Effects of Strategy Use on Children's Motor Performance in a Continuous Timing Task

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The emergence and consistent use of strategies is recognized as an important step in the development of a child’s memory system. Strategy use is increasingly effective for mediating performance throughout the childhood years. By seven years of age, children spontaneously use strategies, but their pattern of strategy use varies qualitatively from older children (Lehmann & Hasselhorn, 2007; Naus & Ornstein, 1983). That is, older children not only use strategies more frequently, but the ones they use are more effective for performance than those used by younger children.

A rich literature documents the benefit of using effective strategies to enhance learning in the cognitive domain (Cox, Ornstein, Naus, Maxfield, & Zimler, 1989; Lehmann & Hasselhorn, 2007; Paris & Winograd, 1990). Training children to use more effective rehearsal strategies (Cox et al., 1989; Naus, Ornstein, & Aivano, 1977), organizational strategies (Lange & Pierce, 1992), and other strategies (Gaultney, 1995; Paris & Oka, 1986) improves their memory performance. The results of these findings indicated that children can benefit from specific strategy use in the cognitive domain when provided with instruction.

It is well established that strategies are beneficial for children when learning a cognitive skill (Cox et al., 1989; Lehmann & Hasselhorn, 2007). The evidence for effectiveness of strategy use when learning a movement skill, however, is less robust (Thomas, Thomas, Lee, Testerman, & Ashy, 1983). Mixed information exists in the motor domain literature with regard to developmental changes in the ability of children to use strategies to aid in the recall of movements. There is evidence to indicate that strategies are effective in learning certain types of movements, such as movement location, distance, and sequence (Dayan & Thomas, 1994, 1995; Gallagher & Thomas, 1984; Thomas et al., 1983). These findings are contradicted, however, by studies showing that attempts at using strategy interfere with the recall of a movement performance (Duffie, Montague, Laabs, & Hillix, 1975; Kvar & VanPelt, 1991; Stelmach & Bassin, 1971). One of the gaps in our knowledge, then, is the information necessary to implement effective strategies for children to support the acquisition of motor skills.

The purposes of this study were twofold. First, we sought to determine developmental changes in the use of strategies during motor skill acquisition. Poor perfor-
performance in children is a typical developmental phenomenon. The tested hypothesis predicted that poor performance would be associated not just with younger age, but with lack of use of recall strategies. Second, we tested the hypothesis that instruction in a specific strategy would lead to children’s improved recall performance, evidenced by improved performance in a motor task. Finding support for the second hypothesis would provide evidence for one of the mechanisms associated with the age-related performance changes observed in early childhood.

We conducted two experiments. Experiment 1 examined whether younger children (ages 5–7 years) differed from older children (ages 8–10 years) in strategy use during the performance of a motor task. Based on the literature, we expected younger children to be less likely to use strategies compared to older children. We also expected younger children to perform worse. The hypothesis is that strategy use is a significant cognitive factor that may lead to younger children’s poor performance. To test that hypothesis, Experiment 2 was designed to examine how instruction in the use of a specific strategy influenced children’s motor task performance.

The outcomes of this study increase our knowledge about the cognitive factors that lead to age-related differences in motor skill performance. Further, the knowledge gained from this research has applications as researchers explore and implement age-appropriate strategies in motor skill learning for children.

**Experiment 1**

Younger and older children differ in recall performance in both cognitive and motor tasks (Flavell, Miller, & Miller, 1993; Gallagher & Thomas, 1984; Naus et al., 1977). A major source of age-related differences in strategy use is the failure of younger children to use appropriate memory processes or to generalize learning strategies. A traditional view of learning and development holds that younger children know and can remember little and therefore spontaneously employ strategies less often than older children, but that they become increasingly competent with age and experience (Chi, 1976; 1977; Dayan & Thomas, 1994, 1995; Justice, 1989; Thomas, 1980).

A vast amount of literature documents age-related differences in strategy use in the cognitive domain (Garner, 1990; Lehmann & Hasselhorn, 2007; Naus et al., 1977; Schneider, Kron, Hunnerkopf, & Krajewski, 2004), while little information exists for the motor domain (Gallagher & Thomas, 1984; Schneider et al., 2004). We know that younger children differ from older children in the effects of strategy use in the cognitive domain. The differences are reflected in the poorer performance from younger children. The source of these deficits lies in less effective application of strategies and a lack of spontaneous strategy use. In this first experiment, we extend this concept to the motor domain, determining the age-related differences in strategy use during the continuous timing-task of pedaling.

The first hypothesis tested was that a greater proportion of older children, compared to younger children, would use a strategy to recall a practiced task. This expectation is consistent with the findings of Thomas et al. (1983) that considerably fewer younger children use strategies, compared to older children, when performing a nontiming task. The corollary to this hypothesis was that the older children would perform significantly better (lower error scores) on the task when compared to the younger children. The rationale for this hypothesis is that children’s pedaling performance improves as they grow older (Liu, Korfiff, Chao, & Jensen, 2003). The second hypothesis tested was that superior performance would be associated with strategy use. This expectation is derived from the findings of Winther and Thomas (1981), in which they showed that younger children did nothing specific to remember the end locations of the movement, while older children used a visual image to recall the movement patterns. Moreover, the older children achieved better performance than the younger children. The results led the authors to hypothesize that a lack of strategy use may result in poor motor skill performance.

**Method**

**Participants**

A total of 18 younger children, ages 5–7 years, and 18 older children, ages 8–10 years, participated in Experiment 1 (see Table 1). The selection of the age groups was for two reasons based on the literature. First, considerable evidence suggests that effortful processing, such as the use of strategies, does not occur spontaneously in children 5–7 years of age (Gallagher & Thomas, 1984; Naus et al., 1977). In contrast, children 8–10 years of age are capable of engaging in deliberate strategy use. Second, when children 5–7 years of age do use strategies, they are less effective in performance compared to children 8–10 years of age (Thomas et al., 1983; Wildernberg & Molen, 2004).

The children were recruited through advertisements and personal contacts from local communities. We obtained both informed consent from parents and assent from the children. The local university institutional review board approved the study.

The children’s bicycle-riding experience was assessed using a questionnaire, and selection criteria included minimal cycling experience. The questionnaire and experience criterion were based on a previously conducted study (Brown & Jensen, 2003). An estimate of the total number of hours that each participant had ridden a bicycle during the past 5 years was obtained (see Table 1).
All participants were noncompetitive, recreational bike riders who had not received explicit training. According to Jensen and Korff (2004), children with more than 300 hr of cycling experience are defined as experienced cyclists. The participants included in this study had low cycling experience (i.e., less than 100 hr) in the past 5 years. A t test for the number of bicycle-riding hours was performed for the age groups. No significant group difference was found, \( t(17) = .79, p > .05 \). It was concluded that the cycling experience of these participants did not confound the present analysis. This conclusion indicated comparable levels of bicycle-riding experience between age groups.

### Experimental Design

The experimental design included one between-subjects factor, age (younger children, older children), and one within-subjects factor, cadence (60, 80, and 100 revolutions per minute [rpm]). The three cadences chosen were based on previous studies that indicated a cadence window (60–100 rpm) exists in which children, even the youngest and least experienced, can easily meet the performance goals (Liu et al., 2003). Furthermore, testing across different tasks helps to demonstrate the generality of strategy use (Waters & Andreassen, 1983). By changing cadence, differences in strategy use can be examined in adjusting to changes in the timing of movement production. Three cadences were used in this study in order to demonstrate the robustness of the finding across a range of task conditions.

The dependent variables were (a) the accuracy of recall performance, as measured by root mean square error (RMSE) between the target cadence and the participant-produced cadence, and (b) the consistency of recall performance, as measured by variable error (VE) between the participant-produced cadence and the participant’s average (Schmidt & Lee, 1999).

### Instrumentation

Participants performed all tasks on a stationary Monark ergometer (Model 829E; Monark, Varberg, Sweden). In this study, pedaling was a continuous timing-task. It is an ideal motor task for studying cognitive development and understanding motor skill acquisition in children, because it is a controllable task. An advantage of pedaling over other motor tasks is that identical kinematics across all trials can be created among children with different developmental characteristics. Moreover, the task demands of pedaling can be controlled, thus performance comparisons can be made between age groups. It is important that each child perform the same task so the confounding performance factor (i.e., children performed differently because they did not move in the same manner) can be eliminated.

To achieve a standardized riding position, crank length was adjusted to 20% of each participant’s leg length. The toe cages were adjusted so that the first metatarsal-phalangeal joint rested over the pedal spindle. The handle bars were adjusted so that the trunk was 60° from the anterior horizontal, and the seat height was adjusted so that each participant’s posterior knee angle was approximately 70° at the top dead center and 155° at bottom dead center. To ensure that the task was the same work load for each individual, participant-specific pedaling peak power was predicted by individual lean thigh volume using a method established by Martin, Farrar, Wagner, and Spirduso (2000). The participants pedaled at 10% of their predicted peak power because it represented a comfortable pedaling resistance that would not induce fatigue for the children (Jensen & Korff, 2004).

Data were collected using a five-camera motion system. To determine pedaling cadence, the trajectory of a reflective marker on the right pedal spindle (distal end of the crank) was recorded at 60 Hz. The target cadence range was set at 60 ± 4 rpm, 80 ± 4 rpm, and 100 ± 4 rpm. Previous work had established that these target cadence ranges were sufficient to discriminate performance levels among children (Liu & Jensen, 2009; Liu et al., 2003).

### Test Administration

The experiment was designed to determine age-related differences in children’s strategy use when the children were asked to remember the cadence at which they had pedaled previously. The participants were asked to recall and perform select pedaling cadences (60, 80, and 100 rpm) after they were allowed three practice trials at the selected cadences. During the practice trials, the principal investigator cued the child with verbal confirmations, such as “you are at 60 right now; try to keep the same speed as you pedal,” when he or she was pedaling at the target speed. The number of practice trials was based on pilot findings in which children reported that three practice trials were sufficient for them to remember the target cadence. Children practiced the cadences in a random order. A random order for the cadences was used so that the effects of practice would not affect the performance among tasks. Each trial lasted 15 s, as recommended by

### Table 1. Demographic information of participants in Experiment 1

<table>
<thead>
<tr>
<th>Participants</th>
<th>n</th>
<th>Age (years) M SD</th>
<th>Bicycle riding experience (hours) M SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>18</td>
<td>5–7 5.8 0.7</td>
<td>66.4 63.8</td>
</tr>
<tr>
<td>Older</td>
<td>18</td>
<td>8–10 8.6 0.6</td>
<td>90.0 89.0</td>
</tr>
</tbody>
</table>

Note. M = mean; SD = standard deviation.
Jensen and Korff (2004), who found that 15 s of stationary bike pedaling did not cause fatigue or a reduction of attention in 5-year-old children.

After practice of the target cadence, each child was asked to reproduce three trials for that cadence. Three trials of the recall test provided a representation of the children’s performance consistency. In the recall test, the children verbally informed the principal investigator to start data collection when they believed they were at the target cadence. Strategy use was assessed by questioning the participants immediately after the recall performance. Researchers have indicated that children’s verbal reports of strategy use are indeed accurate even for children 5 years of age (Goldman, Pellegrino, & Mertz, 1988; Siegler, 1996). At that time, the participants were asked to describe how they remembered the target cadence, and their responses were recorded for later analysis and confirmation of response.

Data Analysis

A chi-square test of independence was used to test whether or not age and strategy were independent of one another. The analyses for the effect of strategy were 2 (age) x 2 (strategy) x 3 (cadence) repeated measures analyses of variance (ANOVs) on RMSE and VE. An intrarater reliability test was performed between coding scores of the principal investigator and an assistant. The principal investigator introduced the coding criteria and protocol to the assistant and then asked the assistant to code the strategies by reviewing children’s recorded responses. The strategy use was coded as “No Strategy” (NS) when a child’s verbal report was “I guessed” or “I don’t know” and as “Strategy” (S) when a child said, “I counted” or “I looked at my legs and tried to keep them moving the same.” In the case of children who answered, “I just knew, I remembered,” probing questions were asked (e.g., “How did you know?” or “How did you remember?”). If the children then gave the same answers, they were coded as NS, but if they changed to more articulate answers, such as “My legs felt like it, I kept pedaling the same,” the responses were coded as S. The assistant was considered trained once 90% agreement with the coding scores of the principal investigator was achieved (Bauer, Wenner, Dropik, & Wewerka, 2000; Saigal, Rosenbaum, & Stoskopf, 2005).

All results were considered significant if an alpha level of .05 was achieved. In case of a significant interaction effect, a follow-up ANOVA was performed for comparison of each level of the corresponding independent variable. In addition to statistically significant findings, effect sizes (ES) were determined for practical effect. ES < .40 were categorized as small, .40 < ES < .70 were categorized as moderate, and ES > .70 were categorized as large (Cohen, 1988; Thomas, Salazar, & Landers, 1991). Additionally, 95% confidence intervals (CI) were calculated for the ES.

The CI represent uncertainty in the estimate of the true value in the statistical analysis. It indicates how big or small the true effect can be in the population (Steiger, 2004). Further, CI can serve as important measures for analyzing current findings, estimating sample size, and replicating studies in the future.

Results

Age-Related Difference on Strategy Use—Hypothesis 1

A chi-square test of independence was calculated comparing the frequency of strategy use for younger and older children. A significant interaction was found, \( \chi^2(1) = 11.25, p < .05 \), indicating strategy use was related to age. Most of the younger children (15 of 18; 83%) used NS (e.g., don’t know, just remembered), while 17% (3 of 18) of the younger children used S (e.g., I counted it, I looked at my legs, or I moved them the same way over and over). In contrast, 72% (13 of 18) of the older children used S, and 28% (5 of 18) of the older children used NS. The agreement between the two raters was high (92%).

Age-Related Performance Difference—The Corollary to Hypothesis 1

The main effect for age on performance accuracy (RMSE) was significant, \( F(1, 34) = 11.55, p < .01 \), and a significant Age x Cadence interaction was also found, \( F(2, 33) = 3.42, p < .05 \). The results indicated that the age-related differences in performance accuracy depended on pedaling cadence. Follow-up ANOVAs revealed that the older children showed significantly superior performance at all cadences (60, 80, and 100 rpm) when compared to younger children, but the significant difference was smallest at 80 rpm (see Figure 1).

The age main effect on performance variability (VE) was significant, \( F(1, 34) = 7.51, p < .05 \). The Age x Cadence interaction for performance variability was significant as well, \( F(2, 33) = 3.48, p < .05 \). The age-related differences in performance variability depended on pedaling cadence. Follow-up ANOVAs showed that the older children were significantly less variable at 60 and 100 rpm, but not at 80 rpm, when compared to younger children (see Figure 1).

We calculated ESs for each pairwise comparison. Because the comparison was made between two groups (i.e., younger children and older children), the pooled standard deviation was used (Thomas et al., 1991). Confidence intervals were calculated to yield upper and lower limit for the ES (Gibbons, Hedeker, & Davis, 1993; Wolf, 1986).

The ES describing the performance accuracy differences (RMSE) between younger and older children were large for 60 rpm (ES = 0.99; 95% CI = 0.27, 1.66) and 100 rpm (ES = 1.10; 95% CI = 0.38, 1.78), and moderate at 80 rpm (ES = 0.69; 95% CI = 0.00, 1.35). The large and moderate ESs indicated a difference of .5–1 standard deviation.
between the younger and older children’s means. ESs comparing younger and older children in performance variability (VE) were large at 60 rpm (ES = 0.85; 95% CI = 0.15, 1.51) and 100 rpm (ES = 0.89; 95% CI = 0.18, 1.55). The ES indicated a difference close to 1 standard deviation between the younger and older children’s means. These effect size results suggest that the older children’s performance was more accurate and consistent than that of the younger children. The CI for the ES on both RMSE and VE spanned a range from small to very large, indicating that the true effect in the population may range between small and very large. In addition, the CI did not cross the zero point, suggesting that there was a practical effect on age-related performance differences (Wolf, 1986).

**Effects of Strategy Use on Performance—Hypothesis 2**

The strategy use main effect on RMSE was significant, \(F(1, 34) = 16.77, p < .001\), and a significant Strategy x Cadence interaction was found, \(F(2, 33) = 3.33, p < .05\). The results indicated that performance accuracy differences in strategy use were associated with pedaling cadence. Follow-up ANOVAs revealed that the children who used a strategy were significantly more accurate on performance (lower RMSE) at all cadences (60, 80, and 100 rpm) compared to children who did not use strategy, but the significant difference was smallest at 80 rpm (see Figure 2).

Further, the strategy use main effect on VE was significant, \(F(1, 34) = 4.31, p < .05\). The Strategy x Cadence interaction for performance variability was significant as well, \(F(2, 33) = 4.03, p < .05\). Performance variability differences in strategy use were associated with pedaling cadence. Follow-up ANOVAs revealed that the children who used a strategy were significantly less variable (lower VE) at 60 and 100 rpm, but not at 80 rpm, when compared to the children who did not use strategy (see Figure 2).

The ES describing the performance accuracy differences between NS and S were large at all cadences, indicating there were differences of 1 to 1.5 standard deviations between the means of the NS and S. The ES comparing the NS and S in performance variability were large at 60 rpm and 100 rpm, indicating there were differences of 0.75–1 standard deviation between the means of the NS and S. The effect size findings showed that the children who used strategies were more accurate and consistent than the children who did not use a strategy.

![Figure 1](image-url)
Discussion

Data from Experiment 1 showed that the younger children differed from the older children in performance and strategy use during pedaling. The differences, most notable in performance errors in cadence recall, can be attributed to the younger children’s ineffective strategy use. The first hypothesis, concerning age-related differences in strategy use in the motor domain and age-related effects in performance, was posed to test the performances on a continuous timing-task and place the findings in the context of the existing literature. The predicted age-related differences in strategy use in recall performance were observed. More of the older children used strategies for a continuous timing-task performance than the younger children. This finding was consistent with previous observations of strategy use when performing recall tasks in the cognitive domain (Best & Ornstein, 1986; Chi, 1976; 1977; Lehmann & Hasselhorn, 2007), and noncontinuous timing-tasks, such as location recall, in the motor domain (Thomas et al., 1983; Winther & Thomas, 1981). In fact, few 5–7-year-old children used a strategy in the recall test. This indicated that children at this young age appeared to have little understanding of the concept of timing. In addition, the older children demonstrated lower RMSE and VE (i.e., better performance) when compared to the younger children. The results support previous research, which has shown that younger children are less likely to perform a pedaling task successfully compared to older children (Liu & Jensen, 2009; Liu et al., 2003).

Furthermore, we posed the first hypothesis to determine how children’s performance was related to strategy use. As hypothesized, children who used a strategy performed significantly better (i.e., lower RMSE and VE) compared to those who did not use a strategy. Previous studies also supported the fact that strategy-use differences in variability were associated with cadence (i.e., children who used a strategy were less variable than those who did not when pedaling at 60 and 100 rpm, but not at 80 rpm). Previous research showed that children’s preferred speeds are 70–80 rpm in general (Liu et al., 2003). Although the strategy-related performance difference was small at 80 rpm, one could argue that 80 rpm is the pedaling speed at which most children can perform successfully. The finding suggests that strategy use has greater value for children at more extreme cadences (60 rpm and 100 rpm).

Figure 2. Effect of Strategy x Cadence interaction on recall performance accuracy (root mean square error) and variability (variable error). The strategy-effect was statistically significant (*) at all cadences. Means and standard deviations were plotted for children who used NS and for children who used S.
rpm), but has less value in a typical and possibly practiced speed (80 rpm).

The results provide new information in two aspects. First, the findings extend the knowledge of developmental differences in strategy use observed when performing the continuous timing-tasks. Because pedaling was used to study strategy use in the present experiment, these differences can be attributed to developmental differences in the motor domain. Second, the results of the experiment indicate that the observed age-related differences in motor skill performance may result in part from younger children’s ineffective strategy use. This finding contributes to a more comprehensive understanding of the interactions between the cognitive and motor domains and age-related changes in motor performance.

Conclusion

Age-related differences in performance and strategy use support and extend previous developmental literature in the cognitive and the motor domains. In particular, younger children do not spontaneously use strategies in performance, whereas older children often plan and use strategies when performing a motor task. The observed age-related performance differences may, in part, result from differences in strategy use. Our findings highlight the importance of strategy use in children’s success for performing a continuous timing-task. This is particularly important as educators, teachers, and coaches begin to work with younger children in whom the spontaneous use of strategies is absent. Can we teach those children to use a specific strategy? Will the use of that strategy help children improve their performance? These questions were addressed in Experiment 2.

Experiment 2

A key determinant of learning involves the specific strategies a learner employs during the skill acquisition process. In the motor and cognitive developmental literature, young and older children differ in recall in both cognitive and motor tasks (Flavell et al., 1993; Gallagher & Thomas, 1984). In the cognitive domain, researchers have shown that the use of appropriate strategies can enhance children’s performance (Flavell et al., 1993; Siegler, 1996). Strategy use requires children to use cognitive resources to achieve a goal in certain task environments (Logan, 1985).

A rich literature illustrates the benefits of using recall strategies to enhance learning (Best & Ornstein, 1986; Garner, 1990; Paris & Winograd, 1990). The benefits are clear on the use of strategies to enhance learning in the cognitive domain, specifically strategy use on verbal tasks (Garner, 1990; Paris & Winograd, 1990). In contrast, research on the usefulness of the same strategies when learning a movement is inconsistent (Duffie et al., 1975; Thomas et al., 1983). The results of motor skill strategy studies revealed conflicting findings about the way individuals learn motor tasks using recall strategies compared to those learning in a nonstrategy condition. In order to address this conflict, this experiment tested the effect of teaching children a specific strategy with regard to completing a continuous timing-task. The results of Experiment 1 revealed that the majority of the younger children did not use strategies, while most of the older children used strategies in the pedaling task that was employed. Children who used strategies performed with fewer errors than children who did not use strategies. The superior performance by the older children was observed at all cadences when compared to the performance of younger children. We speculated that the observed age-related performance differences in Experiment 1 may be due in part to younger children’s ineffective strategy use.

To test that speculation, Experiment 2 was designed to examine the effect of strategy instruction on pedaling. We were interested in performance changes that occurred as result of strategy application, not age. Therefore, the participants of Experiment 2 were a subset of those in Experiment 1, and they were grouped by their previous performance. It was hypothesized that instructing poorly performing children in the use of a strategy would lead to improved performance. Specifically, we expected the strategy instruction to lead to a significant reduction in RMSE and VE when compared to these values in children who did not receive instruction. This expectation was based on the belief that instruction in a strategy was likely to help children generate both an organized action plan and appropriate memory processes (Thomas et al., 1983).

Method

Participants

From the 36 participants in Experiment 1, the 18 children who had the poorest performance participated in Experiment 2. The children were grouped by performance instead of age for two reasons. First, grouping children by performance can eliminate confounding factors, such as age, that may distort the findings. Second, Experiment 2 was designed to investigate whether children could improve their pedaling performance after instruction in strategy use. Grouping children by performance can more effectively test the hypothesis and make valid comparisons between the groups. A median split was used to divide the scores so that those with error scores in the top 50th percentile were considered poor performers. Participants were randomly assigned to either an experimental or a control group (see Table 2). The children in the experimental group were taught to use a strategy to assist their recall of the target pedaling cadences. An effective strategy...
(i.e., rhythmic counting with a metronome) used in adult cyclist training was taught in Experiment 2.

**Experimental Design**

The experimental design included one between-participant factor, group (experiment, control), and two within-participant factors, cadence (60, 80, 100 rpm) and test (pre, post). The dependent variables were performance, as measured by RMSE and VE.

**Instrumentation**

The instrumentation was identical to Experiment 1.

**Test Administration**

The experiment was designed to compare the effects on performance when a specific strategy was taught. The task was to recall selected pedaling cadences (60, 80 and 100 rpm). Children in the experimental group received the following instructions:

When you pedal this time, try to remember how fast you are pedaling. Later, you will be asked to try and remember how fast you pedaled on the bike. To help you remember, you should verbally count “1” when you hear a metronome beat, and at the same time push one of your legs down. Then, on the next beat, count “2” and push down with your other leg.

Children were told to count with the metronome beats while pedaling. The principal investigator counted with participants during the practice trials to ensure the correct use of the strategy. All children practiced the target cadences in a random order, with five trials for each cadence. The number of practice trials was based on previous cognitive and motor learning literature, suggesting that discrete tasks may require 10–15 trials to detect a learning effect (Weiss & Rose, 1992; Wulf & Weigelt, 1997), but a window of 1–5 practice trials is sufficient for learning continuous tasks (Thomas et al., 1983). Each trial lasted for 15 s.

Each child in the control group was given the following instructions: “Try to remember how fast you pedaled, because I am going to ask you to pedal the same speed at which you practiced. Do you understand?” If the child said no, then the instructions were explained again. Once the child indicated his or her understanding, the practice trials for the selected target cadence began. All children practiced the target cadences in a random order, with five trials for each cadence, the same as the experimental group (strategy instruction was provided only to the children in the experimental group). Ten minutes after practice, each child was asked to reproduce three trials for the cadence practiced. The children verbally informed the principal investigator to start data collection when they believed they were at the target cadence.

**Data Analysis**

The analyses for the effects of a specific strategy instruction were 2 (group) x 3 (cadence) x 2 (pre-post) repeated measures ANOVAs on RMSE and VE. Also conducted, to understand whether age had a possible effect on children’s performance changes, were 2 (group) x 2 (age) x 3 (cadence) repeated measures ANOVAs on RMSE and VE. The results were considered significant if an alpha level of .05 was achieved. In case of a significant interaction effect, a follow-up ANOVA was performed for comparison of each level of the corresponding independent variable. Effect sizes were calculated for each pairwise comparison using control group standard deviation, following the method of Cohen (1988). In addition, 95% CI were calculated for the ES.

**Results**

**Effect of Strategy Instruction—Experiment 2 Hypothesis**

Before strategy instruction, a test of group differences revealed no significance differences. The group main effect failed to show statistical significance for performance accuracy (i.e., RMSE) between the experimental and the control groups, *F*(1, 16) < 1 (see Figure 3). In addition,
no significant difference was found between the experimental group and the control group on performance variability (i.e., VE), $F(1, 16) < 1$ (see Figure 3). The results indicated that the children in the experimental and the control groups did not differ on either performance accuracy or variability before strategy instruction.

The pre-post main effect for strategy instruction on performance accuracy was significant, $F(1, 16) = 9.57, p < .05$, and the Group x Pre-Post interaction was significant as well, $F(1, 16) = 5.84, p < .05$. The Group x Cadence x Pre-Post interaction failed statistical significance, $F(2, 15) < 1$. The results revealed that children who were taught a counting strategy demonstrated significantly larger RMSE reduction when compared to children who were in the control group only on the posttest. Further, no significant age main effect was found, $F(1, 14) < 1$. The Group x Age interaction for performance accuracy also failed to show statistical significance, $F(1, 14) < 1$, indicating that age did not confound the present analysis in these participants.

The pre-post main effect for strategy instruction on performance variability was significant, $F(1, 16) = 8.60, p < .05$, and the Group x Pre-Post interaction was also significant, $F(1, 16) = 5.47, p < .05$. No significant Group x Cadence x Pre-Post interaction was found, $F(2, 15) < 1$. The results indicated that children who received a counting strategy instruction significantly reduced VE when compared to children in the control group only on the posttest. In addition, the age main effect failed to show statistical significance, $F(1, 14) < 1$. No significant Group x Age interaction for performance variability was found, $F(1, 14) < 1$, indicating that age did not confound the present analysis in these participants.

The effect size describing the performance accuracy differences between the experimental and the control groups was large on the posttest. An effect size of 0.74 (95% CI = 0.12, 1.81) means there was a 0.75 standard deviation difference on RMSE between the means of the experimental and the control groups after applying a specific strategy.

Further, the effect size comparing the experimental and the control group in performance variability was moderate on the posttest (ES = 0.54; 95% CI = 0.37, 1.52), indicating that strategy instruction led to a difference of 0.5 standard deviation on VE between the means of the experimental and the control groups.

These ES results revealed that children who received strategy instruction greatly reduced RMSE and VE when compared to children in the control group. The CI

![Graph showing the effect of strategy instruction on RMSE and VE](image-url)

**Figure 3.** Effect of group x pre-post interaction for strategy instruction on performance accuracy root mean square error (RMSE) and variable error (VE). The experimental group was significantly (*) different from the control group on RMSE and VE on the posttest.
spanned a range from small to large, suggesting that the true effect in the population may range between small and large. In addition, the CIs did not cross the zero point, indicating that the strategy-teaching intervention had a practical effect.

Discussion

In the present study, we investigated whether instructing children in the experimental group to use a specific pedaling strategy would lead to greater performance improvement compared to children in the control group. The results demonstrated that children who were taught a counting strategy showed greater performance accuracy and variability reductions than children in the control group. In conformity with the hypothesis, teaching children to use a specific strategy to remember the cadence they pedaled can improve their recall performance. The performance error of the experimental group was lower than that of the control group. This finding agrees with observations of the teaching of strategy use in the cognitive domain (e.g., picture recall; Keeney, Cannizzo, & Flavell, 1987; Naus et al, 1977) and partly agrees with results using nontiming motor tasks, such as distance jogged (Gallagher & Thomas, 1984; Thomas et al., 1983).

Several studies noted that when young children were taught to use strategies, their motor performance accuracy improved (Gallagher & Thomas, 1984; Thomas et al., 1983). The results of the present investigation confirm this speculation, as children with poor performance improved their pedaling accuracy after using the counting strategy. Thus, teaching specific strategies about movement information enhances children’s performance.

The results of Experiment 2 extend our knowledge by examining children’s performance of a continuous timing-task in response to cadence changes and the effect of strategy use, by attributing observed performance improvement to the effectiveness of strategy learning. These findings are important because they add new information about cognitive factors that lead to performance improvement, and they provide indications to educators, teachers, and coaches about how to teach children to improve their continuous timing-task performance.

In summary, the most significant educational implication of this study derives from the results obtained—that teaching and using strategies can be a sufficient condition to affect children’s continuous timing-task performance. Reproducing a practiced cadence is frequently important in sports. This is made more difficult in some sports when timing is a crucial determining factor for performance. For instance, in rowing, athletes must move their arms in a synchronized motion. To adults, counting the rhythm seems obvious, but it is not necessarily obvious to a child. Teaching children who have not yet developed these strategies can assist them to learn the task faster and in such a way that it is more reliable.

General Discussion

A number of factors influence motor skill development and learning in children. In particular, the memory system plays an important role and accounts for many of the motor performance differences observed throughout childhood. The purpose of this series of studies was to examine how cognitive processes in the memory system affect a continuous timing-task—pedaling performance and learning in children. Emphasis was placed on differences in strategy use as a factor influencing cognitive processes such that the motor skill performance of older children was more successful compared to that of younger children. In addition, we sought to understand whether the application of a specific strategy in these cognitive processes could improve children’s continuous timing-task performance.

Two experiments were performed. The first experiment was the examination of age-related differences in motor performance and strategy use. After exploring developmental differences in continuous timing-task performance, we tested the hypothesis that these differences were associated with ineffective strategy use. Data from Experiment 1 revealed that there were age-related differences in a continuous timing-task performance, and that the differences could be attributed to the ineffective strategy use of younger children. The results of Experiment 1 suggest that younger children have difficulty generating and spontaneously using strategies on their own while performing a continuous timing-task. With increases in age, children come to be more efficient in the use of motor strategies. These findings agree with previous research in the cognitive domain (Cox et al., 1989; Naus et al., 1977), and they are consistent with previous research on continuous motor skill performance in the motor domain (Thomas et al., 1983). These results are valuable for filling the gaps in our knowledge about whether age-related differences exist in a continuous timing-task performance and whether providing specific strategy can improve the children’s performance. Hence, this study extends our understanding of the developmental differences of strategy use in the motor domain and of the relationship between the development of cognitive processes and the continuous timing-task performance.

In Experiment 2, we tested the hypothesis that children can be instructed to use a certain strategy to improve their performance. Data showed that children did improve performance by implementing a specific strategy, regardless of age. The conclusion was possible due to tight between-group performance controls and tight controls within groups in terms of cycling experience. Children
in the experimental and the control groups had similar performance and cycling experience. This indicated that children in both groups started from the same baseline in Experiment 2, and that the bicycle-riding experience did not confound the findings. Moreover, the children were grouped according to their performance from Experiment 1. It is known that manipulating strategy may affect both the likelihood that a young child spontaneously uses a strategy and the efficiency of its use in the cognitive domain (Lehmann & Hasselhorn, 2007; Schneider et al., 2004). The results of Experiment 2 demonstrated that instructing children in effective strategy use led to significant improvement in the continuous timing-task performance. The results of this study increase our knowledge about the cognitive factors that lead to age-related differences in continuous timing-task performance and have great implications for the use of strategies to effectively teach other timing tasks in children between 5 and 10 years old.

The most significant implication of the work presented in this study is evident in the overall result—that teaching and instructing effective strategies can affect children’s timing-task performance. Children’s timing is important because it is a key factor in sports, music, and general life functioning (Ellis, 1992). A child’s timing—the ability to feel and express a steady beat—is fundamental to movement and music, affecting sport skills, musical performance, speech, and performance of timed motor tasks. In addition, timing has been found to be positively related to children’s overall achievement in school, as well as in mathematics and reading achievement, gross motor skills, and language performance (Mitchell, 1994). Teaching children who have not yet developed the strategies for timing can assist them in learning timing tasks, and perhaps others, faster and more reliably. Children also may well be found to improve their school achievement because of their improvement in timing-task performance with the application of effective strategies.

What is the future of strategy research in the motor domain? First of all, we expect that the issue of developmental readiness in strategy use will become more important. When is the best time to teach various strategies to children in motor skill performance? Is earlier always better, or might it be necessary to wait until children’s general cognitive abilities are better developed before beginning instruction? How can we best teach strategies, especially to low-achieving children? Second, as we learn more about the processes of strategy development, researchers will be asking themselves which cognitive factors lead to better motor performance and how these factors relate to age and strategy effectiveness. Third, we expect that researchers will take a close look at memory strategies that develop in motor task performance. It would also be valuable to determine how much practice with a given strategy is needed to produce learning. For example, will children performing a more difficult task show greater response to strategy use? Fourth, there is still more to be learned about movement-related strategies. What role do coaches and teachers play in fostering children’s use of learning and memory strategies? Finally, it is also of interest to understand whether children can apply learned strategies in the motor domain to enhance performance in a cognitive task. How does the role of gaming interact with children’s cognitive and motor performance?

References


Authors’ Notes

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