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Age-Related Differences in Bilateral Asymmetry in Cycling Performance

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Key words: children, limb laterality, pedaling

Bilateral asymmetry, a form of limb laterality in the context of moving two limbs, emerges in childhood. Children and adults show lateral preference in tasks that involve the upper and lower limbs (Porac & Coren, 1981; Porac, Coren, & Dunca, 1980). The importance of research in limb laterality is the insight it could provide about lateralized functions of the cerebral hemispheres (Pompeiano, 1985; Previc, 1991). Because there has been less research on lower limb preference than handedness (Gabbard, & Iteya, 1996; Gentry & Gabbard, 1995; Peters, 1988), studying lower limb preference can be a useful measure in understanding the underlying neuromuscular functioning (Peters, 1988, 1990).

Several researchers on hand laterality suggested that consistent right-handed children are motorically superior to their inconsistent (mixed-sided) and left-handed peers (Gottfried & Bathurst, 1983; Kaufman, Zalma, & Kaufman, 1978; Tan, 1985). A general observation from the literature on footedness hints that it may be a more sensitive index than handedness in motor performance (Bradshaw, 1989; MacNeilage, 1991; Peters, 1990). It has been suggested that footedness is less subject to dextral social pressure and, therefore, a better indicator of hemispheric specialization than handedness (Peters, 1988; Searleman, 1980). However, no evidence shows the mixed- or left-footers are at a performance disadvantage compared to right-footers, and the description of foot-laterality patterns across the lifespan is quite sparse.

Analyzing bilateral asymmetry as a function of pedaling rate is important for a variety of reasons. One concerns the adaptability of the developing motor system to adjust to changing task requirements. Another concerns the potential influence of bilateral asymmetry on success of motor skill performance (Nonis, Larkin, & Parker, 2005; Teixeira, Silva, & Carvalho, 2003). Identifying the less dominant limb may help educators develop training programs to improve children’s motor skill performance. Finally, quantifying pedaling asymmetry across different pedaling rates could provide insight into motor control principles for left/right coordination, which have been investigated in previous studies (Arsenault, Winter, & Marteniuk, 1986, Daly & Cavanagh, 1976; Patterson & Moreno, 1990). An advantage of pedaling over other motor tasks is that identical kinematics across all trials can be created among individuals with different developmental characteristics. Moreover, the task demands of pedaling can be controlled; thus, performance comparisons can be made among age groups. It is important to have each individual perform the same task in order to eliminate confounding performance factors (i.e., different performances because individuals did not move the same way).

A number of previous studies examined bilateral pedaling mechanics in adults (Cavanagh, Petak, Shapiro, & Daly, 1974; Patterson & Moreno, 1990; Sanderson, 1991), but only a few addressed bilateral asymmetry across different pedaling rates (Chavet, Lafortune, & Gray, 1997; Daly & Cavanagh, 1976). It was reported that bilateral asymmetry in cycling changed systematically with pedaling rate in adults, and the asymmetry was not related to leg dominance (Daly & Cavanagh, 1976; Fregly & Zajac, 1996). At present, little is known about the function of bilateral asymmetry with changing pedaling rate in children. A gap in our knowledge is the information necessary to understand the effect of pedaling rate on underlying bilateral motor control in children. Therefore, the purpose of this study was to examine whether bilateral asymmetry...
asymmetry changed with pedaling rates and to investigate the association between bilateral asymmetry and cycling performance in children and adults (i.e., participants’ capacity to meet task goals and the developing motor system’s adaptability to the changing task). An additional objective of this study was to determine whether the dominant leg, as identified by kicking, would contribute more to performance accuracy than the nondominant leg.

**Method**

**Participants**

Twelve younger children (YC; 5–7 years, \(M = 5.80\) years, \(SD = 1.0\)), 12 older children (OC; 8–10 years, \(M = 9.30\) years, \(SD = .80\)), and 12 adults (AD; 24–30 years, \(M = 26.90\) years, \(SD = 2.70\)) with recreational cycling experience participated in this study. We selected the children’s age groups based on evidence in the literature. First, considerable evidence from kicking tests suggests that footedness is established in children by ages 3 and 5 years (Armitage & Larkin, 1993; Belmont & Birch, 1963; Gentry & Gabbard, 1995). Second, research shows a significant shift toward rightfootedness by age 11 years (Gentry & Gabbard, 1995) and then remains relatively stable thereafter. Dargent-Pare, De Agostini, Mesbah, and Dellatolas (1992) reported the switch may occur sometime after late childhood and early adolescence (> 15 years old). Other researchers suggested the adult pattern of hemispheric specialization is established by puberty (Bishop, 1990; Lenneberg, 1967). However, a few studies reported no age-related trend in foot preference (Didia & Nyenwe, 1988; Longoni & Orsini, 1988). Because of mixed findings on bilateral asymmetry development across childhood, we included children younger than 11 years (i.e., before puberty) in our study to ensure similar limb laterality.

We used a questionnaire and experience criterion developed in a previous study (Brown & Jensen, 2003) to estimate of the total number of hours that each participant in our study had ridden a bicycle during the past 5 years (see Table 1). All participants were noncompetitive, recreational bike riders who had no explicit training. According to Jensen and Korff (2004), children with more than 300 hr of cycling experience were experienced cyclists. Participants included in our study had low cycling experience (i.e., less than 100 hr) in the previous 5 years. A one-way analysis of variance (ANOVA) on the number of bicycle riding hours was performed for the different age groups. There was no significant group difference on cycling experience (\(p > .05\)). We concluded that participants’ cycling experience did not confound the data analysis in the present study. This conclusion indicated comparable cycling experience among age groups.

Children were recruited through advertisement and personal contacts from local communities. Adults were undergraduate and graduate students at a local university. Participants were informed of the task and the specific experimental protocol, but they were naive in regard to the experiment’s theoretical question. We obtained informed consent from all participants or a legal guardian prior to participation. The university’s institutional review board approved this study.

**Measurement of Leg Dominance**

Prior to the cycling task, we determined participants’ leg dominance. Kicking has been shown to be an appropriate task for determining leg preference (Chapman, Chapman, & Allen, 1987; Peters, 1988; Previc, 1991). We required each participant to kick a ball (Tan, 1985) placed relative to the midline of the body. Participants performed three trials with a 2–3-min break in between. When they had completed all trials, we categorized them as right- or left-dominant.

**Procedures**

Following introduction of the experiment and measurement of leg dominance, participants performed five 15-s pedaling trials at five randomized target cadences

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**Table 1. Demographic information for participants**

<table>
<thead>
<tr>
<th>Participants</th>
<th>Gender ((n))</th>
<th>Age (years)</th>
<th>Height (in/cm)</th>
<th>Weight (lb/kg)</th>
<th>BRE (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>(M)</td>
<td>(SD)</td>
<td>(M)</td>
</tr>
<tr>
<td>Younger children</td>
<td>(Girls = 6)</td>
<td>5–7</td>
<td>5.8</td>
<td>1.0</td>
<td>46.6/118.4</td>
</tr>
<tr>
<td></td>
<td>(Boys = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Older children</td>
<td>(Girls = 6)</td>
<td>8–10</td>
<td>9.3</td>
<td>0.8</td>
<td>54.6/138.7</td>
</tr>
<tr>
<td></td>
<td>(Boys = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>(Women = 6)</td>
<td>24–30</td>
<td>26.9</td>
<td>2.7</td>
<td>66.1/167.9</td>
</tr>
<tr>
<td></td>
<td>(Men = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. \(M\) = mean; \(SD\) = standard deviation; BRE = bicycle riding experience.*
(40, 60, 80, 100, and 120 rpm). They performed all tasks on a stationary ergometer (Monark, Model 829E). Their task was to maintain a target cadence for 15 s. Jensen and Korff (2004) found that 15 s of stationary bike pedaling did not cause fatigue or reduce YC’s attention span. The range was set at a target cadence ± 4 rpm. Previous work established that these ranges were sufficient to discriminate performance levels among children (Liu & Jensen, 2009). A metronome provided rhythmic timing feedback. Participants were instructed as follows: “When you hear a metronome beat, at the same time push one of your legs down. Then, on the next beat, you push down with your other leg.” All participants performed two practice trials, and all were able to match the metronome beat to their leg motions. Data collection began when they reached the target cadences. Kinematic data were collected using a 5-camera Vicon 250 motion analysis system (Vicon Motion Systems, Lake Forest, CA). To determine cadence, the trajectory of a reflective marker on the right pedal was recorded at 60 Hz. To achieve a standardized riding position for each participant, the handle bars were adjusted so that their trunk was 60° from the anterior horizontal; seat height was adjusted so that the posterior knee angle was approximately 70° at the top center and 155° at bottom center. In addition, crank length was adjusted to 20% of leg length, toe cages were also adjusted so that the first metatarsal-phalangeal joint rested over the pedal spindle. Cycling power was set to 10% of the predicted peak power, and all were able to respond to maximum mechanical advantage for pushing by that in the OC, and AD. A repeated-measures ANOVA found a significant main effect for age group on RMSE difference among groups. Bonferroni post hoc tests were used when there were statistically significant main effects and interactions. A Pearson product-moment correlation was calculated to detect associations between bilateral asymmetry (AI) and cycling performance (RMSE). Correlations were considered significant if alpha was < .05. A 3 (group: YC, OC, AD) x 2 (leg dominance: dominant leg, nondominant leg) multivariate analysis of variance (MANOVA) on RMSE was used to determine performance differences between dominant and nondominant legs. The significance level was established at p < .05. In addition to statistically significant findings, effect sizes (ES) were determined for practical effect. ES ≤ .20 were categorized as small, .20 < ES < .80 were moderate, and ES ≥ .80 were large (Cohen, 1988; Thomas, Salazar, & Landers, 1991).

Results

A repeated-measures analysis indicated significant main effect for age group on cycling performance (RMSE), F(2, 33) = 31.80, p < .001, and a significant Age Group x Pedaling Rate interaction, F(2, 33) = 16.87, p < .001. Follow-up ANOVAs for the interaction revealed that YC showed significantly higher RMSE (poor performance) than AD at all cadences (see Figure 1). In addition, YC performed significantly less accurately than OC at 40, 60, 100, and 120 rpm. OC were less successful than AD at 40, 80, 100, and 120 rpm.

ESs were calculated for each pairwise comparison. Because the comparison was made between two groups (i.e., YC and OC, YC and AD, OC and AD), the pooled standard deviation was used (Thomas et al., 1991).

ESs describing the performance accuracy (RMSE) differences between YC and OC were large, at 40, 60, 100, and 120 rpm (ES> .80). The effect sizes comparing YC and AD on RMSE were large across all cadences (ES>1.50). ES comparison between OC and AD on RMSE were also large across all cadences (ES> .80). Results suggested that OC’s performance was more accurate than YC’s; both groups were less successful than AD. The moderate-to-large ES suggested the true population effect may range between moderate and large.

Bilateral asymmetry was highest in the YC, followed by that in the OC, and AD. A repeated-measures ANOVA found a significant main effect for age group, F(2, 33) = 6.51, p < .01. A Scheffé post hoc test confirmed that YC had a significantly higher AI than the AD.

There were significant positive correlations between AI and RMSE at 40 rpm (r = .53, p < .001), 60 rpm (r = .56,
p < .001), 80 rpm (r = .56, p < .001), 100 rpm (r = .40, p < .05), and 120 rpm (r = .72, p < .001). For describing the magnitude or strength of the association between AI and RMSE, Cohen (1988) defined that r = .1 (absolute value) was a small correlation, r = .3 was medium, and r ≥ .5 was large. Our findings indicated that higher AI was related to poorer cycling performance (i.e., higher RMSE). Further, we examined the coefficient of determination to provide an estimate of the overlapping variance between AI and RMSE. The proportion of variance was different at 40 rpm

Figure 1. The age-related performance differences were statistically significant (*) between (a.) younger children (YC) and adults (AD), (b.) YC and older children (OC), and (c.) OC and AD at different cadences. Higher root mean square error (RMSE) scores indicated poor cycling performance.
(r² = .28), 60 rpm (r² = .31), 80 rpm (r² = .31), 100 rpm (r² = .16), and 120 rpm (r² = .52). Therefore, about 30% (on average) of the variance in RMSE was shared with AI, and 70% of the variance was unexplained by AI.

A MANOVA analysis revealed significant performance difference in RMSE between the dominant and nondominant leg, F(1, 36) = .29, p = .92. In addition, there was no significant Group x Dominant Leg interaction, F(1, 36) = .73, p = .70. These results suggest that leg dominance did not influence cycling performance.

Discussion

Data from this study lead to three general conclusions. First, children differed from AD in cycling performance and bilateral asymmetry. Children’s lower performance compared to AD can be attributed in part to increased asymmetry. This finding suggested that, as task demands increased (the pedaling rate changed), children’s ability to adapt and their capability to adjust to the changing task decreased. ES results indicated the OC’s performance was more accurate than the YC; both groups were less successful and produced more errors than the AD. The moderate to large ES suggested the true age-related performance effect may range between moderate and large.

Previous research suggested that the younger the performer, the more variable and less accurate the cycling performance (Jensen & Korff, 2004; Liu & Jensen 2009). This was consistent in the present study. Further, Chao, Rabago, Korff, and Jensen (2002) reported that YC showed significant declines in performance at extreme cadences (40 and 120 rpm). Also in line with the research, YC in the present study were less accurate at extreme cadences when compared to OC and AD groups.

Second, children were more asymmetrical than AD with changing pedaling rates. YC showed significantly higher AI than did AD. The positive correlation between AI and RMSE led us to believe that high AI may relate to poor cycling performance in YC. In addition, although bilateral asymmetry positively correlated with cycling performance, asymmetry changes with pedaling rate were unrelated to limb dominance. Musculoskeletal and motor control differences between limbs may play an important role in determining limb dominance. That is, asymmetry becomes less pronounced as the pedaling rate increases. This finding was consistent with previous research that bilateral asymmetry was not linked to leg dominance in adults (Chavet et al., 1997; Fergly & Zajac, 1996).

Third, we found that bilateral asymmetry would change with pedaling rate. The highest AI for all three age groups was 40 rpm, then AI decreased as the pedaling rate increased. Previous research showed that individuals’ preferred cycling cadences were between 70–90 rpm. Individuals felt comfortable and exerted less effort when they pedaled at their preferred cadence range (Liu & Jensen, 2009). Further, it is known that cycling at 40 rpm, which is a slow and nonpreferred cadence, normally requires individuals to pedal with more control, which is more difficult compared to other faster, preferred cadences. This finding was in line with previous literature and suggests that bilateral asymmetry becomes less pronounced as the pedaling rate increases (Chavet et al., 1997; Daly & Cavanagh, 1976; Fergly & Zajac, 1996).

The most significant implication of this study is the result that bilateral asymmetry can affect children’s cycling performance: Cycling is a timing task. Timing is important, because it is a key factor in sports, music, and general functioning (Ellis, 1992). Further, it has been reported that language organization coincides with preferred limb control (MacNeilage, 1991; Searleman, 1980). The results of this study increase our knowledge about the function of bilateral asymmetry leading to age-related differences in a timing task and have important implications for using asymmetry development to effectively teach motor skills in children and reduce the risk of overuse injuries (e.g., motor skills that require timing and bilateral symmetry, such as rowing, swimming, and cycling). Studying bilateral asymmetry in children can identify the less dominant limb to help improve training programs, assist children in learning timing tasks, and improve their sport and general life functioning (Teixeira, et al., 2003). In addition, identifying a pedaling rate that more evenly distributes pedaling forces to both legs would allow a teacher to select this pedaling rate for a child to reduce the knee loads transmitted by the more dominant leg. Thus, it could reduce the risk of overuse injuries in recreational cycling.

References


Chao, P., Rabago, C., Korff, T., & Jensen, J. L. (2002). Muscle activation adaptations in children in response to changes...


