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Changes in motor skill and fitness measures among children with high and low motor competence: A five-year longitudinal study

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Summary Children with low motor competence (LMC) are less able to participate fully in many sports and recreational activities typically enjoyed by their well-coordinated peers. Poor fitness outcomes have been reported for these children, although previous studies have not tracked these outcomes over time. In this study, 19 children (8 girls and 11 boys) with LMC aged between 5 and 7 years were matched by age and gender with 19 children with high motor competence (HMC). Six fitness (body composition and cardiovascular endurance) and motor skill (sprint run, standing broad jump and balance) measures were repeated for each group once a year for five years. For each year of the study, the LMC groups performed less well on all measures than the HMC groups. Changes over time were significantly different between groups for cardiovascular endurance, 50-m run and balance, but not for body composition, overhand throw or standing broad jump. Between the two groups, performances were significantly different for all measures, except body composition. These findings confirm the impact of LMC on fitness measures and skill performances over time.

Introduction

Children with motor difficulties are unable to participate successfully in many physical activities enjoyed by their well-coordinated peers. In addition, they have difficulty with everyday tasks important in home, school and social life.[1] As a consequence there may be a reduction in their perceived motor competence,[2] confidence and motivation to participate in physical activity,[3] and, as a result, they withdraw from physical activity opportunities. Bouffard et al.[4] describe this phenomenon as an 'activity deficit'.

One of the many consequences of reduced activity is that fitness components, such as muscle strength and endurance, flexibility, cardiovascular endurance and anaerobic performance are compromised. While motor-coordination may confound some fitness measures, cross-sectional studies have

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shown that young children with low motor competence (LMC) are consistently outperformed by their well-coordinated peers.[5–11] In a study of 85 children with LMC, performances on push-ups, a test of muscle strength and endurance, ranged between 0 and the 65th percentile rank.[10] Hammond[6] used the flexed arm-hang to measure upper limb strength in 17 children with LMC. Their performances ranged between the 5th and 62nd percentile rank. Extreme ranges of flexibility and inflexibility can be observed in this population.[6,10] Hyperflexibility reduces stability around the joint and may make controlled movement difficult, and hypoflexibility limits the range of movement of joints and therefore restricts movement. Reduced cardiovascular endurance was reported for children with LMC compared to well-coordinated children when completing a distance run over 800[5,6] and 1600 m.[12] O'Beirne et al.[11] compared 50-m run times (anaerobic performance) for 24 boys aged between 7 and 9 years with LMC to 24 coordinated controls. The boys with LMC were significantly slower than their peers. The recorded heart rates of children with LMC undertaking a multistage shuttle run reached a maximal level much earlier than a control group and consequently, these children were unable to sustain the task as long.[13] The relationship between body composition and motor competence is less conclusive. Some studies have reported higher levels of overweight and obesity among children with LMC,[6,11,14,15] whereas others have only found significant difference among boys.[16] Low fitness outcomes combined with inefficient motor patterns can contribute to early fatigue[11,13] and thereby, limit opportunities to develop motor skills through playground play, after-school sport and backyard activities.

What is not evident from studies investigating fitness and motor skills performances in children with LMC is whether the reported deficits, when compared to typically developing children, increase or decrease with time and maturity. Few studies have tracked motor skill and fitness variables over time in this population. If the activity deficit hypothesis is correct,[4] children with poor motor competence would increasingly withdraw from physical activity opportunities, and the potential for relatively poorer outcome in fitness levels would increase. Where fitness measures were tracked over time in typically developing children, changes in physical activity level were only related to flexibility among girls and cardiovascular endurance among boys.[17] However, where children with LMC have been tracked into adolescence, quite a few continue to experience motor problems, as well as educational, social and emotional difficulties.[18–20]

The purpose of this paper is to report the results of a subsample of children participating in a longitudinal study tracking fitness and skill levels of children attending a school in metropolitan Perth, Australia. A group of children with LMC were identified in the first year of the study through a motor screen undertaken by all children aged 5 to 7 years. Their fitness and motor skill results for five consecutive years are reported in comparison to a group of same-aged peers who were identified as having high motor competence (HMC).

Method

In 2000, a whole-school fitness and skills testing program was undertaken at a local primary school in the Perth metropolitan area by second-year university students as part of a course requirement and overseen by the author. Prior to the testing day, the students received intensive training in test protocol to ensure inter-rater reliability. As part of the initial phase, students aged between 5 and 7 years completed a four-item gross motor screening test, stay in step (SIS).[21] Subsequently, the fitness and skill measures were repeated at the same time each year for five consecutive years.

Participants

From the pool of 564 students who participated in the year 2000, 85 girls (aged 5 years, $n = 33$; 6 years, $n = 26$, and 7 years, $n = 26$) and 101 boys (aged 5 years, $n = 39$; 6 years, $n = 28$, and 7 years, $n = 34$) completed the gross motor screening test for this age group.[21] From this group of participants, 19 students or 18.8% were identified as having LMC. This group comprised eight girls ($M = 5.75$ years) and 11 boys ($M = 5.91$ years). The prevalence of LMC, sometimes referred to as developmental coordination disorder (DCD), has been estimated to range between 6 and 22%, depending on the assessment strategy.[1] The 19 students were subsequently matched for age (within three months) and gender with 19 students who were identified as having HMC. Thus, 38 students were selected for the current study. In 2000, the cohort was aged between 5 and 7 years, maturing to between 10 and 12 years in 2004. Ethical approval for the study was granted by the University of Notre Dame Australia and National Health and Medical Research Council (NHMRC) guidelines were adhered to at all times.

Measures

Motor competence screening test

Stay in step (SIS) is a gross motor screening test for children ranging in age from 5 to 7 years that has established test–retest reliability for each item ranging between $R = .87$ to $R = .90$ and has been validated for identifying children with poor coordination.[21,22] The four motor skills that make up the SIS are: balance on one foot; volleyball bounce and catch; single hop for distance; and the 50-m run.

Balance on one foot
This test assessed the individual's postural stability while balancing on one foot with eyes open. The participant, with hands on hips, lifted one leg and attempted to balance for a maximum time of 40 s. Time recording was stopped when the unused leg or hand touched the ground, when the participants began to hop, moved their foot from the starting position or when the 40-s time limit was reached. This was repeated on the other leg.

Volleyball bounce and catch
This test assessed the participants' bouncing and catching ability with a large ball. The skill required eye-hand coordination, postural stability, body positioning and control of force over the ball. Standing in an upright position, the participant bounced and caught the ball as many times as possible for a set time of 20 s and the number of complete catches was recorded.

Single hop for distance
This test assessed the explosive movement of a hop for distance. The test required dynamic balance, coordination and leg power. From a stationary position on one foot, the participants completed a single hop as far as possible. Both legs were tested for two trials.

50-m run
This test assessed running speed and required dynamic balance, coordination of arms and legs and anaerobic power. Individually, the participants ran a 50-m course at maximal speed. The time recorded was an indication of leg speed and lower body power.

To be identified as LMC, performances must be categorised as 'low' or 'very low' on at least three of the four test items. On the other hand, a HMC classification is given to children whose performances are categorised as 'high' or 'very high' on at least three of the four test items.

Repeated fitness and motor skill measures

For five consecutive years, the students participated in a battery of fitness and motor skill field tests, which included the 50-m run described above and five other tests described below.

Body composition
Each participant's height and weight measures were used to derive body mass index (BMI) calculated as weight/height^2. Students were classified as acceptable weight, overweight or obese, using internationally-accepted cut points according to age and sex.[23]

The multi-stage fitness test
This test assessed aerobic capacity by using a progressive shuttle run back and forth over a 20-m course. Cadence beeps increased the running speed by 0.5 km/h each minute. Participants ran for as long as possible until they were unable to keep up with the cadence (maximal effort at the end). When each participant was two or more steps from the end line on two consecutive shuttles, the test ended.

Overhand throw
Each participant stood behind a line and threw a tennis ball as far as possible using an overhand throwing pattern. Three throws were measured and the longest distance recorded in centimetres.

Standing broad jump
Each participant stood behind a line with feet slightly apart and used a two-foot take-off to jump as far as possible. The distance in centimetres was recorded for the best of three jumps.

Balance
The protocol followed for the whole-school testing was different to that followed in the SIS. Balance on one foot was timed for a maximum of 30 s.[24] The recording of time was stopped when the other leg touched the ground, the participants began to hop or move their foot from the starting position or when 30-s time limit was reached. Participants were required to complete four separate trials, on preferred and nonpreferred leg with eyes open, and on preferred and nonpreferred leg with eyes closed. If a trial lasted less than 10 s, it was repeated. A composite score for each participant was derived from the four trials.

Statistical analyses

An initial examination of the data matrix revealed that some of the data points were missing for some students in both the LMC and HMC groups over the five years. Of the 570 measures gathered over the five years (30 data points for 19 children), 63 were randomly missing. This was because the participants were absent from school on the day the data were collected for one year of the study phase. Rather than restrict the analysis to participants with complete data sets, estimates of the missing data were made using the expectation-maximisation estimation method (EM). EM finds maximum likelihood estimates in probabilistic models and can be used to estimate and impute missing data if they are missing at random.[25] Data replacement procedures allow statistical power to be maintained.[26,27] Initially, the data were analysed separately for males and females. However, no significant differences emerged. Subsequent analyses included all participants. A mixed between-within subjects analysis of variance was conducted for each test item to compare scores over time (with-in subjects) and between competency groups.

Results

The mean, standard deviations and range of scores for each group over time are shown in Table 1. As would be expected, the analyses of variance revealed that changes in outcomes over time within both groups were significant for all measures. Changes over time were significantly different between groups for cardiovascular endurance, 50-m run and static balance, but not for body composition, overhand throw or standing broad jump. Between the two groups, performances were significantly different for all measures except body composition. The detailed results for the analyses of variance are reported below for each test item.

Body composition

There was a statistically significant main effect for time, Wilk's Lambda = .32, $[F(4,33) = 17.17, p < .0005]$, with a large effect size (partial eta squared = .67). The changes over time were similar for both groups with no significant interaction effect detected, Wilk's Lambda = .94, $[F(4,33) = .50, p = .73]$, and a small effect size (partial eta squared = .06). The main effect for

Table 1 Mean and 95% confidence interval for high motor competence (HMC) and low motor competence (LMC) groups

			2000		2001		2002		2003		2004	
Test	Group	*n*	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
BMI (wt/ht^2)	LMC	19	16.01	14.9–17.2	16.93	15.6–18.3	17.82	16.4–19.2	18.03	16.4–19.6	18.71	17.1–20.3
	HMC	19	15.20	14.6–15.8	15.77	15.0–16.5	16.22	15.4–17.0	16.78	16.1–17.4	17.28	16.4–18.1
Balance (s)	LMC	19	29.63	20.6–38.7	63.09	52.4–73.7	65.32	56.5–74.1	85.47	78.3–92.6	77.64	70.1–85.1
	HMC	19	66.30	8.3–74.3	88.50	78.9–98.1	101.60	93.9–109.3	105.55	98.5–112.6	95.27	88.7–101.8
Run (s)	LMC	19	14.48	13.6–15.3	12.18	11.7–12.6	11.69	11.2–12.2	12.36	11.3–13.4	10.35	9.9–10.7
	HMC	19	11.15	10.6–11.7	10.18	9.8–10.6	9.90	9.6–10.2	9.81	9.5–10.1	9.03	8.7–9.3
Throw (cm)	LMC	19	828.7	675.4–982.0	1119.3	894.2–1344.4	1126.8	979.2–1274.4	1368.8	1187.5–1550.2	1646.0	1459.9–1832.0
	HMC	19	1210.1	946.5–1473.6	1516.4	1267.1–1765.9	1614.2	1403.3–1825.1	1990.6	1715.8–2265.4	2248.1	1989.6–2506.7
SBJ (cm)	LMC	19	90.71	80.2–101.2	102.42	93.5–111.4	110.00	99.6–120.3	115.41	104.6–126.2	125.19	116.6–133.7
	HMC	19	118.2	110.3–126.2	139.78	131.7–147.8	149.18	141.1–157.1	148.96	140.5–157.4	153.11	145.5–160.7
MSFT (shuttles)	LMC	19	16.90	15.2–18.6	10.46	8.8–12.1	21.02	18.4–23.6	24.67	21.6–27.7	22.55	18.4–26.7
	HMC	19	21.53	17.8–25.2	19.71	14.3–25.1	35.22	29.4–41.0	34.63	30.0–39.8	35.94	29.4–42.5

between competency groups was not significant [$F(1,36) = 3.69$, $p = .06$].

MSFT

There was a statistically significant main effect for time, Wilk's Lambda = .21, [$F(4,33) = 30.30$, $p < .0005$], with a large effect size (partial eta squared = .79). There was also a significant interaction effect, Wilk's Lambda = .74, [$F(4,33) = 2.8$, $p \leq .05$], and large effect size (partial eta squared = .26). The main effect for between groups was significant [$F(1,36) = 22.32$, $p \leq .0005$] with a large effect size (partial eta squared = .38).

50-m run

There was a statistically significant main effect for time, Wilk's Lambda = .12, [$F(4,33) = 62.81$, $p < .0005$], with a large effect size (partial eta squared = .88). There was also a significant interaction effect, Wilk's Lambda = .54, [$F(4,33) = 6.99$, $p \leq .0005$], and large effect size (partial eta squared = .46). The main effect for between groups was also significant [$F(1,36) = 54.57$, $p \leq .0005$] with a large effect size (partial eta squared = .60).

Overhand throw

There was a statistically significant main effect for time, Wilk's Lambda = .08, [$F(4,33) = 90.41$, $p < 0005$], with a large effect size (partial eta squared = .92). There was not a significant interaction effect, Wilk's Lambda = .82, [$F(4,33) = 1.86$, $p \geq 05$], and a large effect size (partial eta squared = .18). The main effect for between groups, however, was significant [$F(1,36) = 13.78$, $p \leq .005$] with a large effect size (partial eta squared = .28).

Standing broad jump

There was a statistically significant main effect for time, Wilk's Lambda = .17, [$F(4,33) = 40.93$, $p < .0005$], with a large effect size (partial eta squared = .83). There was not a significant interaction effect, Wilk's Lambda = .79, [$F(4,33) = 2.20$, $p \geq .05$], but a large effect size (partial eta squared = .21). The main effect for between groups, however, was significant [$F(1,36) = 45.08$, $p \leq .0005$] with a large effect size (partial eta squared = .56).

Balance

There was a statistically significant main effect for time, Wilk's Lambda = .15, [$F(4,33) = 48.19$, $p < .0005$], with a large effect size (partial eta squared = .85). There was also a significant interaction effect, Wilk's Lambda = .75, [$F(4,33) = 2.77$, $p \leq .05$], and a large effect size (partial eta squared = .25). The main effect for between groups was also significant [$F(1,36) = 71.36$, $p \leq .0005$] with a large effect size (partial eta squared = .66).

Discussion

Overall, the results supported findings from other studies. As shown in Table 1, the results of the group with LMC were poorer for most fitness items; with a lower performance on the broad jump, slower speed on the 50-m run, reduced balance times, shorter distance throws and lower cardiorespiratory endurance as measured by the MSFT each year. There was no difference between the groups for BMI. These findings confirm the impact of LMC on fitness measures and skill performances over time. While performances on all measures improved significantly for both LMC and HMC groups between 2000 and 2004, the relative differences in outcomes between groups remained similar. The HMC group outperformed the LMC group. Significant time by group interactions for the 50-m run, balance and MSFT indicated that differences between the two groups reduced for the first two tests, but became greater for the latter test. Overall, these results suggest that children who perform poorly on motor skills or have low fitness components when young are unlikely to catch up to their peers with age.

There are two contradictory views on the long term consequences of motor coordination difficulties.[28] One suggests that movement difficulties are temporary and decrease, or even disappear, with age.[29] Erhardt et al.[30] argue that these children simply take longer to reach a performance ceiling. This view is supported by the performance outcomes for static balance, 50-m and possibly the standing broad jump. For the first two tasks the difference over time between the two groups significantly reduced and performances started to level out. For the balance task, several participants in both groups achieved a maximum score of 120 s over the last two or three years. A similar trend was apparent for the standing broad jump, where the mean distance jumped by the HMC group had reached a plateau, yet the mean LMC group performance was still showing an upward trend, and for the 50-m run, where the average time was dropping more steeply for the LMC group than the HMC group. A more pessimistic view suggests that those children with relatively severe movement difficulties continue to experience persistent movement related difficulties into adolescence and possibly adulthood,[20] and their difficulties may even increase with age. While the results suggest that the LMC group will never achieve the same results as the HMC group, the differences increased for the MSFT, commonly known as the shuttle run. This task measures cardiovascular endurance which is developed and maintained through regular participation in vigorous physical activity and may be the fitness component that with time is most affected by LMC. A relationship between motor competence and cardiorespiratory endurance, particularly for the girls, has been observed in older children.[31] Cairney et al.[32] also observed significant performance differences between children with and without DCD on the shuttle run.

One encouraging aspect of these results is that most skill outcomes did not deteriorate with age among the children with LMC relative to the HMC group, a result that might be expected as the result of long term inactivity.[4] These findings are similar to those reported by Cairney et al.[33], who investigated the activity—deficit with age hypothesis by comparing time spent in organised and free play between children of different ages with and without DCD. The researchers found no evidence to support an increase in inactivity with age among the LMC group.

There was a greater range of performance among the LMC groups than the HMC groups for body composition, balance, run and standing broad jump and the reverse for the distance throw and MSFT (Table 1). For the first group of skills, these differences probably reflect the heterogeneous nature of LMC. The quality of movement varies significantly among children with LMC, ranging between over-constraint to lack of constraint.[34] For some children, motor skill patterns are highly erratic and vary from performance to performance. They are unable to repeat a skill pattern consistently, whereas other children may hold themselves very rigidly, resulting in a very limited outcome. It is highly likely therefore that these skills (except for body composition) require a higher level of coordination than fitness and that the outcomes were more heavily affected by the poor coordination and erratic motor control of the LMC group. For example, the run and jump involve precise timing and positioning of the limbs during different phases of the skill. Hoare[35] reported that the 50-m run was a good predictor of coordination level. On the other hand, the measurement of body composition does not involve motor coordination and therefore, outcome differences are more likely to reflect other factors. Among the LMC group, several of the children recorded very high BMIs compared to the rest of the group. The greater range of scores in the overhand throw and MSFT among the HMC is because of the far superior performances of some of the children in these tests. For example, some children threw the ball more than 34 m or completed up to 66 shuttles in the MSFT. Although coordination is important for these skills, fitness variables, such as cardiovascular endurance and muscle strength may be more important.

Clearly the valid measurement of children with different levels of motor proficiency requires further research. These findings support the notion that poor results on fitness tests may be compounded by coordination as well as fitness and also highlight the need for further research in teasing out the underlying skill, fitness factors and psychological factors important to the successful performance of a task.[36] Recently Cairney et al.[32] suggested that low perceived motor competence and motivation may significantly contribute to performance outcomes on endurance tests among children with DCD.

Practical implications

- Some skill tests such as the distance throw and standing broad jump and some fitness tests such as the 50-m run are suitable for children with LMC as they do not seem to plateau, but continue to improve between the ages of 5 and 12 years. On the other hand, the MSFT may not be suitable with these children.
- It was encouraging to find that motor skills and fitness improve, even without specific interventions, in young children with LMC. This suggests that most aspects of fitness can be maintained or even improved with regular—ideally, daily—activity opportunities.

Future implications

More longitudinal studies such as this one are needed to better understand changes in motor competence over time. The data gathered for this study were narrowly focused on motor skill and fitness. Ideally, further studies will comprise more participants and also include other factors that are thought to impact on these outcomes such as physical activity levels, self-efficacy and perceived motor competence.

These findings highlight the importance of identifying and supporting children with LMC when young. Physical inactivity and low fitness levels have been linked to a heightened risk of cardiovascular disease, overweight and obesity, diabetes and osteoporosis.[37]

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