Quiet Eye Distinguishes Children of High and Low Motor Coordination Abilities

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ABSTRACT

WILSON, M. R., C. A. L. MILES, S. J. VINE, and J. N. VICKERS. Quiet Eye Distinguishes Children of High and Low Motor Coordination Abilities. Med. Sci. Sports Exerc., Vol. 45, No. 6, pp. 00–00, 2012. Purpose: This is the first study to use the quiet eye (QE) as an objective measure of visuomotor control underpinning proficiency differences in children’s motor coordination. Methods: Fifty-seven, year 5 primary school children (9–10 yr old) completed the Movement Assessment Battery for Children, Second Edition (MABC-2), while wearing a gaze registration system. Participants were subsequently divided into one of three ability groups: high motor coordination (HMC), median motor coordination (MMC), and low motor coordination (LMC) based on these MABC-2 scores (mean % rank: HMC = 84%, MMC = 51%, LMC = 19%). QE analyses were performed for the fourth task of the MABC-2, which involved throwing a tennis ball against a wall and catching it on the return. Results: The HMC group was more successful in the catching task than both other groups (catching percentage: HMC = 92%, MMC = 62%, LMC = 35%) and demonstrated superior visuomotor control throughout the throwing and catching phases of the task. Compared with the other groups, the HMC group demonstrated longer targeting QE fixations before the release of the ball (HMC = 500 ms, MMC = 410 ms, LMC = 260 ms) and longer tracking QE durations before catching (HMC = 260 ms, MMC = 200 ms, LMC = 150 ms). There were no significant differences in ball flight time between the groups. Mediation analyses revealed that only the duration of the tracking QE predicted group differences in catching ability. Conclusions: Findings suggest that the ability to predict and calibrate movements based on sensory feedback may be impaired in children with movement coordination difficulties and have implications for how they are taught fundamental movement skills.

Key Words: VISUOMOTOR CONTROL, DCD, GAZE BEHAVIOR, CATCHING

Effective motor coordination is critical for the performance of functional movements underpinning physical activity and cardiorespiratory fitness in children and adolescents (4,12,20). It is well known that children with low motor coordination (LMC) score lower in cardiovascular endurance, balance, body composition, and movement time than their normally developing peers (12,20). Children with LMC also suffer from deficits in motor programming and attentional control (30,31), but much less is known about how deficits in how they mentally interact with the world underlay their physical deficits. Although studies have documented perceptual differences between LMC and "typically developing" children (8,19,23,37), these have been carried out using laboratory tasks where there has been no attempt to couple the child's visual perception of the task environment with their movements as a real-world task is performed.

Gaze registration techniques provide an insight into how external visual information is used to guide and control goal-directed motor actions (17). Research has shown that children with impaired motor coordination use less effective gaze strategies in controlled laboratory reaction time (9), visual tracking (19), and cued reach-to-grasp (37) tasks. Although laboratory tasks provide strong internal control, they therefore provide limited transferability to the sort of dynamic, interceptive tasks relevant to sport and physical activity. For this reason, there has been a call from researchers to extend the gaze analysis paradigm to more ecologically valid, real-life tasks (19,37).

The extensive body of literature in the sporting domain that has revealed a perceptual–cognitive advantage for expert performers (21) provides a useful departure point for research examining motor coordination in children in more ecologically valid settings. Expert performers direct high acuity foveal vision to the right place at the right time to provide accurate and timely information to the neural systems controlling goal-directed movements (17,33). This strategy has been termed the quiet eye (QE), defined as the final fixation or tracking gaze to a target before the initiation of a planned motor response (32). The QE has been proposed to reflect a critical period of cognitive processing...
during which the parameters of a motor skill, such as force, direction, and velocity, are fine-tuned and programmed (21,32). A growing body of research has revealed that there are consistent expert–novices differences with respect to the timing and duration of QE in both self-paced far-aiming tasks and interceptive tasks (for reviews, see 21,33,36).

The current study seeks to be the first to translate the knowledge about proficiency-related differences in QE in adults, to children of varying levels of motor coordination ability. Children with poor motor skills struggle particularly with the high degree of accurate coordination required to effectively perform dynamic interceptive tasks (2,3). We have therefore chosen to examine a throwing and catching task, as it not only successfully differentiates motor ability but also is a critical component of many sports and playground games. We hypothesize that more coordinated children will have a superior visuomotor strategy on both the targeting and tracking phases of a throw-and-catch task than children with low coordination. Specifically, children with high motor coordination (HMC) ability will reveal earlier and longer targeting QE periods during the prethrow phase and earlier and longer tracking QE periods on the ball before the catch attempt compared with children with LMC ability. As this strategy will provide advanced target information by which to accurately plan the catching action, coordinated children should also make more successful catches.

METHODS

Participants

Fifty-seven children (29 girls and 28 boys) were recruited from year 5 classes in two primary schools in the southwest of England (mean ± SD age = 10.4 ± 0.47 yr). Before commencing the study, ethical approval was gained from a local ethics committee, and informed written parental and participant consent was provided. Participants attended individually and were tested in a classroom provided for the duration of the research.

Tasks/Assessment

The Movement Assessment Battery for Children, Second Edition (MABC-2), was used to determine a motor coordination score for each participant (14). The test was designed to identify and describe impairments in the motor function of children and is one of the most used measures in both clinical and research settings (28). The MABC-2 consists of eight tasks designed for three age bands (3–6, 7–10, and 11–16 yr old), incorporating manual dexterity, aiming and catching, and balance elements. The child's performance on each of these tasks (either a score for accuracy or completion time) are age adjusted and converted to standardized scores. An overall score is then computed, which can be converted to a population percentile to aid diagnosis (14).

Apparatus

Each participant was fitted with an Applied Science Laboratories Mobile Eye gaze registration system (ASL, Bedford, MA), which measures momentary point of gaze at 30 Hz. The system incorporates a pair of lightweight (78 g) glasses fitted with eye and scene cameras and a portable recording device—a modified digital videocassette recorder. Gaze data were collected wirelessly to digital videotape and an experimenter held the videocassette recorder behind the participant to ensure that relevant objects were within the field of view. All testing equipment was provided with the MABC-2 assessment pack, and standard testing procedures were followed.

Experimental Protocol

Participants completed all eight tasks from the MABC-2 following the instructions outlined in the manual (14). The eye tracker was calibrated at the outset of the testing period and at the start of each new task, as the scene camera sometimes had to be adjusted to ensure that the field of view included the objects of interest. Although gaze data were collected for all tasks, we were most interested in the throwing and catching task (task 4): Not only is this interception skill highly relevant for sport and playground game participation, but specific predictions could be based on other targeting and interceptive tasks studied in the sport (33). Participants stood behind a line marked 2 m from a blank wall and were instructed to throw a tennis ball against the wall and attempt to catch it cleanly in their hands. They were instructed to use only their hands to catch the ball (not to gather it against their chests) and to not allow it to bounce on the floor before it reached them. They were allowed to step forward to catch the ball once they had thrown it. The task was first explained to the participant by a researcher and then demonstrated once. Participants were then given five practice trials to reduce practice effects, before completing 10 experimental trials with the outcome of each being recorded (catch/no catch).

Catching Performance

Catching performance was indexed by both an absolute score out of ten, expressed as a percentage (number caught cleanly × 100 / 10), and a standardized score—accounting for age differences—taken from tables in the MABC-2 manual (range 5–15) (14).

Ball Flight Times

Ball flight time (ms) was recorded as a proxy measure of how the throw and the catch were performed. Two specific phases were identified. 1) Ball flight 1 (throw: hand–wall) was defined as the time from ball release to wall contact and reflects the speed and trajectory of the throw (time “E” in Fig. 1). 2) Ball flight 2 (rebound: wall–hand) was defined as...
The gaze data were downloaded from digital tapes to a computer (Lenovo Thinkpad R500) using the Eyevision software (ASL). The location and the duration of gaze were then analyzed in a frame-by-frame manner for each throw, using Quiet Eye Solutions vision-in-action software (www.QuietEyeSolutions.com). The QE is the final fixation or tracking gaze directed to a single location or object in the performance space within 3° of visual angle for a minimum of 100 ms (33). This generic definition is operationalized for each task in relation to three consistent components: its onset, offset, and duration (time from onset to offset). Earlier and longer QE periods are indicative of more expert-like performance, whether they are fixations to a stationary target or a tracking gaze on a moving object (33). Figure 1 provides a schematic representation of how the QE variables were operationally defined with respect to the key actions and outcomes of the throw and catch task. All trials where a QE onset and offset could be determined were included to help calculate a mean value for each participant, to be used in subsequent analyses (see Results section).

**Targeting QE.** The onset of the targeting QE was defined as the start of the final fixation (within a 3° area on the wall) before the critical targeting action (33,36)—the release of the ball. As with other QE research for throwing tasks (32,38), the onset is reported relative to a standardized preparation phase—set at 2000 ms before the ball release (time “A” in Fig. 1). Offset occurred when the gaze deviated off the fixated location (by 3° or more) for more than three frames (100 ms). The targeting QE duration was therefore defined as the duration between targeting QE onset and offset (ms; time “B” in Fig. 1).

**Tracking QE.** In interceptive tasks such as catching, pursuit tracking on the object occurs before the hands contact the ball (1,25,27). Tracking QE onset (ms) was the first gaze on the ball as it traveled toward the participant (time “C” in Fig. 1). Offset occurred when the gaze deviated off the ball by more than 3° for three frames (100 ms) as it traveled toward the participant, or when the trial ended (end of ball flight time 2). Tracking QE duration was defined as the duration between tracking QE onset and offset (ms; time “D” in Fig. 1). To control for differences in throwing and catching strategies, we also calculated tracking QE onset and duration relative to ball flight time 2 (time “F” in Fig. 1) (6,7). The relative QE measures were therefore calculated as: \( \frac{(QE \times 100)}{ball \ flight \ time \ 2} \).

### Data Analysis

The MABC-2 performance data were recorded using a standardized answer booklet and scored in accordance with the test protocol, including age corrections and standardization procedures (14). A tertiary split was then performed on the MABC-2 percentile scores for the sample, creating an HMC group, a median motor coordination (MMC) group, and an LMC group. One-way ANOVA (Statistical Package for the Social Sciences, version 19; SPSS Inc., Chicago, IL) were computed to compare differences in MABC-2 score, catching performance, ball flight, and QE measures between these three groups. Effect sizes were calculated using partial eta squared (\( \eta^2 \)) for omnibus comparisons, and LSD post hoc tests were used to interrogate significant main effects.

As significant group differences in the visuomotor variables of interest may be due in part to functional differences between “catch” and “no-catch” attempts (LMC will have fewer successful catches than HMC participants), we also ran the ANOVAs on caught trials only. Mediation analyses were finally computed to determine whether any QE measures mediated between-group differences in catching performance, using the MEDIATE SPSS custom dialog (13). This process determines the total, direct, and indirect effect of group on catching performance, through a series of proposed mediators, allowing inferences to be made about the indirect effects using percentile bootstrap confidence intervals.

### RESULTS

The gaze data of some participants were of poor quality and could not be accurately coded. In order for a participant to be included in the analyses, a minimum criterion of 3 of 10 codable trials was set for each QE variable (see degrees of freedom for each analysis). A second analyst blindly
scored 10% of the codable trials (one from each participant), and interrater reliability was assessed using the interobserver agreement method (29). This analysis revealed a satisfactory level of agreement at 92.5% (24).

Movement Assessment Battery for Children, Second Edition

Motor coordination ability varied across the sample of 57 children (mean ± SD MABC-2 percentile rank = 51.05 ± 26.38, range = 97.90). Four participants were classified as “highly likely” to have a clinical movement disorder (developmental coordination disorder [DCD]), scoring below the 5th percentile of a population norm (14). A further four children were found to be at risk of having DCD as they scored below the 16th percentile. At the high end of the range, two children scored at or above the 95th percentile, demonstrating excellent movement coordination, and a further 10 children scored at or above the 84th percentile.

A tertiary split of the sample population was performed based on MABC-2 percentile rankings. The LMC group contained 16 participants (6 females and 10 males) with an MABC-2 score of 64.06 ± 13.12 and a percentile rank of 18.76 ± 8.58 (mean ± SD). The MMC group contained 25 participants (10 males and 15 females) with an MABC-2 score of 79.24 ± 3.96 and a percentile rank of 50.52 ± 10.92 (mean ± SD). The HMC group was made up of 16 participants (8 females and 8 males) with a an MABC-2 score of 91.13 ± 3.61 and a percentile rank of 84.19 ± 7.02 (mean ± SD). The ANOVA yielded a significant effect of group on MABC-2 score ($F_{2,54} = 40.49$, $P < 0.001$, $\eta^2 = 0.65$) and percentile rank ($F_{2,54} = 106.41$, $P < 0.001$, $\eta^2 = 0.88$). The LSD comparisons revealed significant differences in movement coordination score and percentile rank between all three groups (all $P$ values < 0.001). Age was not significantly correlated with percentile rank ($r = -0.16$, $P = 0.242$) or MABC-2 score ($r = -0.18$, $P = 0.182$), and independent $t$-tests showed there was no significant difference between sexes in percentile rank (t55 = 0.93, $P = 0.358$) or MABC-2 score (t55 = 1.30, $P = 0.200$). The MABC-2 data are presented in Table 1.

### Catching Performance

ANOVA yielded a significant group difference in percentage number of balls caught ($F_{2,54} = 18.78$, $P < 0.001$, $\eta^2 = 0.41$) and the standardized catching score ($F_{2,54} = 16.46$, $P < 0.001$, $\eta^2 = 0.38$). LSD comparisons revealed that the HMC group performed significantly better than either the MMC or the LMC groups (all $P$ values < 0.001), and the MMC group performed significantly better than the LMC group ($P = 0.002$ for balls caught and $P = 0.048$ for score). Age was not significantly correlated with catching performance, $r = -0.15$, $P = 0.274$, although boys were significantly better at catching than girls, $t(55) = -2.33$, $P = 0.024$. The catching performance data are presented in Table 1.

### Ball Flight

ANOVA revealed no significant group differences in ball flight 1 (throw; $F_{2,45} = 2.06$, $P = 0.140$), ball flight 2 (rebound; $F_{2,45} = 0.44$, $P = 0.645$), or total ball flight time ($F_{2,45} = 1.58$, $P = 0.217$). The ball flight data are presented in Table 2.

### Targeting QE

**Onset.** ANOVA revealed a significant difference in the time to targeting QE onset between the groups ($F_{2,44} = 8.30$, $P = 0.001$, $\eta^2 = 0.27$). LSD comparisons demonstrated that the LMC group had significantly later onsets than both the MMC ($P = 0.012$) and the HMC ($P < 0.001$) groups. Although the MMC group also had a later onset than the HMC group, this difference only approached significance ($P = 0.076$). Targeting QE onset data are presented in Table 3.

**Offset.** There were no significant differences in the offset time ($F_{2,44} = 2.19$, $P = 0.124$), with all groups ending their fixation on the wall at around the point of ball release (see Table 3).

### Duration

There were significant differences in the duration of the targeting QE period between groups ($F_{2,44} = 10.12$, $P < 0.001$, $\eta^2 = 0.32$). LSD comparisons revealed that the LMC group had significantly shorter QE periods than both the MMC ($P = 0.003$) and the HMC ($P < 0.001$) groups.

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### Table 1. Movement ability and catching performance data for LMC, MMC, and HMC groups.

<table>
<thead>
<tr>
<th></th>
<th>LMC</th>
<th>MMC</th>
<th>HMC</th>
<th>$F_{2,54}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MABC-2 score</td>
<td>64.06 ± 13.12</td>
<td>79.24 ± 3.96</td>
<td>91.13 ± 3.61</td>
<td>50.49***</td>
</tr>
<tr>
<td>MABC-2 % rank</td>
<td>18.76 ± 8.58</td>
<td>50.52 ± 10.92</td>
<td>84.19 ± 7.02</td>
<td>196.41***</td>
</tr>
<tr>
<td>Catching Performance (% caught)</td>
<td>35.00 ± 32.86</td>
<td>62.00 ± 27.84</td>
<td>91.88 ± 12.76</td>
<td>18.78***</td>
</tr>
<tr>
<td>Catching Performance (standardized score)</td>
<td>7.50 ± 2.66</td>
<td>9.12 ± 2.52</td>
<td>12.44 ± 2.28</td>
<td>16.46***</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD. MABC-2 score range = 73. Letters a and b indicate significant differences from LMC and MMC group values, respectively.

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### Table 2. Ball flight times (ms) for LMC, MMC, and HMC groups.

<table>
<thead>
<tr>
<th></th>
<th>LMC</th>
<th>MMC</th>
<th>HMC</th>
<th>$F_{2,45}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball flight (throw)</td>
<td>363.54 ± 60.73</td>
<td>351.86 ± 94.31</td>
<td>305.39 ± 74.76</td>
<td>2.06</td>
</tr>
<tr>
<td>Ball flight 2 (rebound)</td>
<td>506.42 ± 46.33</td>
<td>515.86 ± 72.81</td>
<td>496.49 ± 33.63</td>
<td>0.44</td>
</tr>
<tr>
<td>Total ball flight (throw + rebound)</td>
<td>889.96 ± 96.43</td>
<td>867.14 ± 121.66</td>
<td>806.46 ± 77.54</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD. No significant group differences found.

*Degrees of freedom for ball flight 2 and total ball flight were (2,44).
Although the MMC group also had a shorter QE period than the HMC group, this difference only approached significance \((P = 0.098)\). Targeting QE duration data are presented in Table 3.

### Tracking QE

**Onset.** ANOVA yielded an almost significant group difference in the time to tracking QE onset \((F_{2,40} = 3.10, P = 0.056, \eta_p^2 = 0.13)\). As this finding approached significance, LSD analyses were carried out. These revealed that the effect was largely driven by the LMC group having significantly later onsets than the HMC group \((P = 0.018)\). The effect of standardizing this time with respect to ball flight 2 (relative tracking QE onset) was negligible \((F_{2,40} = 3.14, P = 0.054, \eta_p^2 = 0.14)\). Tracking QE onset data are presented in Table 4.

**Offset.** The ANOVA on both the absolute tracking offset data \((F_{2,40} = 2.85, P = 0.069, \eta_p^2 = 0.13)\) and the relative tracking offset data \((F_{2,40} = 2.68, P = 0.081, \eta_p^2 = 0.12)\) also only approached significance. Again, this effect was driven by the significant differences in offset between LMC and HMC groups \((P = 0.022\) and 0.027, respectively). Tracking QE offset data are presented in Table 4.

**Duration.** ANOVA revealed a significant difference for the duration of the tracking QE duration \((F_{2,40} = 13.66, P < 0.001, \eta_p^2 = 0.41)\). LSD comparisons showed that the LMC group had significantly shorter tracking durations than both the MMC \((P = 0.005)\) and the HMC \((P < 0.001)\) groups. The MMC group also had significantly shorter tracking durations than the HMC group \((P = 0.007)\). When the tracking duration was standardized to account for ball flight time 2, the between-group ANOVA remained significant \((F_{2,40} = 12.29, P < 0.001, \eta_p^2 = 0.38)\). LSD comparisons remained significant between all groups. Tracking QE duration data are presented in Table 4.

### Caught Trials Only

When only the trials that resulted in a catch were subjected to the same ANOVA as described previously for all codeable trials, the significant main effects for targeting QE onset and duration and tracking QE duration (absolute and relative) remained but were reduced. Table 5 provides a detailed summary of the ball flight and QE data for caught trials only.

### Mediation

To check whether catching performance had been mediated by any of the gaze variables, group (coded as 1 = HMC, 2 = MMC, 3 = LMC) was entered as the independent variable, catching performance score as the dependent variable, and the significant QE measures from the ANOVA individually entered as mediators. Results from bootstrapping (based on 10,000 sampling rate) indicated that there was only a significant indirect effect for tracking QE duration \((95\% \text{ confidence interval} = 2.80–24.00)\). When caught trials only were considered, no QE variables mediated the significant group performance differences.

### DISCUSSION

This is the first study to measure the QE in children, providing a novel examination of processes underpinning differences in children’s motor coordination ability. The strength of the study was that it used an ecologically valid interception task (throwing and catching), that not only has relevance to sport and playground games but also has been shown to have predictive validity in many studies \((28)\). We hypothesized that children with HMC ability would reveal a perceptual–cognitive advantage over less coordinated children. Specifically, we predicted that they would demonstrate earlier and longer targeting QE fixations (prethrow) and earlier and longer tracking QE gaze (precatch). We also performed additional mediation analyses to better understand which (if any) of these gaze differences mediates catching ability. This final step is seldom performed in the QE or motor expertise literature \((24)\) and is necessary to avoid overinflating the importance of “matching” group effects across variables of interest.

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**TABLE 3. Targeting QE variables for LMC, MMC, and HMC groups.**

<table>
<thead>
<tr>
<th></th>
<th>LMC</th>
<th>MMC</th>
<th>HMC</th>
<th>(F_{2,40})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targeting QE Onset (ms)</td>
<td>1705.98 ± 84.72</td>
<td>1607.06 ± 112.57 (^a)</td>
<td>1533.32 ± 135.10 (^a)</td>
<td>8.30**</td>
</tr>
<tr>
<td>Targeting QE Onset (ms)</td>
<td>1964.97 ± 60.43</td>
<td>2016.80 ± 105.88</td>
<td>2029.70 ± 84.45</td>
<td>2.19</td>
</tr>
<tr>
<td>Targeting QE Duration (ms)</td>
<td>258.99 ± 88.19</td>
<td>409.74 ± 151.99 (^a)</td>
<td>496.38 ± 170.69 (^a)</td>
<td>10.12***</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD. Letters a and b indicate significant differences from LMC and MMC group values, respectively.

- \(^aP < 0.05\), \(^bP < 0.001\), \(^*P < 0.001\), \(^**P < 0.01\), \(^***P < 0.001\).
Table 5. Ball flight and QE variables for caught trials only, for LMC, MMC, and HMC groups.

<table>
<thead>
<tr>
<th></th>
<th>LMC</th>
<th>MMC</th>
<th>HMC</th>
<th>F</th>
<th>Degrees of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball flight 1 (ms)</td>
<td>314.54 ± 31.81</td>
<td>316.46 ± 41.05</td>
<td>308.95 ± 76.20</td>
<td>0.08</td>
<td>(2.36)</td>
</tr>
<tr>
<td>Ball flight 2 (ms)</td>
<td>490.47 ± 43.33</td>
<td>480.50 ± 55.92</td>
<td>502.89 ± 33.63</td>
<td>0.73</td>
<td>(2.31)</td>
</tr>
<tr>
<td>Total ball flight (ms)</td>
<td>799.79 ± 64.70</td>
<td>794.28 ± 65.93</td>
<td>814.97 ± 78.01</td>
<td>0.29</td>
<td>(2.31)</td>
</tr>
<tr>
<td>Targeting QE Onset (ms)</td>
<td>1755.36 ± 69.82</td>
<td>1556.54 ± 142.31</td>
<td>1535.65 ± 136.05</td>
<td>7.54** (2.36)</td>
<td></td>
</tr>
<tr>
<td>Targeting QE Offset (ms)</td>
<td>2000.01 ± 30.25</td>
<td>2010.95 ± 90.94</td>
<td>2059.03 ± 84.54</td>
<td>0.37</td>
<td>(2.36)</td>
</tr>
<tr>
<td>Targeting QE Duration (ms)</td>
<td>264.65 ± 89.40</td>
<td>454.41 ± 145.08</td>
<td>493.35 ± 170.80</td>
<td>7.34** (2.36)</td>
<td></td>
</tr>
<tr>
<td>Tracking QE Onset (ms)</td>
<td>195.36 ± 53.26</td>
<td>184.56 ± 64.36</td>
<td>149.55 ± 43.74</td>
<td>1.86</td>
<td>(2.31)</td>
</tr>
<tr>
<td>Relative tracking QE Onset (%)</td>
<td>34.95 ± 9.82</td>
<td>38.87 ± 13.00</td>
<td>29.09 ± 8.05**</td>
<td>3.05 (2.31)</td>
<td></td>
</tr>
<tr>
<td>Tracking QE Offset (ms)</td>
<td>389.79 ± 70.11</td>
<td>388.16 ± 60.15</td>
<td>408.80 ± 53.18</td>
<td>0.42</td>
<td>(2.31)</td>
</tr>
<tr>
<td>Relative tracking QE Offset (%)</td>
<td>73.96 ± 11.50</td>
<td>80.86 ± 9.28</td>
<td>81.18 ± 7.62</td>
<td>0.09</td>
<td>(2.31)</td>
</tr>
<tr>
<td>Tracking QE Duration (ms)</td>
<td>193.43 ± 29.74</td>
<td>203.60 ± 47.23</td>
<td>259.25 ± 61.43**</td>
<td>5.31** (2.31)</td>
<td></td>
</tr>
<tr>
<td>Relative tracking QE duration (%)</td>
<td>39.54 ± 4.58</td>
<td>43.36 ± 9.46</td>
<td>51.17 ± 11.04**</td>
<td>3.97 (2.31)</td>
<td></td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD. Letters a and b indicate significant differences from LMC and MMC group values, respectively.
than typically developing children. In relation to the current study, LMC children may have greater difficulty in determining the consequences of using a particular level of force when throwing. We suggest that this may be not due to limitations in physiology and/or biomechanical characteristics but due to deficits in identifying relevant targets in space, allocating sufficient visual attention to that location to be successful, and predicting the consequences of the ensuing action. These children therefore base their catching movement on inaccurate cues, formulate inaccurate motor plans, and gain inappropriate feedback due to inhibited perception and sensory feedback—driven in the main by their shorter QE periods.

There are some caveats to the findings presented, which are reflective of limitations in the study design. Although using a standardized task with existing normative comparisons was the strength of the study, the MABC-2 protocol also added some constraints. First, the low number of trials meant that it was difficult to examine intraindividual differences in visuomotor control in participants who were at either end of the ability spectrum: 13 participants caught all 10 attempts, whereas 7 participants caught none. The power of the analyses was reduced when participants had to be omitted for having insufficient successful trials to analyze (Table 5). Second, the scoring system is rather imprecise and fails to distinguish between better and poorer attempts, where the result was still a failed catch. The imprecision of the dependent variable in the mediation analyses may therefore partially explain why more potential mediators were not found. Future studies could seek to apply more precise quantitative judgments of catching performance, which may be more sensitive to differences in visuomotor strategy (26). A third limitation of the study, reflected in the findings of the mediation analysis for the caught trials, was that other unconsidered variables are clearly important for the successful completion of the task. Although we found no differences in our proxy measure of how the task was performed (ball flight times), this is a rather crude measure. Future research should look to perform more detailed movement kinematic analyses of the participants during the task to further our understanding of the processes underpinning successful interception skill in children (2,22).

Although the results of this first study investigating the QE phenomenon in children need to be replicated for other tasks, they suggest that children with high movement coordination are better able to predict ball flight for the interceptive task of throwing and catching a ball. This interpretation is supported by previous QE research in interceptive tasks with adults (1,6,25,27), and by research examining more abstract tasks in adults (10,11), and in children with DCD (2,3,16,37). The findings also suggest that interventions designed to improve such prediction may be useful to support children with conditions like DCD. Indeed, a systematic review of DCD interventions found that those focusing on supporting perceptual motor training displayed the most positive benefits (15). There may therefore be utility in designing QE training interventions for basic interceptive tasks like catching, which are important building blocks to increased physical activity. Previous research has supported the efficacy of such training interventions in other interceptive tasks with skilled adults (1,7) and for targeting tasks with novice performers (24,34,35). Although such interventions will need to be specifically tailored to the needs of children with motor coordination difficulties, there is evidence to suggest that QE training may have additional benefits for psychological constructs related to control and beliefs about success (39). It is recognized that children with DCD have lower beliefs about their ability to be successful in performing movement skills (5) and may therefore especially benefit from QE training.

To conclude, the current study was the first to examine the QE phenomenon in children and answers the call from researchers to examine the processes underpinning movement coordination difficulties in real-life tasks (19,37). Children with LMC ability demonstrated impaired visuomotor control and performance in a throwing and catching task, which were related to an inability to accurately track the ball as it rebounded off the wall. These results need to be replicated with other tasks, but there appears to be utility in exploring the application of QE training to populations outside of adult sport performers. Such interventions may help children with LMC to break the negative cycle linking low motor skill competence with low levels of physical activity and cardiorespiratory fitness.

The authors declare no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

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