials: (1) reaching for and grasping a cup, (2) turning a page in a book, (3) using a hairbrush or comb, (4) proper use a writing utensil, and (5) proper use of an eating utensil. As part of this trial, participants had been scheduled to return to this laboratory 6 months after completing the trial’s intervention phase. Procedures for this study had been included in the consenting process for the MP trial, and all participants gave informed consent in accordance with the local Institutional Review Board.

**PP Trial.** On arriving at the laboratory, each participant was escorted to a quiet room and seated at a table, where a research assistant reminded him or her of the procedures. Participants were then reoriented to the study tasks (approximately 5 min), which consisted of laying out the objects used during each movement and reminding the participant of how he or she had previously physically rehearsed its use. Each task was presented approximately 15.2 cm from the edge of the table and involved predetermined components, for example, for reaching for a cup: reaching for the handle, grasping the handle, and then bringing the cup toward the mouth.

On the command “ready, go” participants physically attempted each task 3 times, first with the less-affected arm and then with the more-affected arm. A 1-min rest break was provided after each attempt; a 3-min rest break was provided between the last attempt of one task and the first attempt of the next new task in sequence. The research assistant recorded each timed trial in seconds (to the hundredths), using a standard stopwatch. The participants were
allotted 120 s to complete each trial. After attempting all of the physical tasks 3 times with each arm, each participant was given a 10-min rest break.

**MP Trial.** After the break, participants were again seated at the table. The participants were then reminded of the practice in which they had engaged during the PP trial, reminded of the current chronometry trial objectives, and told that they were now going to mentally rehearse each task. The sequencing and duration of the MP attempts and rest breaks were the same as for PP. All the tasks were cognitively rehearsed 3 times with each arm. Participants were instructed to mentally rehearse tasks in their current physical status. Again, on the “ready, go” command, participants mentally attempted each movement 3 times.

They were instructed to indicate completion of the cognitive rehearsal with a verbal “done” or by raising their less-affected arm. The research assistant recorded each timed trial, as with the PP, on the participant’s indication of completion.

We decided that all participants would first physically perform the tasks and then mentally perform them because this ordering mimicked how PP and MP were presented in participants’ previous experiences. That is, during the trial in which they had participated, participants underwent occupational therapy of the study tasks; then, after a short rest break, they mentally rehearsed them.

All data were maintained in accordance with the local institutional review board. Each participant’s files were de-identified and separated from his or her consent forms. Files were stored in a locked filing cabinet, and only approved study personnel were granted access.

### Data Analyses

Numerical variables were summarized using means ± standard error, medians (ranges), or both; categorical variables were summarized by frequency in percentage. The primary analysis assessed the association of time taken (or time to complete a task, in seconds) on the more-affected arm only (PP and MP trials), with consideration of stroke types (ischemic and hemorrhagic stroke) and tasks. Hence, we applied a mixed-effect model in the analysis, using the numerical variable of time taken as the dependent variable, the trial and its interactions with stroke type and the task as major fixed effects of interest, and patient’s demographics and impairment levels (FM) as controlling covariates. A random effect (i.e., the participants) was introduced in the model to account for within-participant correlation caused by repeated observations of two trials. We performed post hoc comparisons of means
of time taken between trials for each stroke type and each task under the mixed effect model framework. The Bonferroni method was used to adjust for overall Type I error when multiple comparisons of means were involved. In the secondary analysis, we used a similar mixed-effect model to compare time taken between more-affected and less-affected arms in the MP trial. The fixed effect of interest was the arm (more-affected and less-affected arms) and its interaction with the task. Finally, to compare the rates of successfully completing a task in PP and MP, we used McNemar’s (1947) test in each task on the more-affected arm only. All analyses were performed using SAS 9.1 software (SAS, Cary, NC). We considered $p < .05$ statistically significant.

### Results

Using the aforementioned criteria, 18 participants were included (7 women and 11 men); median age = 61.5, range = 35–74; median time since stroke = 50.0 months, range = 15–215. Participant demographics and baseline information are provided in Table 1.

Means of time taken using the more-affected arm to complete tasks are summarized in Table 2. For this analysis, significant $p < .01$ do not support our primary hypothesis of highly similar times between the PP and MP trials. For all participants, time taken to complete PP trial tasks ranged from 7.5 to 11.3 s. For MP trial tasks, time taken ranged from 3.8 to 7.1 s, significantly shorter than in the PP trial ($p < .01$). Although patients with hemorrhagic stroke took longer to complete tasks in the PP trial, they showed significant reductions in time taken for Tasks 3–5 during the MP trial ($p < .01$). By contrast, patients with ischemic stroke did not show differences between times required to mentally and physically practice four of the five tasks.

When comparing more-affected and less-affected arms in the MP trial, we found that a significantly greater amount of time was taken to mentally rehearse each of the tasks with the more-affected arm than with the less-affected arm (Table 3). The average time taken was 3.7–7.2 s for the more-affected arm compared with 1.7–1.9 s for the less-affected arm ($p < .01$).

In the PP trial, only 8 participants (44%) completed all tasks successfully. Those in MP trial showed an 89% completion rate, which is much improved from the PP trial ($p < .01$). When looking at each task individually, Tasks 1, 2, and 5 were the least difficult, with completion rates $\geq$94% in both trials (MP and PP). Demonstrating proper use of a writing utensil was, however, most difficult in the PP trial, with a completion rate of 50%. This rate was 89% in the MP trial ($p < .01$; Table 4).

### Discussion

On the basis of this study’s results, participants required a significantly larger amount of time to physically practice the tasks than to mentally rehearse the same tasks. This finding did not confirm the primary study hypothesis. Because no study has examined this phenomenon for tasks involving the more-affected arm, no standard of comparison is available. However, one possible explanation for this outcome is that this study involved a series of complex, multistep tasks—tasks requiring a significant degree of coordination, precision, and timing of the more-affected arm.

The complexity of this study’s tasks required participants to have a higher level of function. As such, to physically complete such tasks would take greater effort and time, whereas mentally rehearsing tasks may take less time. Although numerous studies have demonstrated that duration increases as mental task difficulty increases (Decety et al., 1989; Decety & Lindgren, 1991; Jeannerod, 1995, 1999), a review of mental task duration found that when the task is perceived as easy to perform, the duration of mental imagery may be shorter than the duration of actual performance (Guillot & Collet, 2005b). This same review also noted that, in healthy people, time taken was similar for cyclic, highly automatic tasks. In fact, in Malouin, Richards, Durand, and Doyon’s (2008) study of mental chronometry, the stepping task was relatively easy, and Malouin et al. suggested that temporal congruence between imagined and executed tasks remained intact after stroke. Conversely, participants in this study were required to perform more complex tasks that were neither cyclic nor automatic in nature but that demonstrated shorter mental duration times, not longer.

### Table 3. Comparison of Time Taken to Mentally Practice Each Task With the More-Affected Arm and the Less-Affected Arm

<table>
<thead>
<tr>
<th>Task</th>
<th>More Affected</th>
<th>Less Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± Standard Error</td>
<td>Mean ± Standard Error</td>
<td>$p^a$</td>
</tr>
<tr>
<td>1. Reaching for and grasping a cup</td>
<td>5.8 ± 0.6</td>
<td>1.9 ± 0.7</td>
</tr>
<tr>
<td>2. Turning pages in a book</td>
<td>7.2 ± 1.2</td>
<td>1.5 ± 1.3</td>
</tr>
<tr>
<td>3. Using a hairbrush or comb</td>
<td>4.1 ± 0.3</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>4. Proper use of a writing utensil</td>
<td>4.8 ± 0.4</td>
<td>1.9 ± 0.4</td>
</tr>
<tr>
<td>5. Proper use of an eating utensil</td>
<td>3.7 ± 0.2</td>
<td>1.9 ± 0.3</td>
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</tbody>
</table>

$^a$Percentages from mixed-effect models, adjusting for patients’ age and gender.

### Table 4. Percentage of Task Completion During Mental and Physical Practice of Each Task During the Mental Practice Trial

<table>
<thead>
<tr>
<th>Task</th>
<th>Mental Practice, % (n)</th>
<th>Physical Practice, % (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reaching for and grasping a cup</td>
<td>100 (18)</td>
<td>100 (18)</td>
</tr>
<tr>
<td>2. Turning pages in a book</td>
<td>100 (18)</td>
<td>94 (17)</td>
</tr>
<tr>
<td>3. Using a hairbrush or comb</td>
<td>89 (16)</td>
<td>72 (13)</td>
</tr>
<tr>
<td>4. Proper use of a writing utensil</td>
<td>89 (16)$^a$</td>
<td>50 (9)</td>
</tr>
<tr>
<td>5. Proper use of an eating utensil</td>
<td>94 (17)</td>
<td>100 (18)</td>
</tr>
<tr>
<td>All tasks</td>
<td>89 (16)$^a$</td>
<td>44 (8)</td>
</tr>
</tbody>
</table>

$^a$Percentage of completion is higher using mental practice than using physical practice, with $p < .01$ from a McNemar’s test.
Thus, this study’s combination of tasks, along with perception of task difficulty, may contribute to the primary finding of a significant discrepancy between time taken to physically versus mentally practice tasks.

Participants who had ischemic stroke performed both mental and physical tasks faster than those who had hemorrhagic stroke. Ischemic stroke damage is typically more localized and isolated. That participants with ischemic stroke demonstrated no difference in time taken on four of the five tasks suggests that their ischemic strokes spared portions of the parietal lobe responsible for estimating temporal aspects of motor performance. We verified this suggestion when we examined participants’ computed tomography scans. The contrary is true of people with hemorrhagic stroke, which often results in more diffuse damage with nonspecific borders. This finding has definite implications when considering possible candidates for MP. Patients with ischemic stroke may stand to benefit more from MP because timing is a crucial component of movement.

We also hypothesized that participants would expend more time mentally practicing tasks with their more-affected arm than mentally practicing the same tasks with their less-affected arm. This hypothesis was supported; every mentally rehearsed movement using the more-affected arm took significantly longer to complete ($p < .01$), which suggests that participants with stroke who are mentally practicing create an accurate mental depiction of their arms as exhibiting motor deficits. Data in Table 3, however, also suggest that these participants may underestimate the severity of deficit in their more-affected arm during MP. Indeed, during MP, we found that participants often overestimated the speed with which they could complete tasks that they could not physically complete.

Taken together, these findings suggest that clinicians can expect patients to recognize that they have arm motor deficits during MP; however, their mental depictions of these tasks may not accurately portray the extent of their motor deficits, their ability to perform these tasks, or both. MP audiotapes, thus, need to explicitly encourage patients to attend to how far and how well they are moving their arms in relation to actual movement abilities. Clinicians may also want to carefully review patients’ motor abilities with them before they initiate MP, so that the mental skill depictions accurately reflect the timing of movements. Higher completion rates observed during MP are promising because MP can provide safe, repetitive practice in the absence of a therapist. Although MP may be beneficial, using chronometry to monitor actual engagement in MP in participants with stroke may not be warranted because temporal characteristics of movements appears to be disrupted after stroke.

Limitations

This study had two primary limitations. First, because of time constraints, the number of participants was relatively small. However, we expect to overcome this limitation with larger MP studies, which are currently under way. Second, the participants practiced each task on only three occasions, whereas in other chronometry studies, the number of practice trials has been significantly higher. However, such studies also involved healthy people who were capable of performing such tasks with little difficulty, whereas patients with stroke may experience greater movement difficulty, fatigue, and frustration. Despite these limitations, we suspect that our findings are valid and have important implications for MP implementation in clinical practice. ▲

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References


Papaxanthis, C., Schieppati, M., Gentili, R., & Pozzo, T. (2002). Imagined and actual arm movements have similar durations when performed under different conditions of direction and mass. *Experimental Brain Research, 143*, 447–452.


