Motor Competence and its relationship to fitness in children

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Motor Competence and its relationship to fitness in children

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ARTICLE SUMMARY

Article Focus

- Exercise tolerance was not limited by the LMC group not willing to push themselves maximally, with the level of motor competence significantly related to VO_2 peak and muscular strength.
- Children with LMC have a reduced movement economy during cycling exercise.

Key Messages

- Children with low motor competence fail to exercise hard enough to maximally tax the cardiovascular system.
- Children with LMC are willing to push themselves maximally during exercise, despite limited exercise capacity. Utilising short duration, high intensity exercise bouts, focusing on the development of the exercising musculature, may be a better method for improving the limited fitness parameters in this population.

Strengths and Limitations

- Few studies have directly measured limiting factors to exercise alongside standard motor competence tests.
- The use of cycle ergometry is a safer option for maximal testing, allowing participants to give a maximal effort. However, due to the nature of the exercise, the weakness in the exercising musculature may be accentuated.

Abstract

Background: Children with movement impairments are known to perform poorly in exercise tests but the nature of the limiting factor is often unknown.

Aim: The aim of this work was to explore physiological and perceptual limits to exercise in children with varying degrees of motor competence, and the relationships to measures of health.

Methods: 35 boys aged 12-15yrs completed the Movement ABC test for the assessment of motor competence, followed by an incremental cycle ergometer test to exhaustion for the assessment of maximal oxygen uptake (VO_{2peak}), respiratory exchange ratio (RER), heart rate (HR) and rating of perceived exertion (RPE). 10 participants classified as having either high or low motor competence also performed a maximal isometric voluntary contraction (MVIC) for the assessment of lower limb extensor strength.

Results: 18 boys were classified as having lower motor competence. All but one participant met the criteria for maximum effort, both perceptually and physiologically, in the exercise test. There was a significant difference in $\dot{V}O_2$ peak (34.9 v 48.5 ml.kg.min^{-1}), $\dot{V}O_2$ workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188 beats.min^{-1}), maximal oxygen pulse (12.1 v 15.9 ml.beat) and MVIC (5.7 v 9.1 Nm.kg) between the low and high motor competent participants respectively. There was no significant difference in the RER or RPE between the groups.

Conclusion: When performing cycling ergometry, perceived exertion was not a limiting factor in children with low motor competence. The lower heart rate at exercise cessation, coupled with reduced movement efficiency and lower muscle strength reported in this group, would suggest exercise is limited by impairment at the muscular level as evidenced by the high RER values despite low maximal heart rate

values attained during the exercise test and reduced maximal strength. Perception of effort is not heightened in children with low motor competence and future exercise interventions should be focused on improving muscular condition in participants with low motor competence to enable them to be better prepared to engage in physical activity for health.

Introduction

Physical activity levels in childhood have been shown to predict adult activity behavior [1 2], affecting life expectancy and quality of life years. As such, successfully achieving an active lifestyle in childhood is critical. Children with movement difficulties and poor coordination tend to have lower levels of physical activity participation than their typically developing peers [3-5]. Further, this group of children, with reduced motor coordination and low activity levels, have been found to have significantly higher metabolic syndrome indicators [6], including: abdominal adiposity, blood pressure and triglyceride levels compared to their typically developing peers [7 8]. These findings are supported by evidence that these children are particularly at risk of developing secondary health disorders associated with physical inactivity [4 9-11]. Of added concern is that such motor impairments are known to persist into adulthood, further impacting on the ability of these individuals to achieve a physically active lifestyle as adults [12-14]. The number of people with some form of motor impairment in the UK population is 2.6 million [15] and as such this group is an important proportion of society who should be considered within public health policy. Understanding factors particularly affecting the exercise experience in these individuals is essential if higher physical activity levels are to be achieved.

In a series of interviews in adolescents with Developmental Coordination Disorder (DCD) [16 17] and in children with cerebral palsy [18], exercise-induced symptoms of muscle fatigue, poor physical tolerance and low energy levels have also been reported as major factors reducing enjoyment, tolerance and participation. However, as yet, the underpinning physiological limits have not been fully explored. We know that iindividuals judge and limit effort during exercise from symptoms arising from muscles, joints and the cardiovascular system; choosing to reduce how hard they are exercising when symptoms become too strong [19 20]. Children with reduced motor competence are known to perform poorly in sport and exercise fitness screening tests [9 21], but the physiological and perceptual responses limiting exercise performance have not been explored in these individuals [9 22 23].

Aims

The study set out to explore, in individuals with different levels of motor competence, physiological and perceptual measures during and limiting maximal exercise performance.

Methods

Procedure

The study was approved by the University Research Ethics Committee (UREC). Participants were recruited through two routes, either through a database of those who had taken part in our previous research or through advertisements and posters. Families indicating that they were interested in taking part were sent separate child and parent information sheets and gave their written consent prior to the study. Participants attended the Human Performance Laboratory for testing, with parents attending only to help complete a health screening questionnaire for their child. The testing session consisted of the participant completing the Movement ABC-2 Test (MABC-2) [24] for a measure of motor competence, followed by the exercise testing. Details of these measures can be found below. Participants were asked to refrain from eating, performing exercise or drinking caffeine in the 2-hour period before attending the sessions.

Participants

35 males aged 12 to 15 years with no known neurological condition were recruited. Individuals were classified on the level of motor ability using the Movement ABC-2 test.

Measures

Movement ABC-2 Test (MABC-2) [24].

This standardised test of motor skill was used to confirm the presence of significant movement difficulties. Eight age appropriate items were individually administered as described in the test manual. Raw scores for each task were converted to standard scores, summed across three sub-sections to obtain a standard score for Manual Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was also obtained. For the diagnosis of motor competence, it has been recommended that scores below the 5th percentile indicate definite motor impairment while scores between the 5th and 15th percentile indicate borderline scores [25]. Therefore, any child scoring below the 15th percentile in this current study was classed as having low motor competence

Exercise testing

Height (Holtain stadiometer), weight (Seca sclaes) and body mass index (BMI) were recorded prior to the exercise test. After resting for 6 minutes participants underwent an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen, Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling. Workload was progressed based on the Godfrey protocol [26] (increasing workload by 15-20 Watts from unloaded cycling based on the height of the participant). The test ended at volitional exhaustion or if the participant was unable to maintain a cadence of 60 rpm, with verbal encouragement given throughout.

Pulmonary gas exchange was measured breath-by-breath using an automated metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was calibrated prior to each test in accordance with manufacturer's instructions. All participants wore a face mask covering the nose and mouth connected to a low-resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was recorded continuously throughout the testing protocol using short-range telemetry (Polar S810, Finland). Oxygen uptake ($\dot{V}O_2$) was calculated as the average $\dot{V}O_2$ in the last 30s of each stage, whilst $\dot{V}O_2$ peak was recorded as the highest 60s average before the termination of the test. The respiratory exchange ratio (RER) was calculated from the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ at each workload level throughout the exercise test.

Maximal fat oxidation was calculated using the equations of Frayn [27] in equation 1 below:

$$\text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

The relationship between the amount of oxygen utilised for a given work rate was calculated from the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive indicator of cardiac function, was calculated by dividing the $\dot{V}O_2$ by heart rate ($\dot{V}O_2$/HR). Maximum workload (Workload_{max}) was calculated as the final completed workload. Rating of perceived exertion (RPE) was measured at the end of each stage using the Cart and Load scale (CALER), which has previously been used to assess children's perception of effort during exercise [28]. The CALER has a scale from 1 to 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'. Illustrations of a child pulling a cart behind their bicycle, which was progressively laden with bricks, accompanied the scale.

The criteria for true maximal effort included a plateau in $\dot{V}O_2$ max, maximal heart rate $\geq$ 95% of age predicted maximum and RER >1.06 [29]. All children were fully familiaried with the testing protocol prior to commencing the session.

MVIC Protocol

Participants performed a 1RM leg extensor strength test on a specially designed isometric strength-testing chair. The knee angle was 90^0 and the rotation axis of the strength chair was aligned with the knee axis. Participants were asked to relax for 30 seconds, thereafter subjects performed maximum knee extension for approximately 5 seconds. Verbal encouragement was given to reach the maximum force. After this maximum knee extension subjects relaxed for 30 seconds. This test was repeated three times, 1RM was the maximum output reached.

Electrical signals from the torque transducer were amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401). Torque from maximal voluntary contractions (MVIC) was recorded on a PC for subsequent analysis using Spike data analysis software (Spike 2 Version 5.0 for Windows).

Data Analysis

Descriptive statistics (mean +/- SD, range) were calculated for all variables.

All exercise testing measure distributions were examined for normality. Linear regression analysis was performed to examine relationships between M-ABC score and the exercise variables. 10 participants reporting low motor competence returned to the laboratory to repeat the exercise test to establish reliability data in this population. Test re-test reliability was analysed to test for systematic and random error using student t-test, intraclass correlation coefficient (ICC) [3,1], bias (average difference) and random error (1.96 x SD of differences). Statistical significance was accepted at $p<0.05$.

Results

Movement ABC-2 Test

18 participants obtained total scores considered to be LMC, i.e. below the ABC 15th percentile, with 5 at or below the 5th.

As expected, there was a significant difference in the Movement ABC percentile score between the LMC and HMC group (4.0 (4.7) v 62.8 (20.7), $p<0.05$).

Exercise Testing

There was a significant difference in $\dot{V}O_2$ peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min^{-1}), $\dot{V}O_2$ /workload (12.5 (3.9) v 10.0 (1.3) $\dot{V}O_2$ /W), oxygen pulse (12.1 (3.7) v 15.9 (4.0) ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0) v 9.0 (1.8) Nm.kg) with the HMC groups achieving higher $\dot{V}O_2$, oxygen pulse, maximum heart rate and MVIC.

There was no difference between the groups in the respiratory exchange ratio (RER), with all but one participant demonstrating a maximal value greater than 1.0 at the end of the test. There was also no significant difference in maximal fat oxidation levels between the groups.

Compared to established maximal criteria for typically developing children [30] all but one of the participants met the criteria for a maximal effort during the exercise test, with no significant difference between the LMC and HMC groups. There was no difference in the perception of effort throughout the exercise trial and at exercise termination, with all participants reporting an RPE rating of 9 or 10 at the end of the test, despite individuals in the LMC group having significantly lower maximum HR values at the end of the cycle ergometer test.

There were significant relationships between the MABC score and $\dot{V}O_2$ peak (r = 0.36, p<0.05) (figure 1) and MVIC (r = 0.76, p<0.01) (figure 2).

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Figure 2. Relationship between M-ABC score and MVIC.

Test re-test reliability of exercise measures

10 LMC participants returned to the laboratory to complete a second maximal exercise test for the assessment of reliability in this population. The maximal exercise data demonstrated good reliability with ICC scores for $\dot{V}O_2$ peak 0.75 (CI 0.23-0.94; t 0.39, bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8, random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).

Discussion

The study set out to explore, in individuals with different levels of motor competence, physiological and perceptual factors during and limiting maximal exercise performance. When considering limits to exercise in people with low motor competence, symptoms of perceived exertion were limiting individuals underpinned by typical maximal RER and fat oxidation levels at test termination, suggesting low levels of aerobic muscle performance. Examination of the exercise test data showed a significant difference in $\dot{V}O_2$ peak, $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the LMC and HMC group. Furthermore, individuals with lower motor competence had both a lower exercise capacity and lower muscle strength. These findings together are important as they highlight a low level of aerobic muscle performance as a factor limiting exercise performance in children with poor coordination and a number of changes in health indicators in children with low motor competence which, if left unaddressed, is likely to continue into adulthood and contribute to the development of metabolic disorders in this population.

Despite children with LMC demonstrating a linear $\dot{V}O_2$ / workload response, the value of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise [31]. $\dot{V}O_2$ normally raises at a rate of about 8.5-11ml.min.watt and is independent of sex, age, body weight or height [32]. Thus, in children with LMC, exercise participation may be limited by the impaired ability of the muscle to work aerobically. The reduced muscular strength of the quadriceps reported in this study further supports the main limiting factor being at the muscular level and this finding supports the findings from previous studies citing a reduced strength in other muscle groups in children with poor motor competence [33].

In comparison to the HMC group, the LMC group had a reduced exercise capacity, with a mean $\dot{V}O_2$ peak of 34.9 ml.kg.min^{-1}. The $\dot{V}O_2$ peak was below the cardiovascular fitness threshold in the LMC children [34] and as such associated with an increased risk of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood [35]. Considered alongside the low maximum heart rates demonstrated by these children (mean 176 beats.min^{-1}) in comparison to HMC participants (188 beats.min^{-1}) and those reported in normal healthy children at the end of a similar cycling protocol [36], our findings suggest that a low level of aerobic muscle performance was limiting the ability of children with LMC to push themselves hard enough to maximally tax the cardiovascular system. Despite a significantly lower oxygen pulse level between the groups (12.1 (3.7) v 15.9 (4.0)ml.beat, $p<0.05$), the LMC group was not different to those in healthy individuals reported previously [37]. This further supports the findings that the limiting factor is of peripheral, and not central, origin. Given the emerging role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic capability in the muscles of children with poor motor control may impact on their long-term health and may prevent them from increasing heart rate to the level required to achieve an aerobic training stimulus and attain fitness, health and wellbeing benefits according to current guidelines for physical activity in children [38]. Interestingly, despite the reduced aerobic fitness there was no difference in the utilisation of fat as a substrate during the exercise protocol between the groups in this study (0.56 (0.28) v 0.72 (0.36)g.min, $p>0.05$) for LMC and HMC respectively. The levels of fat oxidation in this current study were within the range previously reported in healthy participants of similar age [39]. The number of individuals in this sample is relatively small, however we included a range of individuals with different motor capabilities and in the sub group of LMC participants that returned to the laboratory we established good reliability in the clinical exercise testing in this population. Muscle function has been found to have an important role in long term health [40] and considering our observation of reduced muscle capacity in individuals with LMC, it is important to investigate interventions that can be implemented in childhood to improve muscle function and performance [41]. This is further supported with the significantly lower MVIC in the LMC group in comparison to HMC. The reduced strength of the major locomotor muscle group in the LMC not only has implications for function, with some reports of increased co-contraction [42], but also for the impact on health and quality of life. In a recent study by Buchan et al.[43], high intensity exercise has been shown to reduce cardiovascular risk and improve muscle function in healthy children. As yet, this type of intensity has not been investigated in the population of children included in this current study, however the evidence of their willingness to push themselves maximally in this study warrants the application of such intensities of exercise to measure the impact on health and movement measures.

The findings from this work highlight the significant relationship between motor competence level and health status. The reduced exercise capacity and muscular performance demonstrated by the participants with poor motor competence highlight the need for any exercise interventions to target the development of muscular function. Research has shown that exercise interventions play a possible role in improving motor competence levels in children with movement difficulties [44] however, how these changes relate to alterations in markers of cardiovascular and muscular health and the long term involvement in physical activity have yet to be elucidated.

Contributorship statement

Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design, acquisition of data or analysis and interpretation of data, and drafting the article or revising it critically for important intellectual content.

Dr Ken Howells - Conception and design and drafting the article or revising it critically for important intellectual content.

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Data Sharing

No additional data available.

Competing Interests

None

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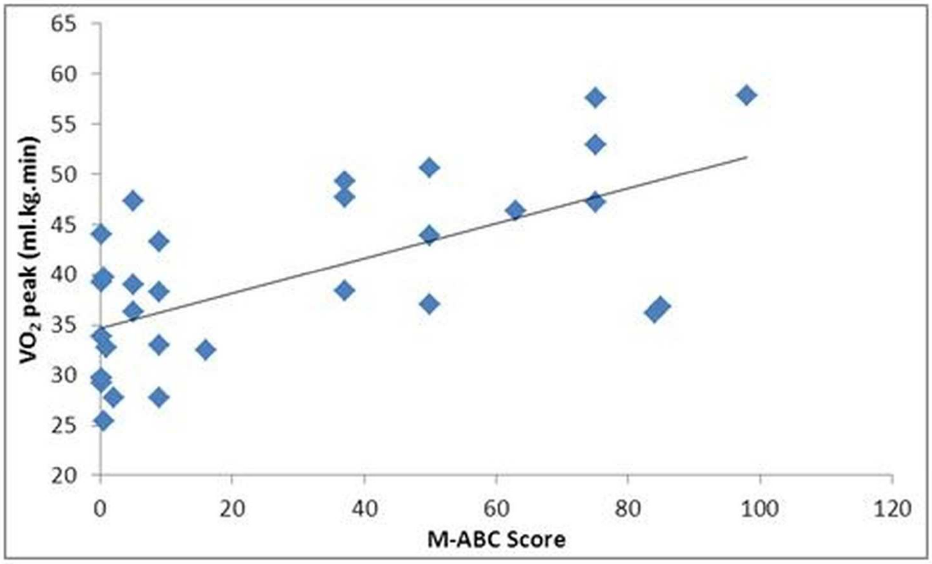

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Figure 1. Relationship between M-ABC score and peak.
137x96mm (300 x 300 DPI)

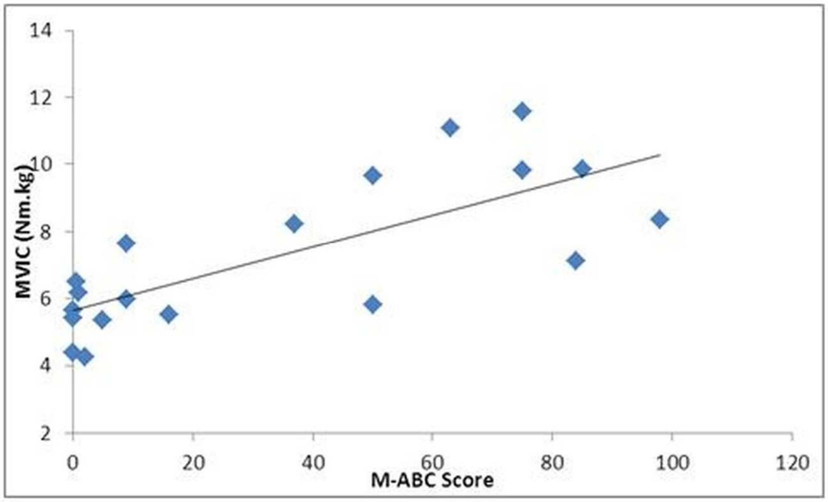

Figure 2. Relationship between M-ABC score and MVIC.

Figure 2. Relationship between M-ABC score and MVIC.
155x106mm (300 x 300 DPI)

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Aim: The aim of this work was to explore physiological and perceptual limits to exercise in children with varying degrees of motor impairment, and the relationships to measures of health.

Methods: 35 boys aged 12-15yrs completed the Movement ABC test for the assessment of motor impairment, followed by an incremental cycle ergometer test to exhaustion for the assessment of maximal oxygen uptake (VO_{2peak}), respiratory exchange ratio (RER), heart rate (HR) and rating of perceived exertion (RPE). 10 participants classified as having either high or low motor impairment also performed a maximal voluntary isometric contraction (MVIC) for the assessment of lower limb extensor strength.

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Conclusion: When performing cycling ergometry, perceived exertion was not a limiting factor in children with high motor impairment. The lower heart rate at exercise cessation, coupled with reduced movement efficiency and lower muscle strength reported in this group, would suggest exercise is limited by impairment at the muscular level. This finding was supported by the high RER values despite low

maximal heart rate values attained during the exercise test and reduced maximal strength. Perception of effort is not heightened in children with high motor impairment and future exercise interventions should be focused on improving muscular condition in participants with high motor impairment to enable them to be better prepared to engage in physical activity for health.

Introduction

Physical activity levels in childhood have been shown to predict adult activity behavior [1 2], affecting life expectancy and quality of life years. As such, successfully achieving an active lifestyle in childhood is critical. Children with movement difficulties and poor coordination tend to have lower levels of physical activity participation than their typically developing peers [3-5]. Further, this group of children, with reduced motor coordination and low activity levels, have been found to have significantly higher metabolic syndrome indicators [6], including: abdominal adiposity, blood pressure and triglyceride levels compared to their typically developing peers [7 8]. Of added concern is that such motor impairments are known to persist into adulthood, further impacting on the ability of these individuals to achieve a physically active lifestyle as adults [9-11]. The number of people with some form of motor impairment in the UK population is 2.6 million [12] and as such this group is an important proportion of society who should be considered within public health policy. Understanding factors particularly affecting the exercise experience in these individuals is essential if higher physical activity levels are to be achieved.

In a series of interviews with adolescents with Developmental Coordination Disorder (DCD) [13 14] and with children with cerebral palsy [15], exercise-induced symptoms of muscle fatigue, poor physical tolerance and low energy levels have also been reported as major factors reducing enjoyment, tolerance and participation. However, as yet, the underpinning physiological limits have not been fully explored. We know that individual's judge and limit effort during exercise from symptoms arising from muscles, joints and the cardiovascular system; choosing to reduce how hard they are exercising when symptoms become too strong [16 17]. Children with increased motor impairment are known to perform poorly in sport and exercise fitness screening tests

[18 19], but the physiological and perceptual responses limiting exercise performance have not been explored in these individuals [18 20 21].

Aims

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual measures during and limiting maximal exercise performance.

Methods

Procedure

The study was approved by the University Research Ethics Committee (UREC). Participants were recruited through two routes, either through a database of those who had taken part in our previous research or through advertisements and posters. Families indicating that they were interested in taking part were sent separate child and parent information sheets and gave their written consent prior to the study. Participants attended the Human Performance Laboratory for testing, with parents attending only to help complete a health screening questionnaire for their child. The testing session consisted of the participant completing the Movement ABC-2 Test (MABC-2) [22] for a measure of motor impairment, followed by the exercise testing. Details of these measures can be found below.

Participants were asked to refrain from eating, performing exercise or drinking caffeine in the 2-hour period before attending the sessions.

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Thirty five males aged 12 to 15 years with no known neurological condition were recruited. Individuals were classified on the level of motor ability using the Movement ABC-2 test.

Measures

Movement ABC-2 Test (MABC-2) [22].

This standardised test of motor skill was used to confirm the presence of significant movement difficulties. Eight age appropriate items were individually administered as described in the test manual. Raw scores for each task were converted to standard scores, summed across three sub-sections to obtain a standard score for Manual Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was also obtained. For the diagnosis of motor impairment, it has been recommended that scores below the 5th percentile indicate definite motor impairment while scores between the 5th and 15th percentile indicate borderline scores [23]. Therefore, any child scoring below the 15th percentile in this current study was classed as having high motor impairment (HMI).

Exercise testing

Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the exercise test. After resting for 6 minutes participants underwent an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen, Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling. Workload was progressed based on the Godfrey protocol [24] (increasing workload by 15-20 Watts from unloaded cycling based on the height of the participant). The test ended at volitional exhaustion or if the participant was unable to maintain a cadence of 60 rpm, with verbal encouragement given throughout.

Pulmonary gas exchange was measured breath-by-breath using an automated metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was calibrated prior to each test in accordance with manufacturer's instructions. All participants wore a face mask covering the nose and mouth connected to a low-resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was recorded continuously throughout the testing protocol using short-range telemetry (Polar S810, Finland). Oxygen uptake ($\dot{V}O_2$) was calculated as the average $\dot{V}O_2$ in the last 30s of each stage, whilst $\dot{V}O_2$ peak was recorded as the highest 60s average before the termination of the test. The respiratory exchange ratio (RER) was calculated from the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ at each workload level throughout the exercise test.

Maximal fat oxidation was calculated using the equations of Frayn [25] in equation 1 below:

$$\text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

The relationship between the amount of oxygen utilised for a given work rate was calculated from the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive indicator of cardiac function, was calculated by dividing the $\dot{V}O_2$ by heart rate ($\dot{V}O_2$/HR). Maximum workload (Workload_{max}) was calculated as the final completed workload. Rating of perceived exertion (RPE) was measured at the end of each stage using the Cart and Load scale (CALER), which has previously been used to assess children's perception of effort during exercise [26]. The CALER has a scale from 1 to 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'. Illustrations of a child pulling a cart behind their bicycle, which was progressively laden with bricks, accompanied the scale.

The criteria for true maximal effort included a plateau in $\dot{V}O_2$ max, maximal heart rate ≥ 95% of age predicted maximum and RER >1.06 [27]. All children were fully familiaried with the testing protocol prior to commencing the session.

MVIC Protocol

Participants performed a 1RM leg extensor strength test on a specially designed isometric strength-testing chair. The knee angle was 90^0 and the rotation axis of the strength chair was aligned with the knee axis. Participants were asked to relax for 30 seconds, thereafter subjects performed maximum knee extension for approximately 5 seconds. Verbal encouragement was given to reach the maximum force. After this maximum knee extension subjects relaxed for 30 seconds. This test was repeated three times, 1RM was the maximum output reached.

Electrical signals from the torque transducer were amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401). Torque from maximal voluntary contractions (MVIC) was recorded on a PC for subsequent analysis using Spike data analysis software (Spike 2 Version 5.0 for Windows).

Data Analysis

Descriptive statistics (mean +/- SD, range) were calculated for all variables.

All exercise testing measure distributions were examined for normality. Linear regression analysis was performed to examine relationships between M-ABC score and the exercise variables. Ten participants reporting high motor impairment returned to the laboratory to repeat the exercise test to establish reliability data in this population. Test re-test reliability was analysed to test for systematic and random error using student t-test, intraclass correlation coefficient (ICC) [3,1], bias (average difference) and random error (1.96 x SD of differences). Statistical significance was accepted at $p<0.05$.

Results

Movement ABC-2 Test

Eighteen participants obtained total scores considered to be HMI, i.e. below the M-ABC 15th percentile, with 5 at or below the 5th percentile, and 17 classified as low motor impairment (LMI) (M-ABC > 15th percentile). Table 1 displays the participant characteristics from the test battery.

>>>>insert table 1 here

As expected, there was a significant difference in the Movement ABC percentile score between the HMI and LMI group (4.0 (4.7) v 62.8 (20.7), $p<0.05$).

Exercise Testing

There was a significant difference in $\dot{V}O_2$ peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min^{-1}), $\dot{V}O_2$ /workload (12.5 (3.9) v 10.0 (1.3) $\dot{V}O_2$ /W), oxygen pulse (12.1 (3.7) v 15.9 (4.0) ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0) v 9.0 (1.8) Nm.kg) with the LMI group achieving higher $\dot{V}O_2$, oxygen pulse, maximum heart rate and MVIC.

There was no difference between the groups in the respiratory exchange ratio (RER), with all but one participant demonstrating a maximal value greater than 1.0 at the end of the test. There was also no significant difference in maximal fat oxidation levels between the groups.

Compared to established maximal criteria for typically developing children [28] all but one of the participants met the criteria for a maximal effort during the exercise test, with no significant difference between the HMI and LMI groups. There was no difference in the perception of effort throughout the exercise trial and at exercise termination, with all participants reporting an RPE rating of 9 or 10 at the end of the test, despite individuals in the HMI group having significantly lower maximum HR values at the end of the cycle ergometer test.

There were significant relationships between the MABC score and $\dot{V}O_2$ peak ($r = 0.36$, $p<0.05$) (figure 1) and MVIC ($r = 0.76$, $p<0.01$) (figure 2).

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Table 2 below displays the characteristics of the paprticipants who undertook the MVIC testsing

>>>>>>insert table 2 here

Figure 2. Relationship between M-ABC score and MVIC.

Test re-test reliability of exercise measures

10 HMI participants returned to the laboratory to complete a second maximal exercise test for the assessment of reliability in this population. The maximal exercise data demonstrated good reliability with ICC scores for $\dot{V}O_2$ peak 0.75 (CI 0.23-0.94; t 0.39, bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8, random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).

Discussion

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual factors during and limiting maximal exercise performance. Examination of the exercise test data showed a significant difference in $\dot{V}O_2$ peak, $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the HMI and LMI group. Interestingly there was no difference maximal rating of perceived exertion or RER. When considering limits to exercise in people with high motor impairment, the maximal RER and fat oxidation levels at test termination, suggest low levels of aerobic muscle performance and not a heightened perceived level of exertion, were limiting exercise performance. These findings are important as they highlight a low level of aerobic muscle performance as a major factor limiting exercise performance in children with poor coordination. Muscle plays a central role in health and disease across the lifespan[29] and, if left unaddressed in children with HMI, is likely to continue into adulthood and contribute to the development of metabolic disorders in this population.

Despite children with HMI demonstrating a linear $\dot{V}O_2$ / workload response, the value of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise [30]. $\dot{V}O_2$ normally rises at a rate of about 8.5-11ml.min.watt and is independent of sex, age, body weight or height [31]. Thus, in children with HMI, exercise participation may be limited by the impaired ability of the muscle to work aerobically. The reduced muscular strength of the quadriceps reported in this study further supports the main limiting factor being at the muscular level and this finding supports the findings from previous studies citing a reduced strength in other muscle groups in children with greater motor impairment [32].

In comparison to the LMI group, the HMI group had a reduced exercise capacity, with a mean $\dot{V}O_2$ peak of 34.9 ml.kg.min^{-1}. The $\dot{V}O_2$ peak was below the cardiovascular fitness threshold in the HMI children [33] and as such associated with an increased risk of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood [34]. Considered alongside the low maximum heart rates demonstrated by these children (mean 176 beats.min^{-1}) in comparison to LMI participants (188 beats.min^{-1}) and those reported in normal healthy children at the end of a similar cycling protocol [35], our findings suggest that a low level of aerobic muscle performance was limiting the ability of children with HMI to push themselves hard enough to maximally tax the cardiovascular system. Despite a significantly lower oxygen pulse level between the groups (12.1 (3.7) v 15.9 (4.0)ml.beat, $p<0.05$), the HMI group was not different to those in healthy individuals reported previously [36]. This further supports the findings that the limiting factor is of peripheral, and not central, origin. Given the emerging role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic capability in the muscles of children with poor motor control may impact on their long-term health and may prevent them from increasing their heart rate to the level required to achieve an aerobic training stimulus and attain fitness, health and wellbeing benefits according to current guidelines for physical activity in children [37]. Interestingly, despite the reduced aerobic fitness there was no difference in the utilisation of fat as a substrate during the exercise protocol between the groups in this study. The levels of fat oxidation in this current study were within the range previously reported in healthy participants of similar age [38]. The number of individuals in this sample is relatively small, however we included a range of individuals with different motor capabilities and in the sub group of HMI participants

that returned to the laboratory we established good reliability in the clinical exercise testing in this population.

Muscle function has been found to have an important role in long term health [29] and considering our observation of reduced muscle capacity in individuals with HMI, it is important to investigate interventions that can be implemented in childhood to improve muscle function and performance [39]. This is further supported with the significantly lower MVIC in the HMI group in comparison to LMI. The reduced strength of the major locomotor muscle group in the HMI not only has implications for function, with some reports of increased co-contraction [40], but also for the impact on health and quality of life. In a recent study by Buchan et al.[41], high intensity exercise has been shown to reduce cardiovascular risk and improve muscle function in healthy children. As yet, this type of intensity has not been investigated in the population of children included in this current study, however the evidence of their willingness to push themselves maximally in this study warrants the application of such intensities of exercise to measure the impact on health and movement measures. Work by Cairney et.al.[18] suggested that reduced exercise performance of children with motor impairment was partly related to the level of perceived adequacy for the task. The findings of this current work suggest that the limitations to exercise in the high motor impairment group had strong physiological underpinnings reflected in the criteria for a maximal effort being attained in all but one of the participants.

The findings from this work highlight the significant relationship between motor impairment level and health status. The reduced exercise capacity and muscular performance demonstrated by the participants with greater motor impairment highlight the need for any exercise interventions to target the development of

muscular function. Research has shown that exercise interventions play a possible role in improving motor competence levels in children with movement difficulties [42] however, how these changes relate to alterations in markers of cardiovascular and muscular health and the long term involvement in physical activity have yet to be elucidated.

Contributorship statement

Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design, acquisition of data or analysis and interpretation of data, and drafting the article or revising it critically for important intellectual content.

Dr Ken Howells - Conception and design and drafting the article or revising it critically for important intellectual content.

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Article Focus

- Exercise tolerance was not limited by the HMI group not willing to push themselves maximally, with the level of motor impairment significantly related to VO_2 peak and muscular strength.
- Children with HMI have a reduced movement economy during cycling exercise.

Key Messages

- Children with high motor impairment fail to exercise hard enough to maximally tax the cardiovascular system.
- Children with HMI are willing to push themselves maximally during exercise, despite limited exercise capacity. Utilising short duration, high intensity exercise bouts, focusing on the development of the exercising musculature, may be a better method for improving the limited fitness parameters in this population.

Strengths and Limitations

- Few studies have directly measured limiting factors to exercise alongside standard motor impairment tests.
- The use of cycle ergometry is a safe option for maximal testing, allowing participants to give a maximal effort. However, due to the nature of the exercise, the weakness in the exercising musculature may be accentuated.

Motor Impairment and its relationship to fitness in children

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Key words: Motor impairment, $\dot{V}O_2$ max, fitness, muscle

Word count: 2621

Abstract

Background: Children with movement impairments are known to perform poorly in exercise tests but the nature of the limiting factor is often unknown.

Aim: The aim of this work was to explore physiological and perceptual limits to exercise in children with varying degrees of motor impairment, and the relationships to measures of health.

Methods: 35 boys aged 12-15yrs completed the Movement ABC test for the assessment of motor impairment, followed by an incremental cycle ergometer test to exhaustion for the assessment of maximal oxygen uptake (VO_{2peak}), respiratory exchange ratio (RER), heart rate (HR) and rating of perceived exertion (RPE). 10 participants classified as having either high or low motor impairment also performed a maximal voluntary isometric contraction (MVIC) for the assessment of lower limb extensor strength.

Results: 18 boys were classified as having high motor impairment. All but one participant met the criteria for maximum effort, both perceptually and physiologically, in the exercise test. There was a significant difference in $\dot{V}O_2$ peak (34.9 v 48.5 $ml.kg.min^{-1}$), $\dot{V}O_2$ workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188 $beats.min^{-1}$), maximal oxygen pulse (12.1 v 15.9 ml.beat) and MVIC (5.7 v 9.1 Nm.kg) between the high and low motor impaired participants respectively. There was no significant difference in the RER or RPE between the groups.

Conclusion: When performing cycling ergometry, perceived exertion was not a limiting factor in children with high motor impairment. The lower heart rate at exercise cessation, coupled with reduced movement efficiency and lower muscle strength reported in this group, would suggest exercise is limited by impairment at the muscular level. This finding was supported by the high RER values despite low

maximal heart rate values attained during the exercise test and reduced maximal strength. Perception of effort is not heightened in children with high motor impairment and future exercise interventions should be focused on improving muscular condition in participants with high motor impairment to enable them to be better prepared to engage in physical activity for health.

Introduction

Physical activity levels in childhood have been shown to predict adult activity behavior [1 2], affecting life expectancy and quality of life years. As such, successfully achieving an active lifestyle in childhood is critical. Children with movement difficulties and poor coordination tend to have lower levels of physical activity participation than their typically developing peers [3-5]. Further, this group of children, with reduced motor coordination and low activity levels, have been found to have significantly higher metabolic syndrome indicators [6], including: abdominal adiposity, blood pressure and triglyceride levels compared to their typically developing peers [7 8]. Of added concern is that such motor impairments are known to persist into adulthood, further impacting on the ability of these individuals to achieve a physically active lifestyle as adults [9-11]. The number of people with some form of motor impairment in the UK population is 2.6 million [12] and as such this group is an important proportion of society who should be considered within public health policy. Understanding factors particularly affecting the exercise experience in these individuals is essential if higher physical activity levels are to be achieved.

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Exercise testing

Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the exercise test. After resting for 6 minutes participants underwent an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen, Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling. Workload was progressed based on the Godfrey protocol [24] (increasing workload by 15-20 Watts from unloaded cycling based on the height of the participant). The test ended at volitional exhaustion or if the participant was unable to maintain a cadence of 60 rpm, with verbal encouragement given throughout.

Pulmonary gas exchange was measured breath-by-breath using an automated metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was calibrated prior to each test in accordance with manufacturer's instructions. All participants wore a face mask covering the nose and mouth connected to a low-resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was recorded continuously throughout the testing protocol using short-range telemetry (Polar S810, Finland). Oxygen uptake ($\dot{V}O_2$) was calculated as the average $\dot{V}O_2$ in the last 30s of each stage, whilst $\dot{V}O_2$ peak was recorded as the highest 60s average before the termination of the test. The respiratory exchange ratio (RER) was calculated from the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ at each workload level throughout the exercise test.

Maximal fat oxidation was calculated using the equations of Frayn [25] in equation 1 below:

$$\text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

The relationship between the amount of oxygen utilised for a given work rate was calculated from the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive indicator of cardiac function, was calculated by dividing the $\dot{V}O_2$ by heart rate ($\dot{V}O_2$/HR). Maximum workload ($Workload_{max}$) was calculated as the final completed workload. Rating of perceived exertion (RPE) was measured at the end of each stage using the Cart and Load scale (CALER), which has previously been used to assess children's perception of effort during exercise [26]. The CALER has a scale from 1 to 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'. Illustrations of a child pulling a cart behind their bicycle, which was progressively laden with bricks, accompanied the scale.

The criteria for true maximal effort included a plateau in $\dot{V}O_2$ max, maximal heart rate ≥ 95% of age predicted maximum and RER >1.06 [27]. All children were fully familiaried with the testing protocol prior to commencing the session.

MVIC Protocol

Participants performed a 1RM leg extensor strength test on a specially designed isometric strength-testing chair. The knee angle was 90^0 and the rotation axis of the strength chair was aligned with the knee axis. Participants were asked to relax for 30 seconds, thereafter subjects performed maximum knee extension for approximately 5 seconds. Verbal encouragement was given to reach the maximum force. After this maximum knee extension subjects relaxed for 30 seconds. This test was repeated three times, 1RM was the maximum output reached.

Electrical signals from the torque transducer were amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401). Torque from maximal voluntary contractions (MVIC) was recorded on a PC for subsequent analysis using Spike data analysis software (Spike 2 Version 5.0 for Windows).

Data Analysis

Descriptive statistics (mean +/- SD, range) were calculated for all variables.

All exercise testing measure distributions were examined for normality. Linear regression analysis was performed to examine relationships between M-ABC score and the exercise variables. Ten participants reporting high motor impairment returned to the laboratory to repeat the exercise test to establish reliability data in this population. Test re-test reliability was analysed to test for systematic and random error using student t-test, intraclass correlation coefficient (ICC) [3,1], bias (average difference) and random error (1.96 x SD of differences). Statistical significance was accepted at $p<0.05$.

Results

Movement ABC-2 Test

Eighteen participants obtained total scores considered to be HMI, i.e. below the M-ABC 15th percentile, with 5 at or below the 5th percentile, and 17 classified as low motor impairment (LMI) (M-ABC > 15th percentile). Table 1 displays the participant characteristics from the test battery.

>>>>insert table 1 here

As expected, there was a significant difference in the Movement ABC percentile score between the HMI and LMI group (4.0 (4.7) v 62.8 (20.7), p<0.05).

Exercise Testing

There was a significant difference in $\dot{V}O_2$ peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min^{-1}), $\dot{V}O_2$/workload (12.5 (3.9) v 10.0 (1.3) $\dot{V}O_2$/W), oxygen pulse (12.1 (3.7) v 15.9 (4.0) ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0) v 9.0 (1.8) Nm.kg) with the LMI group achieving higher $\dot{V}O_2$, oxygen pulse, maximum heart rate and MVIC.

There was no difference between the groups in the respiratory exchange ratio (RER), with all but one participant demonstrating a maximal value greater than 1.0 at the end of the test. There was also no significant difference in maximal fat oxidation levels between the groups.

Compared to established maximal criteria for typically developing children [28] all but one of the participants met the criteria for a maximal effort during the exercise test, with no significant difference between the HMI and LMI groups. There was no difference in the perception of effort throughout the exercise trial and at exercise termination, with all participants reporting an RPE rating of 9 or 10 at the end of the test, despite individuals in the HMI group having significantly lower maximum HR values at the end of the cycle ergometer test.

There were significant relationships between the MABC score and $\dot{V}O_2$ peak (r = 0.36, p<0.05) (figure 1) and MVIC (r = 0.76, p<0.01) (figure 2).

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Table 2 below displays the characteristics of the paprticipants who undertook the MVIC testsing

>>>>>>insert table 2 here

Figure 2. Relationship between M-ABC score and MVIC.

Test re-test reliability of exercise measures

10 HMI participants returned to the laboratory to complete a second maximal exercise test for the assessment of reliability in this population. The maximal exercise data demonstrated good reliability with ICC scores for $\dot{V}O_2$ peak 0.75 (CI 0.23-0.94; t 0.39, bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8, random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).

Discussion

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual factors during and limiting maximal exercise performance. Examination of the exercise test data showed a significant difference in $\dot{V}O_2$ peak, $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the HMI and LMI group. Interestingly there was no difference maximal rating of perceived exertion or RER. When considering limits to exercise in people with high motor impairment, the maximal RER and fat oxidation levels at test termination, suggest low levels of aerobic muscle performance and not a heightened perceived level of exertion, were limiting exercise performance. These findings are important as they highlight a low level of aerobic muscle performance as a major factor limiting exercise performance in children with poor coordination. Muscle plays a central role in health and disease across the lifespan[29] and, if left unaddressed in children with HMI, is likely to continue into adulthood and contribute to the development of metabolic disorders in this population.

Despite children with HMI demonstrating a linear $\dot{V}O_2$ / workload response, the value of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise [30]. $\dot{V}O_2$ normally rises at a rate of about 8.5-11ml.min.watt and is independent of sex, age, body weight or height [31]. Thus, in children with HMI, exercise participation may be limited by the impaired ability of the muscle to work aerobically. The reduced muscular strength of the quadriceps reported in this study further supports the main limiting factor being at the muscular level and this finding supports the findings from previous studies citing a reduced strength in other muscle groups in children with greater motor impairment [32].

In comparison to the LMI group, the HMI group had a reduced exercise capacity, with a mean $\dot{V}O_2$ peak of 34.9 ml.kg.min^{-1}. The $\dot{V}O_2$ peak was below the cardiovascular fitness threshold in the HMI children [33] and as such associated with an increased risk of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood [34]. Considered alongside the low maximum heart rates demonstrated by these children (mean 176 beats.min^{-1}) in comparison to LMI participants (188 beats.min^{-1}) and those reported in normal healthy children at the end of a similar cycling protocol [35], our findings suggest that a low level of aerobic muscle performance was limiting the ability of children with HMI to push themselves hard enough to maximally tax the cardiovascular system. Despite a significantly lower oxygen pulse level between the groups (12.1 (3.7) v 15.9 (4.0)ml.beat, $p<0.05$), the HMI group was not different to those in healthy individuals reported previously [36]. This further supports the findings that the limiting factor is of peripheral, and not central, origin. Given the emerging role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic capability in the muscles of children with poor motor control may impact on their long-term health and may prevent them from increasing their heart rate to the level required to achieve an aerobic training stimulus and attain fitness, health and wellbeing benefits according to current guidelines for physical activity in children [37]. Interestingly, despite the reduced aerobic fitness there was no difference in the utilisation of fat as a substrate during the exercise protocol between the groups in this study. The levels of fat oxidation in this current study were within the range previously reported in healthy participants of similar age [38]. The number of individuals in this sample is relatively small, however we included a range of individuals with different motor capabilities and in the sub group of HMI participants

that returned to the laboratory we established good reliability in the clinical exercise testing in this population.

Muscle function has been found to have an important role in long term health [29] and considering our observation of reduced muscle capacity in individuals with HMI, it is important to investigate interventions that can be implemented in childhood to improve muscle function and performance [39]. This is further supported with the significantly lower MVIC in the HMI group in comparison to LMI. The reduced strength of the major locomotor muscle group in the HMI not only has implications for function, with some reports of increased co-contraction [40], but also for the impact on health and quality of life. In a recent study by Buchan et al.[41], high intensity exercise has been shown to reduce cardiovascular risk and improve muscle function in healthy children. As yet, this type of intensity has not been investigated in the population of children included in this current study, however the evidence of their willingness to push themselves maximally in this study warrants the application of such intensities of exercise to measure the impact on health and movement measures. Work by Cairney et.al.[18] suggested that reduced exercise performance of children with motor impairment was partly related to the level of perceived adequacy for the task. The findings of this current work suggest that the limitations to exercise in the high motor impairment group had strong physiological underpinnings reflected in the criteria for a maximal effort being attained in all but one of the participants.

The findings from this work highlight the significant relationship between motor impairment level and health status. The reduced exercise capacity and muscular performance demonstrated by the participants with greater motor impairment highlight the need for any exercise interventions to target the development of

muscular function. Research has shown that exercise interventions play a possible role in improving motor competence levels in children with movement difficulties [42] however, how these changes relate to alterations in markers of cardiovascular and muscular health and the long term involvement in physical activity have yet to be elucidated.

Contributorship statement

Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design, acquisition of data or analysis and interpretation of data, and drafting the article or revising it critically for important intellectual content.

Dr Ken Howells - Conception and design and drafting the article or revising it critically for important intellectual content.

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Article Focus

- Exercise tolerance was not limited by the HMI group not willing to push themselves maximally, with the level of motor impairment significantly related to VO_2 peak and muscular strength.
- Children with HMI have a reduced movement economy during cycling exercise.

Key Messages

- Children with high motor impairment fail to exercise hard enough to maximally tax the cardiovascular system.
- Children with HMI are willing to push themselves maximally during exercise, despite limited exercise capacity. Utilising short duration, high intensity exercise bouts, focusing on the development of the exercising musculature, may be a better method for improving the limited fitness parameters in this population.

Strengths and Limitations

- Few studies have directly measured limiting factors to exercise alongside standard motor impairment tests.
- The use of cycle ergometry is a safe option for maximal testing, allowing participants to give a maximal effort. However, due to the nature of the exercise, the weakness in the exercising musculature may be accentuated.

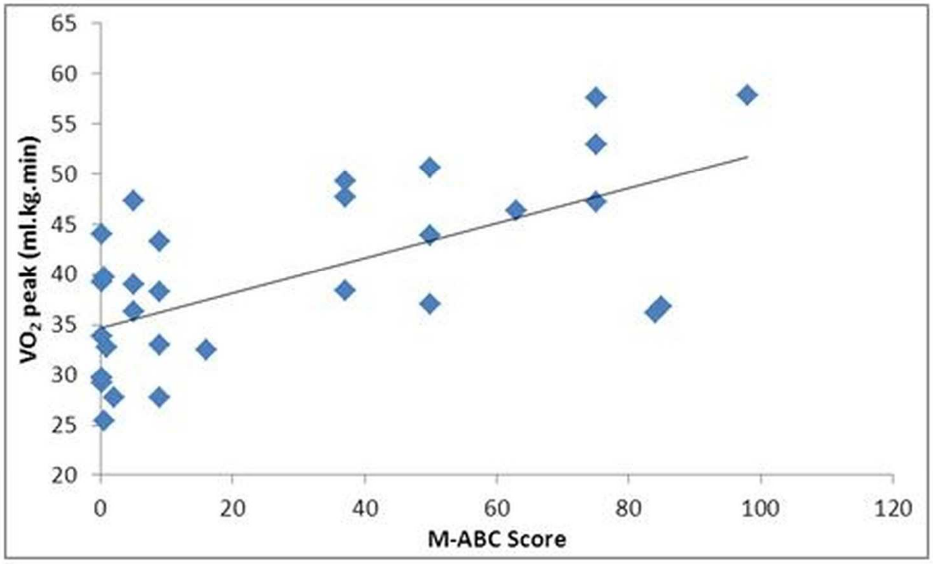

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Figure 1. Relationship between M-ABC score and peak.
137x96mm (300 x 300 DPI)

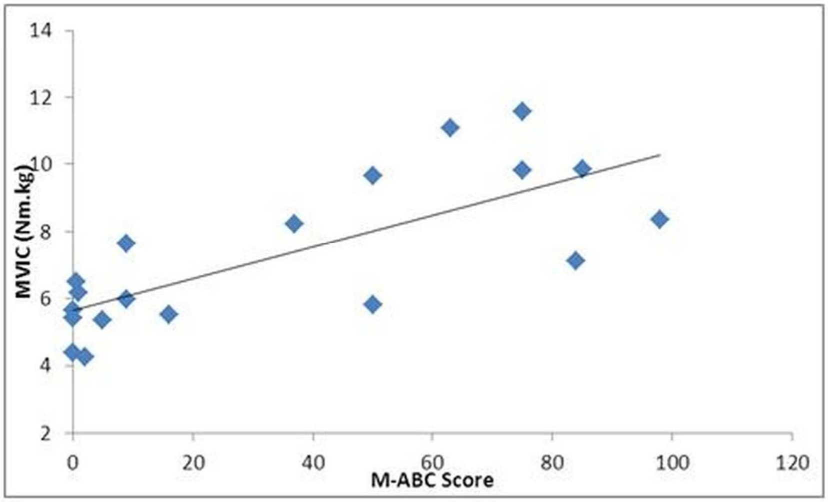

Figure 2. Relationship between M-ABC score and MVIC.

Figure 2. Relationship between M-ABC score and MVIC.
155x106mm (300 x 300 DPI)

Table 1. Participant characteristics and outcome measures.

	LMC (n=18)	HMC (n=17)
M-ABC	4.0 (4.7)	62.8 (20.7)*
Age (yrs)	14.1 (1.5)	14.9 (0.9)
Height (m)	1.70 (0.10)	1.74 (0.10)
Weight (kg)	62.8 (17.9)	60.3 (10.6)
BMI	21.5 (4.0)	19.5 (2.1)
VO_2 max (ml.kg.min)	34.9 (6.3)	48.5 (7.9)*
VO_2/Workload (ml.W)	12.5 (3.9)	10.0 (1.3)*
O_2 Pulse (ml.beat)	12.1 (3.7)	15.9 (4.0)*
Heart Rate max. (beats.min)	176 (19.7)	188 (8.8)*
RER max.	1.15 (0.09)	1.18 (0.09)
RPE max.	9.1 (1.5)	9.6 (0.5)

Table 2. M-ABC and MVIC for the LMC and HMC participants.

	LMC (n=10)	HMC (n=10)
M-ABC	4.3 (5.4)	68.6 (19.9)*
MVIC (Nm.kg)	5.7 (1.0)	9.0 (1.8)*

Motor Impairment and its relationship to fitness in children

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Motor Impairment and its relationship to fitness in children

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ARTICLE SUMMARY

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Abstract

Background: Children with movement impairments are known to perform poorly in exercise tests but the nature of the limiting factor is often unknown.

Aim: The aim of this work was to explore physiological and perceptual limits to exercise in children with varying degrees of motor impairment, and the relationships to measures of health.

Methods: 35 boys aged 12-15yrs completed the Movement ABC test for the assessment of motor impairment, followed by an incremental cycle ergometer test to exhaustion for the assessment of maximal oxygen uptake (VO_{2peak}), respiratory exchange ratio (RER), heart rate (HR) and rating of perceived exertion (RPE). 10 participants classified as having either high or no motor impairment also performed a maximal voluntary isometric contraction (MVIC) for the assessment of lower limb extensor strength.

Results: 18 boys were classified as having high motor impairment. All but one participant met the criteria for maximum effort, both perceptually and physiologically, in the exercise test. There was a significant difference in $\dot{V}O_2$ peak (34.9 v 48.5 ml.kg.min^{-1}), $\dot{V}O_2$ workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188 beats.min^{-1}), maximal oxygen pulse (12.1 v 15.9 ml.beat) and MVIC (5.7 v 9.1 Nm.kg) between the high and non motor impaired participants respectively. There was no significant difference in the RER or RPE between the groups.

Conclusion: When performing cycling ergometry, perceived exertion was not a limiting factor in children with high motor impairment. The lower heart rate at exercise cessation, coupled with reduced movement efficiency and lower muscle strength reported in this group, would suggest exercise is limited by impairment at the muscular level. This finding was supported by the high RER values despite low

maximal heart rate values attained during the exercise test and reduced maximal strength. Perception of effort is not heightened in children with high motor impairment and future exercise interventions should be focused on improving muscular condition in participants with high motor impairment to enable them to be better prepared to engage in physical activity for health.

Introduction

Physical activity levels in childhood have been shown to predict adult activity behavior [1 2], affecting life expectancy and quality of life years. As such, successfully achieving an active lifestyle in childhood is critical. Children with movement difficulties and poor coordination tend to have lower levels of physical activity participation than their typically developing peers [3-5]. Further, this group of children, with reduced motor coordination and low activity levels, have been found to have significantly higher metabolic syndrome indicators [6], including: abdominal adiposity, blood pressure and triglyceride levels compared to their typically developing peers [7] [8]. Of added concern is that such motor impairments are known to persist into adulthood, further impacting on the ability of these individuals to achieve a physically active lifestyle as adults [9-11]. The number of people with some form of motor impairment in the UK population is 2.6 million [12] and as such this group is an important proportion of society who should be considered within public health policy. Understanding factors particularly affecting the exercise experience in these individuals is essential if higher physical activity levels are to be achieved.

In a series of interviews with adolescents with Developmental Coordination Disorder (DCD) [13 14] and with children with cerebral palsy [15], exercise-induced symptoms of muscle fatigue, poor physical tolerance and low energy levels have also been reported as major factors reducing enjoyment, tolerance and participation. However, as yet, the underpinning physiological limits have not been fully explored. We know that individual's judge and limit effort during exercise from symptoms arising from muscles, joints and the cardiovascular system; choosing to reduce how hard they are exercising when symptoms become too strong [16 17]. Children with increased motor impairment are known to perform poorly in sport and exercise fitness screening tests

[18 19], but the physiological and perceptual responses limiting exercise performance have not been explored in these individuals [18 20 21].

Aims

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual measures during and limiting maximal exercise performance.

Methods

Procedure

The study was approved by the University Research Ethics Committee (UREC). Participants were recruited through two routes, either through a database of those who had taken part in our previous research or through advertisements and posters. Families indicating that they were interested in taking part were sent separate child and parent information sheets and gave their written consent prior to the study. Participants attended the Human Performance Laboratory for testing, with parents attending only to help complete a health screening questionnaire for their child. The testing session consisted of the participant completing the Movement ABC-2 Test (MABC-2) [22] for a measure of motor impairment, followed by the exercise testing. Details of these measures can be found below.

Participants were asked to refrain from eating, performing exercise or drinking caffeine in the 2-hour period before attending the sessions.

Participants

Thirty five males aged 12 to 15 years with no known neurological condition were recruited. Individuals were classified on the level of motor ability using the Movement ABC-2 test.

Measures

Movement ABC-2 Test (MABC-2) [22].

This standardised test of motor skill was used to confirm the presence of significant movement difficulties. Eight age appropriate items were individually administered as described in the test manual. Raw scores for each task were converted to standard scores, summed across three sub-sections to obtain a standard score for Manual Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was also obtained. For the diagnosis of motor impairment, it has been recommended that scores below the 5^{th} percentile indicate definite motor impairment while scores between the 5^{th} and 15^{th} percentile indicate borderline scores [23]. Therefore, any child scoring below the 15^{th} percentile in this current study was classed as having high motor impairment (HMI). Children scoring above the 15^{th} percentile were classified as having no motor impairment (NMI).

Exercise testing

Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the exercise test. After resting for 6 minutes participants underwent an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen, Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling. Workload was progressed based on the Godfrey protocol [24] (increasing workload by 15-20 Watts from unloaded cycling based on the height of the participant). The test ended at volitional exhaustion or if the participant was unable to maintain a cadence of 60 rpm, with verbal encouragement given throughout.

Pulmonary gas exchange was measured breath-by-breath using an automated metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was calibrated prior to each test in accordance with manufacturer's instructions. All participants wore a face mask covering the nose and mouth connected to a low-resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was recorded continuously throughout the testing protocol using short-range telemetry (Polar S810, Finland). Oxygen uptake ($\dot{V}O_2$) was calculated as the average $\dot{V}O_2$ in the last 30s of each stage, whilst $\dot{V}O_2$ peak was recorded as the highest 60s average before the termination of the test. The respiratory exchange ratio (RER) was calculated from the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ at each workload level throughout the exercise test. Maximal fat oxidation was calculated using the equations of Frayn [25] in equation 1 below:

$$\text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

The relationship between the amount of oxygen utilised for a given work rate was calculated from the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive indicator of cardiac function, was calculated by dividing the $\dot{V}O_2$ by heart rate ($\dot{V}O_2$/HR). Maximum workload (Workload_{max}) was calculated as the final completed workload. Rating of perceived exertion (RPE) was measured at the end of each stage using the Cart and Load scale (CALER), which has previously been used to assess children's perception of effort during exercise [26]. The CALER has a scale from 1 to 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'. Illustrations of a child pulling a cart behind their bicycle, which was progressively laden with bricks, accompanied the scale.

The criteria for true maximal effort included a plateau in $\dot{V}O_2$ max, maximal heart rate $\geq$ 95% of age predicted maximum and RER >1.06 [27]. All children were fully familiaried with the testing protocol prior to commencing the session.

MVIC Protocol

Participants performed a 1RM leg extensor strength test on a specially designed isometric strength-testing chair. The knee angle was 90^0 and the rotation axis of the strength chair was aligned with the knee axis. Participants were asked to relax for 30 seconds, thereafter subjects performed maximum knee extension for approximately 5 seconds. Verbal encouragement was given to reach the maximum force. After this maximum knee extension subjects relaxed for 30 seconds. This test was repeated three times, 1RM was the maximum output reached.

Electrical signals from the torque transducer were amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401). Torque from maximal voluntary contractions (MVIC) was recorded on a PC for subsequent analysis using Spike data analysis software (Spike 2 Version 5.0 for Windows).

Data Analysis

Descriptive statistics (mean +/- SD, range) were calculated for all variables.

All exercise testing measure distributions were examined for normality. Linear regression analysis was performed to examine relationships between M-ABC score and the exercise variables. Ten participants reporting high motor impairment returned to the laboratory to repeat the exercise test to establish reliability data in this population. Test re-test reliability was analysed to test for systematic and random error using student t-test, intraclass correlation coefficient (ICC) [3,1], bias (average difference) and random error (1.96 x SD of differences). Statistical significance was accepted at $p<0.05$.

Results

Movement ABC-2 Test

Eighteen participants obtained total scores considered to be HMI, i.e. below the M-ABC 15th percentile, with 5 at or below the 5th percentile, and 17 classified as no motor impairment (NMI) (M-ABC > 15th percentile). Table 1 displays the participant characteristics from the test battery.

>>>>insert table 1 here

As expected, there was a significant difference in the Movement ABC percentile score between the HMI and NMI group (4.0 (4.7) v 62.8 (20.7), $p<0.05$).

Exercise Testing

There was a significant difference in $\dot{V}O_2$ peak (34.9 (6.3) v 48.5 (7.9) $ml.kg.min^{-1}$), $\dot{V}O_2$ /workload (12.5 (3.9) v 10.0 (1.3) $\dot{V}O_2$ /W), oxygen pulse (12.1 (3.7) v 15.9 (4.0) ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0) v 9.0 (1.8) Nm.kg) with the NMI group achieving higher $\dot{V}O_2$, oxygen pulse, maximum heart rate and MVIC.

There was no difference between the groups in the respiratory exchange ratio (RER), with all but one participant demonstrating a maximal value greater than 1.0 at the end of the test. There was also no significant difference in maximal fat oxidation levels between the groups.

Compared to established maximal criteria for typically developing children [28] all but one of the participants met the criteria for a maximal effort during the exercise test, with no significant difference between the HMI and NMI groups. There was no difference in the perception of effort throughout the exercise trial and at exercise termination, with all participants reporting an RPE rating of 9 or 10 at the end of the test, despite individuals in the HMI group having significantly lower maximum HR values at the end of the cycle ergometer test.

There were significant relationships between the MABC score and $\dot{V}O_2$ peak ($r = 0.36$, $p<0.05$) (figure 1) and MVIC ($r = 0.76$, $p<0.01$) (figure 2).

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Table 2 below displays the characteristics of the paprticipants who undertook the MVIC testsing

>>>>>>insert table 2 here

Figure 2. Relationship between M-ABC score and MVIC.

Test re-test reliability of exercise measures

10 HMI participants returned to the laboratory to complete a second maximal exercise test for the assessment of reliability in this population. The maximal exercise data demonstrated good reliability with ICC scores for $\dot{V}O_2$ peak 0.75 (CI 0.23-0.94; t 0.39, bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8, random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).

Discussion

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual factors during and limiting maximal exercise performance. Examination of the exercise test data showed a significant difference in $\dot{V}O_2$ peak, $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the HMI and NMI group. Interestingly there was no difference maximal rating of perceived exertion or RER. When considering limits to exercise in people with high motor impairment, the maximal RER and fat oxidation levels at test termination, suggest low levels of aerobic muscle performance and not a heightened perceived level of exertion, were limiting exercise performance. These findings are important as they highlight a low level of aerobic muscle performance as a major factor limiting exercise performance in children with poor coordination. Muscle plays a central role in health and disease across the lifespan[29] and, if left unaddressed in children with HMI, is likely to continue into adulthood and contribute to the development of metabolic disorders in this population.

Despite children with HMI demonstrating a linear $\dot{V}O_2$ / workload response, the value of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise [30]. $\dot{V}O_2$ normally rises at a rate of about 8.5-11ml.min.watt and is independent of sex, age, body weight or height [31]. Thus, in children with HMI, exercise participation may be limited by the impaired ability of the muscle to work aerobically. The reduced muscular strength of the quadriceps reported in this study further supports the main limiting factor being at the muscular level and this finding supports the findings from previous studies citing a reduced strength in other muscle groups in children with greater motor impairment [32].

In comparison to the NMI group, the HMI group had a reduced exercise capacity, with a mean $\dot{V}O_2$ peak of 34.9 ml.kg.min^{-1}. The $\dot{V}O_2$ peak was below the cardiovascular fitness threshold in the HMI children [33] and as such associated with an increased risk of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood [34]. Considered alongside the low maximum heart rates demonstrated by these children (mean 176 beats.min^{-1}) in comparison to NMI participants (188 beats.min^{-1}) and those reported in normal healthy children at the end of a similar cycling protocol [35], our findings suggest that a low level of aerobic muscle performance was limiting the ability of children with HMI to push themselves hard enough to maximally tax the cardiovascular system. Despite a significantly lower oxygen pulse level between the groups (12.1 (3.7) v 15.9 (4.0)ml.beat, $p<0.05$), the HMI group was not different to those in healthy individuals reported previously [36]. This further supports the findings that the limiting factor is of peripheral, and not central, origin. Given the emerging role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic capability in the muscles of children with poor motor control may impact on their long-term health and may prevent them from increasing their heart rate to the level required to achieve an aerobic training stimulus and attain fitness, health and wellbeing benefits according to current guidelines for physical activity in children [37]. Interestingly, despite the reduced aerobic fitness there was no difference in the utilisation of fat as a substrate during the exercise protocol between the groups in this study. The levels of fat oxidation in this current study were within the range previously reported in healthy participants of similar age [38]. The number of individuals in this sample is relatively small, however we included a range of individuals with different motor capabilities and in the sub group of HMI participants

that returned to the laboratory we established good reliability in the clinical exercise testing in this population.

Muscle function has been found to have an important role in long term health [29] and considering our observation of reduced muscle capacity in individuals with HMI, it is important to investigate interventions that can be implemented in childhood to improve muscle function and performance [39]. This is further supported with the significantly lower MVIC in the HMI group in comparison to NMI. The reduced strength of the major locomotor muscle group in the HMI not only has implications for function, with some reports of increased co-contraction [40], but also for the impact on health and quality of life. In a recent study by Buchan et al.[41], high intensity exercise has been shown to reduce cardiovascular risk and improve muscle function in healthy children. As yet, this type of intensity has not been investigated in the population of children included in this current study, however the evidence of their willingness to push themselves maximally in this study warrants the application of such intensities of exercise to measure the impact on health and movement measures. Work by Cairney et.al.[18] suggested that reduced exercise performance of children with motor impairment was partly related to the level of perceived adequacy for the task. The findings of this current work suggest that the limitations to exercise in the high motor impairment group had strong physiological underpinnings reflected in the criteria for a maximal effort being attained in all but one of the participants.

The findings from this work highlight the significant relationship between motor impairment level and health status. The reduced exercise capacity and muscular performance demonstrated by the participants with greater motor impairment highlight the need for any exercise interventions to target the development of

muscular function. Research has shown that exercise interventions play a possible role in improving motor competence levels in children with movement difficulties [42] however, how these changes relate to alterations in markers of cardiovascular and muscular health and the long term involvement in physical activity have yet to be elucidated.

Data sharing

No additional data available.

Contributorship statement

Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design, acquisition of data or analysis and interpretation of data, and drafting the article or revising it critically for important intellectual content.

Dr Ken Howells - Conception and design and drafting the article or revising it critically for important intellectual content.

Competing Interests

None

Funding

None

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Table 1. Participant characteristics and outcome measures.

	HMI (n=18)	NMI (n=17)
M-ABC	4.0 (4.7)	62.8 (20.7)*
Age (yrs)	14.1 (1.5)	14.9 (0.9)
Height (m)	1.70 (0.10)	1.74 (0.10)
Weight (kg)	62.8 (17.9)	60.3 (10.6)
BMI	21.5 (4.0)	19.5 (2.1)
VO_2 max (ml.kg.min)	34.9 (6.3)	48.5 (7.9)*
VO_2/Workload (ml.W)	12.5 (3.9)	10.0 (1.3)*
O_2 Pulse (ml.beat)	12.1 (3.7)	15.9 (4.0)*
Heart Rate max. (beats.min)	176 (19.7)	188 (8.8)*
RER max.	1.15 (0.09)	1.18 (0.09)
RPE max.	9.1 (1.5)	9.6 (0.5)

Table 2. M-ABC and MVIC for the HMI and NMI participants.

	HMI (n=10)	NMI (n=10)
M-ABC	4.3 (5.4)	68.6 (19.9)*
MVIC (Nm.kg)	5.7 (1.0)	9.0 (1.8)*

Motor Impairment and its relationship to fitness in children

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Abstract

Background: Children with movement impairments are known to perform poorly in exercise tests but the nature of the limiting factor is often unknown.

Aim: The aim of this work was to explore physiological and perceptual limits to exercise in children with varying degrees of motor impairment, and the relationships to measures of health.

Methods: 35 boys aged 12-15yrs completed the Movement ABC test for the assessment of motor impairment, followed by an incremental cycle ergometer test to exhaustion for the assessment of maximal oxygen uptake (VO_{2peak}), respiratory exchange ratio (RER), heart rate (HR) and rating of perceived exertion (RPE). 10 participants classified as having either high or no motor impairment also performed a maximal voluntary isometric contraction (MVIC) for the assessment of lower limb extensor strength.

Results: 18 boys were classified as having high motor impairment. All but one participant met the criteria for maximum effort, both perceptually and physiologically, in the exercise test. There was a significant difference in $\dot{V}O_2$ peak (34.9 v 48.5 $ml.kg.min^{-1}$), $\dot{V}O_2$ workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188 $beats.min^{-1}$), maximal oxygen pulse (12.1 v 15.9 ml.beat) and MVIC (5.7 v 9.1 Nm.kg) between the high and non motor impaired participants respectively. There was no significant difference in the RER or RPE between the groups.

Conclusion: When performing cycling ergometry, perceived exertion was not a limiting factor in children with high motor impairment. The lower heart rate at exercise cessation, coupled with reduced movement efficiency and lower muscle strength reported in this group, would suggest exercise is limited by impairment at the muscular level. This finding was supported by the high RER values despite low

maximal heart rate values attained during the exercise test and reduced maximal strength. Perception of effort is not heightened in children with high motor impairment and future exercise interventions should be focused on improving muscular condition in participants with high motor impairment to enable them to be better prepared to engage in physical activity for health.

Introduction

Physical activity levels in childhood have been shown to predict adult activity behavior [1 2], affecting life expectancy and quality of life years. As such, successfully achieving an active lifestyle in childhood is critical. Children with movement difficulties and poor coordination tend to have lower levels of physical activity participation than their typically developing peers [3-5]. Further, this group of children, with reduced motor coordination and low activity levels, have been found to have significantly higher metabolic syndrome indicators [6], including: abdominal adiposity, blood pressure and triglyceride levels compared to their typically developing peers [7] [8]. Of added concern is that such motor impairments are known to persist into adulthood, further impacting on the ability of these individuals to achieve a physically active lifestyle as adults [9-11]. The number of people with some form of motor impairment in the UK population is 2.6 million [12] and as such this group is an important proportion of society who should be considered within public health policy. Understanding factors particularly affecting the exercise experience in these individuals is essential if higher physical activity levels are to be achieved.

In a series of interviews with adolescents with Developmental Coordination Disorder (DCD) [13 14] and with children with cerebral palsy [15], exercise-induced symptoms of muscle fatigue, poor physical tolerance and low energy levels have also been reported as major factors reducing enjoyment, tolerance and participation. However, as yet, the underpinning physiological limits have not been fully explored. We know that individual's judge and limit effort during exercise from symptoms arising from muscles, joints and the cardiovascular system; choosing to reduce how hard they are exercising when symptoms become too strong [16 17]. Children with increased motor impairment are known to perform poorly in sport and exercise fitness screening tests

[18 19], but the physiological and perceptual responses limiting exercise performance have not been explored in these individuals [18 20 21].

Aims

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual measures during and limiting maximal exercise performance.

Methods

Procedure

The study was approved by the University Research Ethics Committee (UREC). Participants were recruited through two routes, either through a database of those who had taken part in our previous research or through advertisements and posters. Families indicating that they were interested in taking part were sent separate child and parent information sheets and gave their written consent prior to the study. Participants attended the Human Performance Laboratory for testing, with parents attending only to help complete a health screening questionnaire for their child. The testing session consisted of the participant completing the Movement ABC-2 Test (MABC-2) [22] for a measure of motor impairment, followed by the exercise testing. Details of these measures can be found below.

Participants were asked to refrain from eating, performing exercise or drinking caffeine in the 2-hour period before attending the sessions.

Participants

Thirty five males aged 12 to 15 years with no known neurological condition were recruited. Individuals were classified on the level of motor ability using the Movement ABC-2 test.

Measures

Movement ABC-2 Test (MABC-2) [22].

This standardised test of motor skill was used to confirm the presence of significant movement difficulties. Eight age appropriate items were individually administered as described in the test manual. Raw scores for each task were converted to standard scores, summed across three sub-sections to obtain a standard score for Manual Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was also obtained. For the diagnosis of motor impairment, it has been recommended that scores below the 5th percentile indicate definite motor impairment while scores between the 5th and 15th percentile indicate borderline scores [23]. Therefore, any child scoring below the 15th percentile in this current study was classed as having high motor impairment (HMI). Children scoring above the 15th percentile were classified as having no motor impairment (NMI).

Exercise testing

Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the exercise test. After resting for 6 minutes participants underwent an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen, Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling. Workload was progressed based on the Godfrey protocol [24] (increasing workload by 15-20 Watts from unloaded cycling based on the height of the participant). The test ended at volitional exhaustion or if the participant was unable to maintain a cadence of 60 rpm, with verbal encouragement given throughout.

Pulmonary gas exchange was measured breath-by-breath using an automated metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was calibrated prior to each test in accordance with manufacturer's instructions. All participants wore a face mask covering the nose and mouth connected to a low-resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was recorded continuously throughout the testing protocol using short-range telemetry (Polar S810, Finland). Oxygen uptake ($\dot{V}O_2$) was calculated as the average $\dot{V}O_2$ in the last 30s of each stage, whilst $\dot{V}O_2$ peak was recorded as the highest 60s average before the termination of the test. The respiratory exchange ratio (RER) was calculated from the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ at each workload level throughout the exercise test. Maximal fat oxidation was calculated using the equations of Frayn [25] in equation 1 below:

$$\text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

The relationship between the amount of oxygen utilised for a given work rate was calculated from the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive indicator of cardiac function, was calculated by dividing the $\dot{V}O_2$ by heart rate ($\dot{V}O_2$/HR). Maximum workload ($Workload_{max}$) was calculated as the final completed workload. Rating of perceived exertion (RPE) was measured at the end of each stage using the Cart and Load scale (CALER), which has previously been used to assess children's perception of effort during exercise [26]. The CALER has a scale from 1 to 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'. Illustrations of a child pulling a cart behind their bicycle, which was progressively laden with bricks, accompanied the scale.

The criteria for true maximal effort included a plateau in $\dot{V}O_2$ max, maximal heart rate $\geq$ 95% of age predicted maximum and RER >1.06 [27]. All children were fully familiaried with the testing protocol prior to commencing the session.

MVIC Protocol

Participants performed a 1RM leg extensor strength test on a specially designed isometric strength-testing chair. The knee angle was 90^0 and the rotation axis of the strength chair was aligned with the knee axis. Participants were asked to relax for 30 seconds, thereafter subjects performed maximum knee extension for approximately 5 seconds. Verbal encouragement was given to reach the maximum force. After this maximum knee extension subjects relaxed for 30 seconds. This test was repeated three times, 1RM was the maximum output reached.

Electrical signals from the torque transducer were amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401). Torque from maximal voluntary contractions (MVIC) was recorded on a PC for subsequent analysis using Spike data analysis software (Spike 2 Version 5.0 for Windows).

Data Analysis

Descriptive statistics (mean +/- SD, range) were calculated for all variables.

All exercise testing measure distributions were examined for normality. Linear regression analysis was performed to examine relationships between M-ABC score and the exercise variables. Ten participants reporting high motor impairment returned to the laboratory to repeat the exercise test to establish reliability data in this population. Test re-test reliability was analysed to test for systematic and random error using student t-test, intraclass correlation coefficient (ICC) [3,1], bias (average difference) and random error (1.96 x SD of differences). Statistical significance was accepted at $p<0.05$.

Results

Movement ABC-2 Test

Eighteen participants obtained total scores considered to be HMI, i.e. below the M-ABC 15th percentile, with 5 at or below the 5th percentile, and 17 classified as no motor impairment (NMI) (M-ABC > 15th percentile). Table 1 displays the participant characteristics from the test battery.

>>>>insert table 1 here

As expected, there was a significant difference in the Movement ABC percentile score between the HMI and NMI group (4.0 (4.7) v 62.8 (20.7), $p<0.05$).

Exercise Testing

There was a significant difference in $\dot{V}O_2$ peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min^{-1}), $\dot{V}O_2$/workload (12.5 (3.9) v 10.0 (1.3) $\dot{V}O_2$/W), oxygen pulse (12.1 (3.7) v 15.9 (4.0) ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0) v 9.0 (1.8) Nm.kg) with the NMI group achieving higher $\dot{V}O_2$, oxygen pulse, maximum heart rate and MVIC.

There was no difference between the groups in the respiratory exchange ratio (RER), with all but one participant demonstrating a maximal value greater than 1.0 at the end of the test. There was also no significant difference in maximal fat oxidation levels between the groups.

Compared to established maximal criteria for typically developing children [28] all but one of the participants met the criteria for a maximal effort during the exercise test, with no significant difference between the HMI and NMI groups. There was no difference in the perception of effort throughout the exercise trial and at exercise termination, with all participants reporting an RPE rating of 9 or 10 at the end of the test, despite individuals in the HMI group having significantly lower maximum HR values at the end of the cycle ergometer test.

There were significant relationships between the MABC score and $\dot{V}O_2$ peak (r = 0.36, p<0.05) (figure 1) and MVIC (r = 0.76, p<0.01) (figure 2).

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

Table 2 below displays the characteristics of the paprticipants who undertook the MVIC testsing

>>>>>>insert table 2 here

Figure 2. Relationship between M-ABC score and MVIC.

Test re-test reliability of exercise measures

10 HMI participants returned to the laboratory to complete a second maximal exercise test for the assessment of reliability in this population. The maximal exercise data demonstrated good reliability with ICC scores for $\dot{V}O_2$ peak 0.75 (CI 0.23-0.94; t 0.39, bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8, random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).

Discussion

The study set out to explore, in individuals with different levels of motor impairment, physiological and perceptual factors during and limiting maximal exercise performance. Examination of the exercise test data showed a significant difference in $\dot{V}O_2$ peak, $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the HMI and NMI group. Interestingly there was no difference maximal rating of perceived exertion or RER. When considering limits to exercise in people with high motor impairment, the maximal RER and fat oxidation levels at test termination, suggest low levels of aerobic muscle performance and not a heightened perceived level of exertion, were limiting exercise performance. These findings are important as they highlight a low level of aerobic muscle performance as a major factor limiting exercise performance in children with poor coordination. Muscle plays a central role in health and disease across the lifespan[29] and, if left unaddressed in children with HMI, is likely to continue into adulthood and contribute to the development of metabolic disorders in this population.

Despite children with HMI demonstrating a linear $\dot{V}O_2$ / workload response, the value of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise [30]. $\dot{V}O_2$ normally rises at a rate of about 8.5-11ml.min.watt and is independent of sex, age, body weight or height [31]. Thus, in children with HMI, exercise participation may be limited by the impaired ability of the muscle to work aerobically. The reduced muscular strength of the quadriceps reported in this study further supports the main limiting factor being at the muscular level and this finding supports the findings from previous studies citing a reduced strength in other muscle groups in children with greater motor impairment [32].

In comparison to the NMI group, the HMI group had a reduced exercise capacity, with a mean $\dot{V}O_2$ peak of 34.9 ml.kg.min^{-1}. The $\dot{V}O_2$ peak was below the cardiovascular fitness threshold in the HMI children [33] and as such associated with an increased risk of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood [34]. Considered alongside the low maximum heart rates demonstrated by these children (mean 176 beats.min^{-1}) in comparison to NMI participants (188 beats.min^{-1}) and those reported in normal healthy children at the end of a similar cycling protocol [35], our findings suggest that a low level of aerobic muscle performance was limiting the ability of children with HMI to push themselves hard enough to maximally tax the cardiovascular system. Despite a significantly lower oxygen pulse level between the groups (12.1 (3.7) v 15.9 (4.0)ml.beat, $p<0.05$), the HMI group was not different to those in healthy individuals reported previously [36]. This further supports the findings that the limiting factor is of peripheral, and not central, origin. Given the emerging role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic capability in the muscles of children with poor motor control may impact on their long-term health and may prevent them from increasing their heart rate to the level required to achieve an aerobic training stimulus and attain fitness, health and wellbeing benefits according to current guidelines for physical activity in children [37]. Interestingly, despite the reduced aerobic fitness there was no difference in the utilisation of fat as a substrate during the exercise protocol between the groups in this study. The levels of fat oxidation in this current study were within the range previously reported in healthy participants of similar age [38]. The number of individuals in this sample is relatively small, however we included a range of individuals with different motor capabilities and in the sub group of HMI participants

that returned to the laboratory we established good reliability in the clinical exercise testing in this population.

Muscle function has been found to have an important role in long term health [29] and considering our observation of reduced muscle capacity in individuals with HMI, it is important to investigate interventions that can be implemented in childhood to improve muscle function and performance [39]. This is further supported with the significantly lower MVIC in the HMI group in comparison to NMI. The reduced strength of the major locomotor muscle group in the HMI not only has implications for function, with some reports of increased co-contraction [40], but also for the impact on health and quality of life. In a recent study by Buchan et al.[41], high intensity exercise has been shown to reduce cardiovascular risk and improve muscle function in healthy children. As yet, this type of intensity has not been investigated in the population of children included in this current study, however the evidence of their willingness to push themselves maximally in this study warrants the application of such intensities of exercise to measure the impact on health and movement measures. Work by Cairney et.al.[18] suggested that reduced exercise performance of children with motor impairment was partly related to the level of perceived adequacy for the task. The findings of this current work suggest that the limitations to exercise in the high motor impairment group had strong physiological underpinnings reflected in the criteria for a maximal effort being attained in all but one of the participants.

The findings from this work highlight the significant relationship between motor impairment level and health status. The reduced exercise capacity and muscular performance demonstrated by the participants with greater motor impairment highlight the need for any exercise interventions to target the development of

muscular function. Research has shown that exercise interventions play a possible role in improving motor competence levels in children with movement difficulties [42] however, how these changes relate to alterations in markers of cardiovascular and muscular health and the long term involvement in physical activity have yet to be elucidated.

Contributorship statement

Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design, acquisition of data or analysis and interpretation of data, and drafting the article or revising it critically for important intellectual content.

Dr Ken Howells - Conception and design and drafting the article or revising it critically for important intellectual content.

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Article Focus

- Exercise tolerance was not limited by the HMI group not willing to push themselves maximally, with the level of motor impairment significantly related to VO_2 peak and muscular strength.
- Children with HMI have a reduced movement economy during cycling exercise.

Key Messages

- Children with high motor impairment fail to exercise hard enough to maximally tax the cardiovascular system.
- Children with HMI are willing to push themselves maximally during exercise, despite limited exercise capacity. Utilising short duration, high intensity exercise bouts, focusing on the development of the exercising musculature, may be a better method for improving the limited fitness parameters in this population.

Strengths and Limitations

- Few studies have directly measured limiting factors to exercise alongside standard motor impairment tests.

- The use of cycle ergometry is a safe option for maximal testing, allowing participants to give a maximal effort. However, due to the nature of the exercise, the weakness in the exercising musculature may be accentuated.

1

Table 1. Participant characteristics and outcome measures.

	HMI (n=18)	NMI (n=17)
M-ABC	4.0 (4.7)	62.8 (20.7)*
Age (yrs)	14.1 (1.5)	14.9 (0.9)
Height (m)	1.70 (0.10)	1.74 (0.10)
Weight (kg)	62.8 (17.9)	60.3 (10.6)
BMI	21.5 (4.0)	19.5 (2.1)
VO_2 max (ml.kg.min)	34.9 (6.3)	48.5 (7.9)*
VO_2/Workload (ml.W)	12.5 (3.9)	10.0 (1.3)*
O_2 Pulse (ml.beat)	12.1 (3.7)	15.9 (4.0)*
Heart Rate max. (beats.min)	176 (19.7)	188 (8.8)*
RER max.	1.15 (0.09)	1.18 (0.09)
RPE max.	9.1 (1.5)	9.6 (0.5)

Table 2. M-ABC and MVIC for the HMI and NMI participants.

	HMI (n=10)	NMI (n=10)
M-ABC	4.3 (5.4)	68.6 (19.9)*
MVIC (Nm.kg)	5.7 (1.0)	9.0 (1.8)*

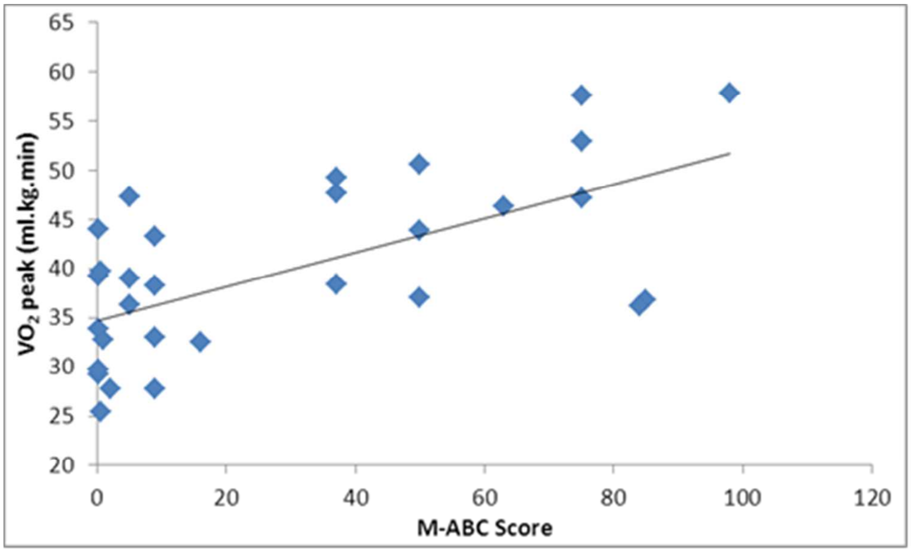

Figure 1. Relationship between M-ABC score and $\dot{V}O_2$ peak.

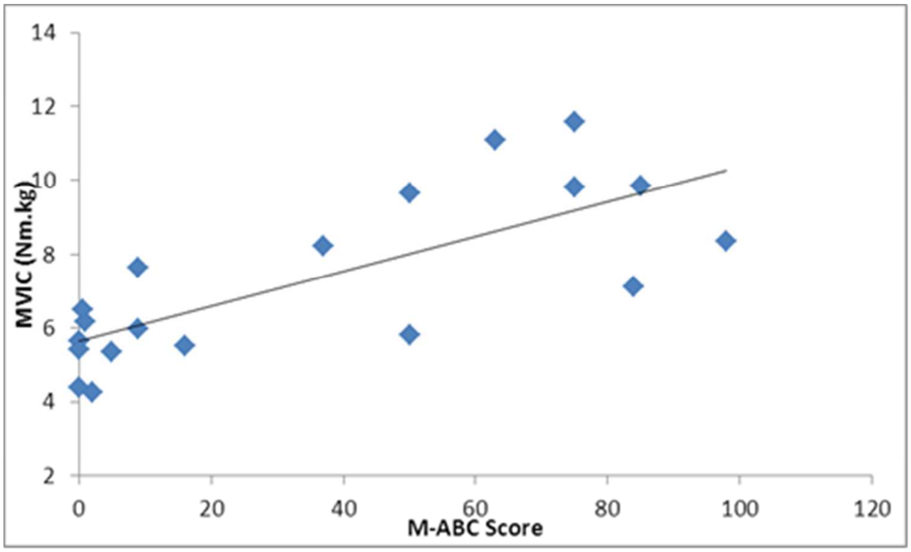

Figure 2. Relationship between M-ABC score and MVIC.