



## Motor Competence and its relationship to fitness in children

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3 1 **Motor Competence and its relationship to fitness in children**  
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3 1 ARTICLE SUMMARY  
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5 2 Article Focus  
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- 7 • Exercise tolerance was not limited by the LMC group not willing to push  
8 themselves maximally, with the level of motor competence significantly  
9 related to VO<sub>2</sub> peak and muscular strength.  
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13 • Children with LMC have a reduced movement economy during cycling  
14 exercise.  
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16  
17 8 Key Messages  
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- 19 • Children with low motor competence fail to exercise hard enough to  
20 maximally tax the cardiovascular system.  
21  
22 • Children with LMC are willing to push themselves maximally during  
23 exercise, despite limited exercise capacity. Utilising short duration, high  
24 intensity exercise bouts, focusing on the development of the exercising  
25 musculature, may be a better method for improving the limited fitness  
26 parameters in this population.  
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32 16 Strengths and Limitations  
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- 34 • Few studies have directly measured limiting factors to exercise alongside  
35 standard motor competence tests.  
36  
37 • The use of cycle ergometry is a safer option for maximal testing, allowing  
38 participants to give a maximal effort. However, due to the nature of the  
39 exercise, the weakness in the exercising musculature may be accentuated.  
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1  
2  
3 **Abstract**

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

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

7 **Methods:** 35 boys aged 12-15yrs completed the Movement ABC test for the  
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assessment of motor competence, followed by an incremental cycle ergometer test to  
exhaustion for the assessment of maximal oxygen uptake ( $\dot{V}O_{2peak}$ ), 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.

14 **Results:** 18 boys were classified as having lower motor competence. All but one  
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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<sup>-1</sup>),  $\dot{V}O_2$  workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188  
beats.min<sup>-1</sup>), 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.

21 **Conclusion:** When performing cycling ergometry, perceived exertion was not a  
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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

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3 1 values attained during the exercise test and reduced maximal strength. Perception of  
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5 2 effort is not heightened in children with low motor competence and future exercise  
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7 3 interventions should be focused on improving muscular condition in participants with  
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10 4 low motor competence to enable them to be better prepared to engage in physical  
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12 5 activity for health.  
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## 1 Introduction

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

19 In a series of interviews in adolescents with Developmental Coordination Disorder  
20 (DCD)<sup>16,17</sup> and in children with cerebral palsy<sup>18</sup>, exercise-induced symptoms of  
21 muscle fatigue, poor physical tolerance and low energy levels have also been  
22 reported as major factors reducing enjoyment, tolerance and participation. However,  
23 as yet, the underpinning physiological limits have not been fully explored. We know  
24 that individuals judge and limit effort during exercise from symptoms arising from  
25 muscles, joints and the cardiovascular system; choosing to reduce how hard they are

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3 1 exercising when symptoms become too strong<sup>19 20</sup>. Children with reduced motor  
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5 2 competence are known to perform poorly in sport and exercise fitness screening tests<sup>9</sup>  
6  
7 3<sup>21</sup>, but the physiological and perceptual responses limiting exercise performance have  
8  
9 4 not been explored in these individuals<sup>9 22 23</sup>.

## 5 **Aims**

6 The study set out to explore, in individuals with different levels of motor competence,  
7  
8 physiological and perceptual measures during and limiting maximal exercise  
9  
10 performance.

## 11 **Methods**

### 12 *Procedure*

13 The study was approved by the University Research Ethics Committee (UREC).  
14  
15 Participants were recruited through two routes, either through a database of those who  
16  
17 had taken part in our previous research or through advertisements and posters.  
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19 Families indicating that they were interested in taking part were sent separate child  
20  
21 and parent information sheets and gave their written consent prior to the study.  
22  
23 Participants attended the Human Performance Laboratory for testing, with parents  
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25 attending only to help complete a health screening questionnaire for their child. The  
26  
27 testing session consisted of the participant completing the Movement ABC-2 Test  
28  
29 (MABC-2)<sup>24</sup> for a measure of motor competence, followed by the exercise testing.  
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31 Details of these measures can be found below. Participants were asked to refrain from  
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33 eating, performing exercise or drinking caffeine in the 2-hour period before attending  
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35 the sessions.  
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3 1 *Participants*

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5 2 35 males aged 12 to 15 years with no known neurological condition were recruited.

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7 3 Individuals were classified on the level of motor ability using the Movement ABC-2  
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9 4 test.

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11 5 *Measures*

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13 6 Movement ABC-2 Test (MABC-2)<sup>24</sup>.

14  
15 7 This standardised test of motor skill was used to confirm the presence of significant  
16  
17 8 movement difficulties. Eight age appropriate items were individually administered as  
18  
19 9 described in the test manual. Raw scores for each task were converted to standard  
20  
21 10 scores, summed across three sub-sections to obtain a standard score for Manual  
22  
23 11 Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was  
24  
25 12 also obtained. For the diagnosis of motor competence, it has been recommended that  
26  
27 13 scores below the 5<sup>th</sup> percentile indicate definite motor impairment while scores  
28  
29 14 between the 5<sup>th</sup> and 15<sup>th</sup> percentile indicate borderline scores<sup>25</sup>. Therefore, any child  
30  
31 15 scoring below the 15<sup>th</sup> percentile in this current study was classed as having low  
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33 16 motor competence

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38 17 *Exercise testing*

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40 18 Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were  
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42 19 recorded prior to the exercise test. After resting for 6 minutes participants underwent  
43  
44 20 an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen,  
45  
46 21 Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling.  
47  
48 22 Workload was progressed based on the Godfrey protocol<sup>26</sup> (increasing workload by  
49  
50 23 15-20 Watts from unloaded cycling based on the height of the participant). The test  
51  
52 24 ended at volitional exhaustion or if the participant was unable to maintain a cadence  
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54 25 of 60 rpm, with verbal encouragement given throughout.  
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1 Pulmonary gas exchange was measured breath-by-breath using an automated  
2 metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was  
3 calibrated prior to each test in accordance with manufacturer's instructions. All  
4 participants wore a face mask covering the nose and mouth connected to a low-  
5 resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was  
6 recorded continuously throughout the testing protocol using short-range telemetry  
7 (Polar S810, Finland). Oxygen uptake ( $\dot{V}O_2$ ) was calculated as the average  $\dot{V}O_2$  in the  
8 last 30s of each stage, whilst  $\dot{V}O_2$  peak was recorded as the highest 60s average before  
9 the termination of the test. The respiratory exchange ratio (RER) was calculated from  
10 the ratio of  $\dot{V}CO_2$  to  $\dot{V}O_2$  at each workload level throughout the exercise test.

11 Maximal fat oxidation was calculated using the equations of Frayn<sup>27</sup> in equation 1  
12 below:

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

13  
14 The relationship between the amount of oxygen utilised for a given work rate was  
15 calculated from the linear slope of the relationship between  $\dot{V}O_2$  and Watts ( $\dot{V}O_2/W$ )  
16 and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive  
17 indicator of cardiac function, was calculated by dividing the  $\dot{V}O_2$  by heart rate  
18 ( $\dot{V}O_2/HR$ ). Maximum workload ( $Workload_{max}$ ) was calculated as the final completed  
19 workload. Rating of perceived exertion (RPE) was measured at the end of each stage  
20 using the Cart and Load scale (CALER), which has previously been used to assess  
21 children's perception of effort during exercise<sup>28</sup>. The CALER has a scale from 1 to  
22 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'.  
23 Illustrations of a child pulling a cart behind their bicycle, which was progressively  
24 laden with bricks, accompanied the scale.

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3 1 The criteria for true maximal effort included a plateau in  $\dot{V}O_2$  max, maximal heart rate  
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5 2  $\geq 95\%$  of age predicted maximum and RER  $>1.06$ <sup>29</sup>. All children were fully  
6  
7 3 familiaried with the testing protocol prior to commencing the session.  
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#### 11 5 MVIC Protocol

12 6 Participants performed a 1RM leg extensor strength test on a specially designed  
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14 7 isometric strength-testing chair. The knee angle was  $90^0$  and the rotation axis of the  
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16 8 strength chair was aligned with the knee axis. Participants were asked to relax for 30  
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18 9 seconds, thereafter subjects performed maximum knee extension for approximately 5  
19  
20 10 seconds. Verbal encouragement was given to reach the maximum force. After this  
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22 11 maximum knee extension subjects relaxed for 30 seconds. This test was repeated three  
23  
24 12 times, 1RM was the maximum output reached.

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26 13 Electrical signals from the torque transducer were amplified (Digitimer Neurolog  
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28 14 NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401).  
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30 15 Torque from maximal voluntary contractions (MVIC) was recorded on a PC for  
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32 16 subsequent analysis using Spike data analysis software (Spike 2 Version 5.0 for  
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34 17 Windows).

#### 35 18 Data Analysis

36 19 Descriptive statistics (mean +/- SD, range) were calculated for all variables.  
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38 20 All exercise testing measure distributions were examined for normality. Linear  
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40 21 regression analysis was performed to examine relationships between M-ABC score  
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42 22 and the exercise variables. 10 participants reporting low motor competence returned  
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44 23 to the laboratory to repeat the exercise test to establish reliability data in this  
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46 24 population. Test re-test reliability was analysed to test for systematic and random  
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48 25 error using student t-test, intraclass correlation coefficient (ICC) [3,1], bias (average  
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1 difference) and random error (1.96 x SD of differences). Statistical significance was  
2 accepted at  $p < 0.05$ .

## 3 4 **Results**

### 5 6 7 *Movement ABC-2 Test*

8 18 participants obtained total scores considered to be LMC, i.e. below the ABC 15<sup>th</sup>  
9 percentile, with 5 at or below the 5<sup>th</sup>.

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

13

### 14 *Exercise Testing*

15 There was a significant difference in  $\dot{V}O_2$  peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min<sup>-1</sup>),  
16  $\dot{V}O_2$ /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)  
17 ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0)  
18 v 9.0 (1.8) Nm.kg) with the HMC groups achieving higher  $\dot{V}O_2$ , oxygen pulse,  
19 maximum heart rate and MVIC.

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

24 Compared to established maximal criteria for typically developing children<sup>30</sup> all but  
25 one of the participants met the criteria for a maximal effort during the exercise test,  
26 with no significant difference between the LMC and HMC groups. There was no  
27 difference in the perception of effort throughout the exercise trial and at exercise

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3 1 termination, with all participants reporting an RPE rating of 9 or 10 at the end of the  
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5 2 test, despite individuals in the LMC group having significantly lower maximum HR  
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7 3 values at the end of the cycle ergometer test.  
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12 5 There were significant relationships between the MABC score and  $\dot{V}O_2$  peak ( $r = 0.36$ ,  
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14 6  $p < 0.05$ ) (figure 1) and MVIC ( $r = 0.76$ ,  $p < 0.01$ ) (figure 2).  
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21 9 Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.  
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23 10  
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27 12 Figure 2. Relationship between M-ABC score and MVIC.  
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### 29 13 30 14 *Test re-test reliability of exercise measures*

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33 15 10 LMC participants returned to the laboratory to complete a second maximal  
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35 16 exercise test for the assessment of reliability in this population. The maximal exercise  
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37 17 data demonstrated good reliability with ICC scores for  $\dot{V}O_2$  peak 0.75 (CI 0.23-0.94; t  
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39 18 0.39, bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86,  
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41 19 bias 7.8, random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07,  
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43 20 random error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the  
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45 21 ICC 0.05 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).  
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### 49 23 **Discussion**

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53 24 The study set out to explore, in individuals with different levels of motor competence,  
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55 25 physiological and perceptual factors during and limiting maximal exercise  
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57 26 performance. When considering limits to exercise in people with low motor  
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3 1 competence, symptoms of perceived exertion were limiting individuals underpinned  
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5 2 by typical maximal RER and fat oxidation levels at test termination, suggesting low  
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7 3 levels of aerobic muscle performance. Examination of the exercise test data showed a  
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10 4 significant difference in  $\dot{V}O_2$  peak,  $\dot{V}O_2$  / workload, oxygen pulse, maximum heart rate  
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12 5 and MVIC between the LMC and HMC group. Furthermore, individuals with lower  
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14 6 motor competence had both a lower exercise capacity and lower muscle strength.  
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16 7 These findings together are important as they highlight a low level of aerobic muscle  
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18 8 performance as a factor limiting exercise performance in children with poor  
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20 9 coordination and a number of changes in health indicators in children with low motor  
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22 10 competence which, if left unaddressed, is likely to continue into adulthood and  
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24 11 contribute to the development of metabolic disorders in this population.  
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30 13 Despite children with LMC demonstrating a linear  $\dot{V}O_2$  / workload response, the  
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32 14 value of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the  
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34 15 exercise<sup>31</sup>.  $\dot{V}O_2$  normally raises at a rate of about 8.5-11ml.min.watt and is  
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36 16 independent of sex, age, body weight or height<sup>32</sup>. Thus, in children with LMC,  
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38 17 exercise participation may be limited by the impaired ability of the muscle to work  
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40 18 aerobically. The reduced muscular strength of the quadriceps reported in this study  
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42 19 further supports the main limiting factor being at the muscular level and this finding  
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44 20 supports the findings from previous studies citing a reduced strength in other muscle  
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46 21 groups in children with poor motor competence<sup>33</sup>.  
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53 23 In comparison to the HMC group, the LMC group had a reduced exercise capacity,  
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55 24 with a mean  $\dot{V}O_2$  peak of 34.9 ml.kg.min<sup>-1</sup>. The  $\dot{V}O_2$  peak was below the cardiovascular  
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57 25 fitness threshold in the LMC children<sup>34</sup> and as such associated with an increased risk  
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1 of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood  
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5 35. Considered alongside the low maximum heart rates demonstrated by these  
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7 children (mean 176 beats.min<sup>-1</sup>) in comparison to HMC participants (188 beats.min<sup>-1</sup>)  
8  
9 and those reported in normal healthy children at the end of a similar cycling protocol  
10  
11 36, our findings suggest that a low level of aerobic muscle performance was limiting  
12  
13 the ability of children with LMC to push themselves hard enough to maximally tax  
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15 the cardiovascular system. Despite a significantly lower oxygen pulse level between  
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17 the groups (12.1 (3.7) v 15.9 (4.0)ml.beat, p<0.05), the LMC group was not different  
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19 to those in healthy individuals reported previously<sup>37</sup>. This further supports the  
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21 findings that the limiting factor is of peripheral, and not central, origin. Given the  
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23 emerging role of mitochondrial dysfunction in many neuromuscular disorders, a lack  
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25 of aerobic capability in the muscles of children with poor motor control may impact  
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27 on their long-term health and may prevent them from increasing heart rate to the level  
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29 required to achieve an aerobic training stimulus and attain fitness, health and  
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31 wellbeing benefits according to current guidelines for physical activity in children<sup>38</sup>.  
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33 Interestingly, despite the reduced aerobic fitness there was no difference in the  
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35 utilisation of fat as a substrate during the exercise protocol between the groups in this  
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37 study (0.56 (0.28) v 0.72 (0.36)g.min, p>0.05) for LMC and HMC respectively. The  
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39 levels of fat oxidation in this current study were within the range previously reported  
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41 in healthy participants of similar age<sup>39</sup>. The number of individuals in this sample is  
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43 relatively small, however we included a range of individuals with different motor  
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45 capabilities and in the sub group of LMC participants that returned to the laboratory  
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47 we established good reliability in the clinical exercise testing in this population.  
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49 Muscle function has been found to have an important role in long term health<sup>40</sup> and  
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51 considering our observation of reduced muscle capacity in individuals with LMC, it is  
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3 1 important to investigate interventions that can be implemented in childhood to  
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5 2 improve muscle function and performance <sup>41</sup>. This is further supported with the  
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7 3 significantly lower MVIC in the LMC group in comparison to HMC. The reduced  
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10 4 strength of the major locomotor muscle group in the LMC not only has implications  
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12 5 for function, with some reports of increased co-contraction <sup>42</sup>, but also for the impact  
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14 6 on health and quality of life. In a recent study by Buchan et al. <sup>43</sup>, high intensity  
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16 7 exercise has been shown to reduce cardiovascular risk and improve muscle function in  
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18 8 healthy children. As yet, this type of intensity has not been investigated in the  
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20 9 population of children included in this current study, however the evidence of their  
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22 10 willingness to push themselves maximally in this study warrants the application of  
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24 11 such intensities of exercise to measure the impact on health and movement measures.  
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30 13 The findings from this work highlight the significant relationship between motor  
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32 14 competence level and health status. The reduced exercise capacity and muscular  
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34 15 performance demonstrated by the participants with poor motor competence highlight  
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36 16 the need for any exercise interventions to target the development of muscular  
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38 17 function. Research has shown that exercise interventions play a possible role in  
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40 18 improving motor competence levels in children with movement difficulties <sup>44</sup>  
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42 19 however, how these changes relate to alterations in markers of cardiovascular and  
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44 20 muscular health and the long term involvement in physical activity have yet to be  
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46 21 elucidated.  
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3 **Contributorship statement**  
4

5 Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design,  
6  
7 acquisition of data or analysis and interpretation of data, and drafting the article or  
8  
9 revising it critically for important intellectual content.  
10

11 Dr Ken Howells - Conception and design and drafting the article or revising it critically  
12  
13 for important intellectual content.  
14

15  
16 **Funding**  
17

18 None  
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20  
21 **Data Sharing**  
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23 No additional data available.  
24

25 **Competing Interests**  
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27 None  
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33 **References**  
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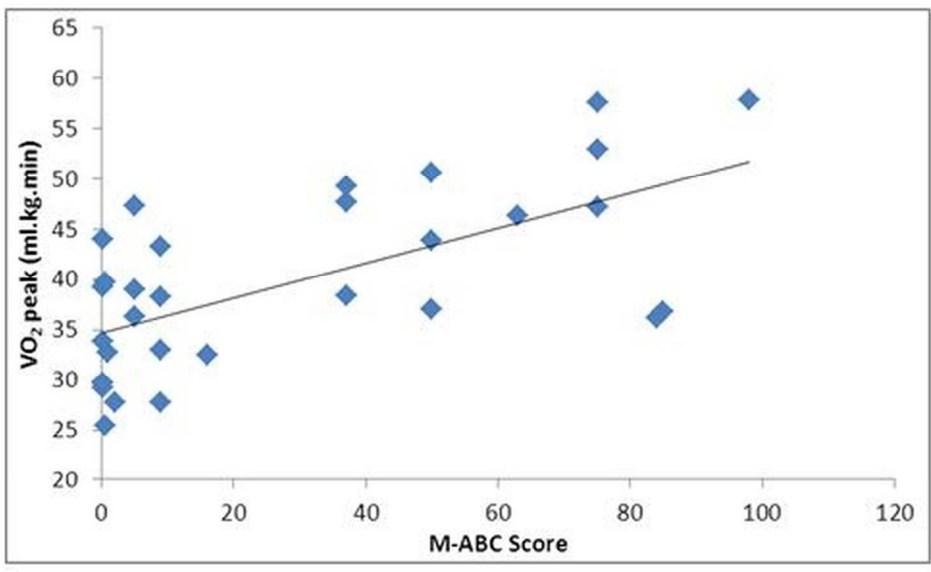


Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.

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

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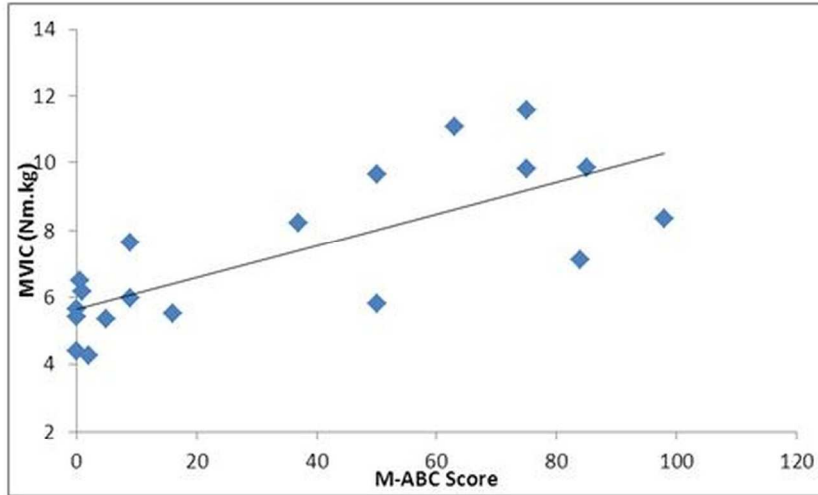


Figure 2. Relationship between M-ABC score and MVIC.

Figure 2. Relationship between M-ABC score and MVIC.  
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## Motor Impairment and its relationship to fitness in children

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Keywords:	PAEDIATRICS, Muscle, Health, Motor competence

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3 1 **Motor Impairment and its relationship to fitness in children**  
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11 5 Ken Howells  
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38 17 **Key words:** Motor impairment,  $\dot{V}O_2$  max, fitness, muscle  
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40 18 **Word count: 2621**  
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2  
3 **Abstract**

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

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

7 **Methods:** 35 boys aged 12-15yrs completed the Movement ABC test for the  
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assessment of motor impairment, followed by an incremental cycle ergometer test to  
exhaustion for the assessment of maximal oxygen uptake ( $\dot{V}O_{2peak}$ ), 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.

14 **Results:** 18 boys were classified as having high motor impairment. All but one  
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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<sup>-1</sup>),  $\dot{V}O_2$  workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188  
beats.min<sup>-1</sup>), 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.

21 **Conclusion:** When performing cycling ergometry, perceived exertion was not a  
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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

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3 1 maximal heart rate values attained during the exercise test and reduced maximal  
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5 2 strength. Perception of effort is not heightened in children with high motor  
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7 3 impairment and future exercise interventions should be focused on improving  
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10 4 muscular condition in participants with high motor impairment to enable them to be  
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12 5 better prepared to engage in physical activity for health.  
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## 1 Introduction

2 Physical activity levels in childhood have been shown to predict adult activity  
3 behavior<sup>1,2</sup>, affecting life expectancy and quality of life years. As such, successfully  
4 achieving an active lifestyle in childhood is critical. Children with movement  
5 difficulties and poor coordination tend to have lower levels of physical activity  
6 participation than their typically developing peers<sup>3-5</sup>. Further, this group of children,  
7 with reduced motor coordination and low activity levels, have been found to have  
8 significantly higher metabolic syndrome indicators<sup>6</sup>, including: abdominal adiposity,  
9 blood pressure and triglyceride levels compared to their typically developing peers<sup>7</sup>  
10<sup>8</sup>. Of added concern is that such motor impairments are known to persist into  
11 adulthood, further impacting on the ability of these individuals to achieve a physically  
12 active lifestyle as adults<sup>9-11</sup>. The number of people with some form of motor  
13 impairment in the UK population is 2.6 million<sup>12</sup> and as such this group is an  
14 important proportion of society who should be considered within public health policy.  
15 Understanding factors particularly affecting the exercise experience in these  
16 individuals is essential if higher physical activity levels are to be achieved.  
17 In a series of interviews with adolescents with Developmental Coordination Disorder  
18 (DCD)<sup>13,14</sup> and with children with cerebral palsy<sup>15</sup>, exercise-induced symptoms of  
19 muscle fatigue, poor physical tolerance and low energy levels have also been  
20 reported as major factors reducing enjoyment, tolerance and participation. However,  
21 as yet, the underpinning physiological limits have not been fully explored. We know  
22 that individual's judge and limit effort during exercise from symptoms arising from  
23 muscles, joints and the cardiovascular system; choosing to reduce how hard they are  
24 exercising when symptoms become too strong<sup>16,17</sup>. Children with increased motor  
25 impairment are known to perform poorly in sport and exercise fitness screening tests

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3 1<sup>18 19</sup>, but the physiological and perceptual responses limiting exercise performance  
4  
5 2 have not been explored in these individuals<sup>18 20 21</sup>.  
6

### 7 **Aims**

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10 4 The study set out to explore, in individuals with different levels of motor impairment,  
11  
12 5 physiological and perceptual measures during and limiting maximal exercise  
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14 6 performance.  
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### 16 **Methods**

#### 17 *Procedure*

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19  
20 9 The study was approved by the University Research Ethics Committee (UREC).  
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23 10 Participants were recruited through two routes, either through a database of those who  
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25 11 had taken part in our previous research or through advertisements and posters.  
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27 12 Families indicating that they were interested in taking part were sent separate child  
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29 13 and parent information sheets and gave their written consent prior to the study.  
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31  
32 14 Participants attended the Human Performance Laboratory for testing, with parents  
33  
34 15 attending only to help complete a health screening questionnaire for their child. The  
35  
36 16 testing session consisted of the participant completing the Movement ABC-2 Test  
37  
38 17 (MABC-2)<sup>22</sup> for a measure of motor impairment, followed by the exercise testing.  
39  
40  
41 18 Details of these measures can be found below.

42  
43 19 Participants were asked to refrain from eating, performing exercise or drinking  
44  
45 20 caffeine in the 2-hour period before attending the sessions.  
46

47  
48 21

#### 49 *Participants*

50  
51  
52 23 Thirty five males aged 12 to 15 years with no known neurological condition were  
53  
54 24 recruited. Individuals were classified on the level of motor ability using the  
55  
56 25 Movement ABC-2 test.  
57  
58  
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60

1  
2  
3 1 *Measures*

4  
5 2 Movement ABC-2 Test (MABC-2)<sup>22</sup>.

6  
7 3 This standardised test of motor skill was used to confirm the presence of significant  
8  
9 4 movement difficulties. Eight age appropriate items were individually administered as  
10  
11 5 described in the test manual. Raw scores for each task were converted to standard  
12  
13 6 scores, summed across three sub-sections to obtain a standard score for Manual  
14  
15 7 Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was  
16  
17 8 also obtained. For the diagnosis of motor impairment, it has been recommended that  
18  
19 9 scores below the 5<sup>th</sup> percentile indicate definite motor impairment while scores  
20  
21 10 between the 5<sup>th</sup> and 15<sup>th</sup> percentile indicate borderline scores<sup>23</sup>. Therefore, any child  
22  
23 11 scoring below the 15<sup>th</sup> percentile in this current study was classed as having high  
24  
25 12 motor impairment (HMI).

26  
27  
28  
29 13 *Exercise testing*

30  
31  
32 14 Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were  
33  
34 15 recorded prior to the exercise test. After resting for 6 minutes participants underwent  
35  
36 16 an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen,  
37  
38 17 Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling.  
39  
40 18 Workload was progressed based on the Godfrey protocol<sup>24</sup> (increasing workload by  
41  
42 19 15-20 Watts from unloaded cycling based on the height of the participant). The test  
43  
44 20 ended at volitional exhaustion or if the participant was unable to maintain a cadence  
45  
46 21 of 60 rpm, with verbal encouragement given throughout.

47  
48  
49 22 Pulmonary gas exchange was measured breath-by-breath using an automated  
50  
51 23 metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was  
52  
53 24 calibrated prior to each test in accordance with manufacturer's instructions. All  
54  
55 25 participants wore a face mask covering the nose and mouth connected to a low-

1  
2  
3 1 resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was  
4  
5 2 recorded continuously throughout the testing protocol using short-range telemetry  
6  
7 3 (Polar S810, Finland). Oxygen uptake ( $\dot{V}O_2$ ) was calculated as the average  $\dot{V}O_2$  in the  
8  
9  
10 4 last 30s of each stage, whilst  $\dot{V}O_2$  peak was recorded as the highest 60s average before  
11  
12 5 the termination of the test. The respiratory exchange ratio (RER) was calculated from  
13  
14 6 the ratio of  $\dot{V}CO_2$  to  $\dot{V}O_2$  at each workload level throughout the exercise test.

15  
16  
17 7 Maximal fat oxidation was calculated using the equations of Frayn<sup>25</sup> in equation 1  
18  
19 8 below:

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

20  
21  
22 9  
23  
24 10 The relationship between the amount of oxygen utilised for a given work rate was  
25  
26 11 calculated from the linear slope of the relationship between  $\dot{V}O_2$  and Watts ( $\dot{V}O_2/W$ )  
27  
28 12 and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive  
29  
30 13 indicator of cardiac function, was calculated by dividing the  $\dot{V}O_2$  by heart rate  
31  
32  
33 14 ( $\dot{V}O_2/HR$ ). Maximum workload ( $Workload_{max}$ ) was calculated as the final completed  
34  
35  
36 15 workload. Rating of perceived exertion (RPE) was measured at the end of each stage  
37  
38 16 using the Cart and Load scale (CALER), which has previously been used to assess  
39  
40 17 children's perception of effort during exercise<sup>26</sup>. The CALER has a scale from 1 to  
41  
42 18 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'.  
43  
44 19 Illustrations of a child pulling a cart behind their bicycle, which was progressively  
45  
46 20 laden with bricks, accompanied the scale.  
47  
48  
49 21 The criteria for true maximal effort included a plateau in  $\dot{V}O_2$  max, maximal heart rate  
50  
51 22  $\geq 95\%$  of age predicted maximum and RER  $>1.06$ <sup>27</sup>. All children were fully  
52  
53  
54 23 familiarised with the testing protocol prior to commencing the session.  
55  
56 24  
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## 1 MVIC Protocol

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

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

## 14 **Data Analysis**

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

24  
25  
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27



## 1 Results

### 4 *Movement ABC-2 Test*

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

9 >>>>insert table 1 here

10

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

13

### 14 *Exercise Testing*

15 There was a significant difference in  $\dot{V}O_2$  peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min<sup>-1</sup>),  
16  $\dot{V}O_2$ /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)  
17 ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0)  
18 v 9.0 (1.8) Nm.kg) with the LMI group achieving higher  $\dot{V}O_2$ , oxygen pulse,  
19 maximum heart rate and MVIC.

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

24 Compared to established maximal criteria for typically developing children<sup>28</sup> all but  
25 one of the participants met the criteria for a maximal effort during the exercise test,  
26 with no significant difference between the HMI and LMI groups. There was no  
27 difference in the perception of effort throughout the exercise trial and at exercise

1  
2  
3 1 termination, with all participants reporting an RPE rating of 9 or 10 at the end of the  
4  
5 2 test, despite individuals in the HMI group having significantly lower maximum HR  
6  
7 3 values at the end of the cycle ergometer test.  
8  
9  
10 4

11  
12 5 There were significant relationships between the MABC score and  $\dot{V}O_2$  peak ( $r = 0.36$ ,  
13  
14 6  $p < 0.05$ ) (figure 1) and MVIC ( $r = 0.76$ ,  $p < 0.01$ ) (figure 2).  
15  
16  
17 7

18  
19 8  
20  
21 9 Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.  
22

23 10 Table 2 below displays the characteristics of the participants who undertook the  
24  
25 11 MVIC testing  
26

27 12  
28  
29  
30 13 >>>>>>insert table 2 here  
31

32 14  
33  
34 15 Figure 2. Relationship between M-ABC score and MVIC.  
35  
36 16

### 37 17 *Test re-test reliability of exercise measures*

38  
39 18 10 HMI participants returned to the laboratory to complete a second maximal exercise  
40  
41 19 test for the assessment of reliability in this population. The maximal exercise data  
42  
43 20 demonstrated good reliability with ICC scores for  $\dot{V}O_2$  peak 0.75 (CI 0.23-0.94; t 0.39,  
44  
45 21 bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8,  
46  
47 22 random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random  
48  
49 23 error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05  
50  
51 24 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).  
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## 58 26 **Discussion**

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3 1 The study set out to explore, in individuals with different levels of motor impairment,  
4  
5 2 physiological and perceptual factors during and limiting maximal exercise  
6  
7 3 performance. Examination of the exercise test data showed a significant difference in  
8  
9 4  $\dot{V}O_2$  peak,  $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the  
10  
11 5 HMI and LMI group. Interestingly there was no difference maximal rating of  
12  
13 6 perceived exertion or RER. When considering limits to exercise in people with high  
14  
15 7 motor impairment, the maximal RER and fat oxidation levels at test termination,  
16  
17 8 suggest low levels of aerobic muscle performance and not a heightened perceived  
18  
19 9 level of exertion, were limiting exercise performance. These findings are important as  
20  
21 10 they highlight a low level of aerobic muscle performance as a major factor limiting  
22  
23 11 exercise performance in children with poor coordination. Muscle plays a central role  
24  
25 12 in health and disease across the lifespan<sup>29</sup> and, if left unaddressed in children with  
26  
27 13 HMI, is likely to continue into adulthood and contribute to the development of  
28  
29 14 metabolic disorders in this population.  
30  
31  
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37 16 Despite children with HMI demonstrating a linear  $\dot{V}O_2$ / workload response, the value  
38  
39 17 of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise<sup>30</sup>.  
40  
41 18  $\dot{V}O_2$  normally rises at a rate of about 8.5-11 ml.min.watt and is independent of sex,  
42  
43 19 age, body weight or height<sup>31</sup>. Thus, in children with HMI, exercise participation may  
44  
45 20 be limited by the impaired ability of the muscle to work aerobically. The reduced  
46  
47 21 muscular strength of the quadriceps reported in this study further supports the main  
48  
49 22 limiting factor being at the muscular level and this finding supports the findings from  
50  
51 23 previous studies citing a reduced strength in other muscle groups in children with  
52  
53 24 greater motor impairment<sup>32</sup>.  
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3 1 In comparison to the LMI group, the HMI group had a reduced exercise capacity, with  
4  
5 2 a mean  $\dot{V}O_2$  peak of 34.9 ml.kg.min<sup>-1</sup>. The  $\dot{V}O_2$  peak was below the cardiovascular  
6  
7 3 fitness threshold in the HMI children<sup>33</sup> and as such associated with an increased risk  
8  
9 4 of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood  
10  
11 5<sup>34</sup>. Considered alongside the low maximum heart rates demonstrated by these  
12  
13 6 children (mean 176 beats.min<sup>-1</sup>) in comparison to LMI participants (188 beats.min<sup>-1</sup>)  
14  
15 7 and those reported in normal healthy children at the end of a similar cycling protocol  
16  
17 8<sup>35</sup>, our findings suggest that a low level of aerobic muscle performance was limiting  
18  
19 9 the ability of children with HMI to push themselves hard enough to maximally tax the  
20  
21 10 cardiovascular system. Despite a significantly lower oxygen pulse level between the  
22  
23 11 groups (12.1 (3.7) v 15.9 (4.0)ml.beat, p<0.05), the HMI group was not different to  
24  
25 12 those in healthy individuals reported previously<sup>36</sup>. This further supports the findings  
26  
27 13 that the limiting factor is of peripheral, and not central, origin. Given the emerging  
28  
29 14 role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic  
30  
31 15 capability in the muscles of children with poor motor control may impact on their  
32  
33 16 long-term health and may prevent them from increasing their heart rate to the level  
34  
35 17 required to achieve an aerobic training stimulus and attain fitness, health and  
36  
37 18 wellbeing benefits according to current guidelines for physical activity in children<sup>37</sup>.  
38  
39 19 Interestingly, despite the reduced aerobic fitness there was no difference in the  
40  
41 20 utilisation of fat as a substrate during the exercise protocol between the groups in this  
42  
43 21 study. The levels of fat oxidation in this current study were within the range  
44  
45 22 previously reported in healthy participants of similar age<sup>38</sup>. The number of  
46  
47 23 individuals in this sample is relatively small, however we included a range of  
48  
49 24 individuals with different motor capabilities and in the sub group of HMI participants  
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3 1 that returned to the laboratory we established good reliability in the clinical exercise  
4  
5 2 testing in this population.  
6

7 3 Muscle function has been found to have an important role in long term health <sup>29</sup> and  
8  
9 4 considering our observation of reduced muscle capacity in individuals with HMI, it is  
10  
11 5 important to investigate interventions that can be implemented in childhood to  
12  
13 6 improve muscle function and performance <sup>39</sup>. This is further supported with the  
14  
15 7 significantly lower MVIC in the HMI group in comparison to LMI. The reduced  
16  
17 8 strength of the major locomotor muscle group in the HMI not only has implications  
18  
19 9 for function, with some reports of increased co-contraction <sup>40</sup>, but also for the impact  
20  
21 10 on health and quality of life. In a recent study by Buchan et al. <sup>41</sup>, high intensity  
22  
23 11 exercise has been shown to reduce cardiovascular risk and improve muscle function in  
24  
25 12 healthy children. As yet, this type of intensity has not been investigated in the  
26  
27 13 population of children included in this current study, however the evidence of their  
28  
29 14 willingness to push themselves maximally in this study warrants the application of  
30  
31 15 such intensities of exercise to measure the impact on health and movement measures.  
32  
33 16 Work by Cairney et.al. <sup>18</sup> suggested that reduced exercise performance of children with  
34  
35 17 motor impairment was partly related to the level of perceived adequacy for the task.  
36  
37 18 The findings of this current work suggest that the limitations to exercise in the high  
38  
39 19 motor impairment group had strong physiological underpinnings reflected in the  
40  
41 20 criteria for a maximal effort being attained in all but one of the participants.  
42  
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49 21  
50 22 The findings from this work highlight the significant relationship between motor  
51  
52 23 impairment level and health status. The reduced exercise capacity and muscular  
53  
54 24 performance demonstrated by the participants with greater motor impairment  
55  
56 25 highlight the need for any exercise interventions to target the development of  
57  
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1 muscular function. Research has shown that exercise interventions play a possible  
2 role in improving motor competence levels in children with movement difficulties <sup>42</sup>  
3 however, how these changes relate to alterations in markers of cardiovascular and  
4 muscular health and the long term involvement in physical activity have yet to be  
5 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.

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3 1 **Motor Impairment** and its relationship to fitness in children  
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7 3 Martyn Morris  
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9 4 Helen Dawes  
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11 5 Ken Howells  
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37  
38 17 **Key words:** Motor impairment,  $\dot{V}O_2$  max, fitness, muscle  
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40 18 **Word count: 2621**  
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1  
2  
3 **Abstract**

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

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

7 **Methods:** 35 boys aged 12-15yrs completed the Movement ABC test for the  
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assessment of motor impairment, followed by an incremental cycle ergometer test to  
exhaustion for the assessment of maximal oxygen uptake ( $\dot{V}O_{2peak}$ ), 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.

14 **Results:** 18 boys were classified as having high motor impairment. All but one  
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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<sup>-1</sup>),  $\dot{V}O_2$  workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188  
beats.min<sup>-1</sup>), 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.

21 **Conclusion:** When performing cycling ergometry, perceived exertion was not a  
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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

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3 1 maximal heart rate values attained during the exercise test and reduced maximal  
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5 2 strength. Perception of effort is not heightened in children with high motor  
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7 3 impairment and future exercise interventions should be focused on improving  
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10 4 muscular condition in participants with high motor impairment to enable them to be  
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12 5 better prepared to engage in physical activity for health.  
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## 1 Introduction

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

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

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3 18<sup>19</sup>, but the physiological and perceptual responses limiting exercise performance  
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5 have not been explored in these individuals<sup>18 20 21</sup>.  
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### 7 **Aims**

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10 4 The study set out to explore, in individuals with different levels of motor impairment,  
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12 5 physiological and perceptual measures during and limiting maximal exercise  
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14 6 performance.  
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### 16 **Methods**

#### 17 *Procedure*

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20 9 The study was approved by the University Research Ethics Committee (UREC).  
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22 10 Participants were recruited through two routes, either through a database of those who  
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24 11 had taken part in our previous research or through advertisements and posters.  
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26 12 Families indicating that they were interested in taking part were sent separate child  
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28 13 and parent information sheets and gave their written consent prior to the study.  
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30 14 Participants attended the Human Performance Laboratory for testing, with parents  
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32 15 attending only to help complete a health screening questionnaire for their child. The  
33  
34 16 testing session consisted of the participant completing the Movement ABC-2 Test  
35  
36 17 (MABC-2)<sup>22</sup> for a measure of motor impairment, followed by the exercise testing.  
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38 18 Details of these measures can be found below.  
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40 19 Participants were asked to refrain from eating, performing exercise or drinking  
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42 20 caffeine in the 2-hour period before attending the sessions.  
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#### 49 *Participants*

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52 23 **Thirty five** males aged 12 to 15 years with no known neurological condition were  
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54 24 recruited. Individuals were classified on the level of motor ability using the  
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56 25 Movement ABC-2 test.  
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3 1 *Measures*

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5 2 Movement ABC-2 Test (MABC-2)<sup>22</sup>.

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7 3 This standardised test of motor skill was used to confirm the presence of significant  
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9 4 movement difficulties. Eight age appropriate items were individually administered as  
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11 5 described in the test manual. Raw scores for each task were converted to standard  
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13 6 scores, summed across three sub-sections to obtain a standard score for Manual  
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15 7 Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was  
16  
17 8 also obtained. For the diagnosis of motor impairment, it has been recommended that  
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19 9 scores below the 5<sup>th</sup> percentile indicate definite motor impairment while scores  
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21 10 between the 5<sup>th</sup> and 15<sup>th</sup> percentile indicate borderline scores<sup>23</sup>. Therefore, any child  
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23 11 scoring below the 15<sup>th</sup> percentile in this current study was classed as having high  
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25 12 motor impairment (HMI).

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29 13 *Exercise testing*

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32 14 Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were  
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34 15 recorded prior to the exercise test. After resting for 6 minutes participants underwent  
35  
36 16 an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen,  
37  
38 17 Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling.  
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40 18 Workload was progressed based on the Godfrey protocol<sup>24</sup> (increasing workload by  
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42 19 15-20 Watts from unloaded cycling based on the height of the participant). The test  
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44 20 ended at volitional exhaustion or if the participant was unable to maintain a cadence  
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46 21 of 60 rpm, with verbal encouragement given throughout.

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49 22 Pulmonary gas exchange was measured breath-by-breath using an automated  
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51 23 metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was  
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53 24 calibrated prior to each test in accordance with manufacturer's instructions. All  
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55 25 participants wore a face mask covering the nose and mouth connected to a low-

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3 1 resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was  
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5 2 recorded continuously throughout the testing protocol using short-range telemetry  
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7 3 (Polar S810, Finland). Oxygen uptake ( $\dot{V}O_2$ ) was calculated as the average  $\dot{V}O_2$  in the  
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9 4 last 30s of each stage, whilst  $\dot{V}O_2$  peak was recorded as the highest 60s average before  
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11 5 the termination of the test. The respiratory exchange ratio (RER) was calculated from  
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13 6 the ratio of  $\dot{V}CO_2$  to  $\dot{V}O_2$  at each workload level throughout the exercise test.  
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17 7 Maximal fat oxidation was calculated using the equations of Frayn<sup>25</sup> in equation 1  
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19 8 below:

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

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24 10 The relationship between the amount of oxygen utilised for a given work rate was  
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26 11 calculated from the linear slope of the relationship between  $\dot{V}O_2$  and Watts ( $\dot{V}O_2/W$ )  
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28 12 and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive  
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30 13 indicator of cardiac function, was calculated by dividing the  $\dot{V}O_2$  by heart rate  
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32 14 ( $\dot{V}O_2/HR$ ). Maximum workload ( $Workload_{max}$ ) was calculated as the final completed  
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34 15 workload. Rating of perceived exertion (RPE) was measured at the end of each stage  
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36 16 using the Cart and Load scale (CALER), which has previously been used to assess  
37  
38 17 children's perception of effort during exercise<sup>26</sup>. The CALER has a scale from 1 to  
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40 18 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'.  
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42 19 Illustrations of a child pulling a cart behind their bicycle, which was progressively  
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44 20 laden with bricks, accompanied the scale.  
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49 21 The criteria for true maximal effort included a plateau in  $\dot{V}O_2$  max, maximal heart rate  
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51 22  $\geq 95\%$  of age predicted maximum and RER  $>1.06$ <sup>27</sup>. All children were fully  
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53 23 familiarised with the testing protocol prior to commencing the session.  
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## 1 MVIC Protocol

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

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

## 14 Data Analysis

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

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## 1 Results

### 4 *Movement ABC-2 Test*

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

9 >>>>insert table 1 here

10

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

13

### 14 *Exercise Testing*

15 There was a significant difference in  $\dot{V}O_2$  peak (34.9 (6.3) v 48.5 (7.9) ml.kg.min<sup>-1</sup>),  
16  $\dot{V}O_2$ /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)  
17 ml.beat), maximum heart rate (176 (19.7) v 188 (8.8) beats.min) and MVIC (5.7 (1.0)  
18 v 9.0 (1.8) Nm.kg) with the LMI group achieving higher  $\dot{V}O_2$ , oxygen pulse,  
19 maximum heart rate and MVIC.

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

24 Compared to established maximal criteria for typically developing children<sup>28</sup> all but  
25 one of the participants met the criteria for a maximal effort during the exercise test,  
26 with no significant difference between the HMI and LMI groups. There was no  
27 difference in the perception of effort throughout the exercise trial and at exercise

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3 1 termination, with all participants reporting an RPE rating of 9 or 10 at the end of the  
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5 2 test, despite individuals in the HMI group having significantly lower maximum HR  
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7 3 values at the end of the cycle ergometer test.  
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12 5 There were significant relationships between the MABC score and  $\dot{V}O_2$  peak ( $r = 0.36$ ,  
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14 6  $p < 0.05$ ) (figure 1) and MVIC ( $r = 0.76$ ,  $p < 0.01$ ) (figure 2).  
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21 9 Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.  
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23 10 Table 2 below displays the characteristics of the participants who undertook the  
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25 11 MVIC testing  
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30 13 >>>>>>insert table 2 here  
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32 14  
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34 15 Figure 2. Relationship between M-ABC score and MVIC.  
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### 37 17 *Test re-test reliability of exercise measures*

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40 18 10 HMI participants returned to the laboratory to complete a second maximal exercise  
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42 19 test for the assessment of reliability in this population. The maximal exercise data  
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44 20 demonstrated good reliability with ICC scores for  $\dot{V}O_2$  peak 0.75 (CI 0.23-0.94; t 0.39,  
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46 21 bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8,  
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48 22 random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random  
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50 23 error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05  
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52 24 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).  
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### 57 58 26 **Discussion**

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3 1 The study set out to explore, in individuals with different levels of motor impairment,  
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5 2 physiological and perceptual factors during and limiting maximal exercise  
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7 3 performance. Examination of the exercise test data showed a significant difference in  
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9 4  $\dot{V}O_2$  peak,  $\dot{V}O_2$ / workload, oxygen pulse, maximum heart rate and MVIC between the  
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11 5 HMI and LMI group. Interestingly there was no difference maximal rating of  
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13 6 perceived exertion or RER. When considering limits to exercise in people with high  
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15 7 motor impairment, the maximal RER and fat oxidation levels at test termination,  
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17 8 suggest low levels of aerobic muscle performance and not a heightened perceived  
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19 9 level of exertion, were limiting exercise performance. These findings are important as  
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21 10 they highlight a low level of aerobic muscle performance as a major factor limiting  
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23 11 exercise performance in children with poor coordination. Muscle plays a central role  
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25 12 in health and disease across the lifespan<sup>29</sup> and, if left unaddressed in children with  
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27 13 HMI, is likely to continue into adulthood and contribute to the development of  
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29 14 metabolic disorders in this population.  
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37 16 Despite children with HMI demonstrating a linear  $\dot{V}O_2$ / workload response, the value  
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39 17 of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise<sup>30</sup>.  
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41 18  $\dot{V}O_2$  normally rises at a rate of about 8.5-11 ml.min.watt and is independent of sex,  
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43 19 age, body weight or height<sup>31</sup>. Thus, in children with HMI, exercise participation may  
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45 20 be limited by the impaired ability of the muscle to work aerobically. The reduced  
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47 21 muscular strength of the quadriceps reported in this study further supports the main  
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49 22 limiting factor being at the muscular level and this finding supports the findings from  
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51 23 previous studies citing a reduced strength in other muscle groups in children with  
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53 24 greater motor impairment<sup>32</sup>.  
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3 1 In comparison to the LMI group, the HMI group had a reduced exercise capacity, with  
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5 2 a mean  $\dot{V}O_2$  peak of 34.9 ml.kg.min<sup>-1</sup>. The  $\dot{V}O_2$  peak was below the cardiovascular  
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7 3 fitness threshold in the HMI children<sup>33</sup> and as such associated with an increased risk  
8  
9 4 of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood  
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11 5<sup>34</sup>. Considered alongside the low maximum heart rates demonstrated by these  
12  
13 6 children (mean 176 beats.min<sup>-1</sup>) in comparison to LMI participants (188 beats.min<sup>-1</sup>)  
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15 7 and those reported in normal healthy children at the end of a similar cycling protocol  
16  
17 8<sup>35</sup>, our findings suggest that a low level of aerobic muscle performance was limiting  
18  
19 9 the ability of children with HMI to push themselves hard enough to maximally tax the  
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21 10 cardiovascular system. Despite a significantly lower oxygen pulse level between the  
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23 11 groups (12.1 (3.7) v 15.9 (4.0)ml.beat, p<0.05), the HMI group was not different to  
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25 12 those in healthy individuals reported previously<sup>36</sup>. This further supports the findings  
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27 13 that the limiting factor is of peripheral, and not central, origin. Given the emerging  
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29 14 role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic  
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31 15 capability in the muscles of children with poor motor control may impact on their  
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33 16 long-term health and may prevent them from increasing their heart rate to the level  
34  
35 17 required to achieve an aerobic training stimulus and attain fitness, health and  
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37 18 wellbeing benefits according to current guidelines for physical activity in children<sup>37</sup>.  
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39 19 Interestingly, despite the reduced aerobic fitness there was no difference in the  
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41 20 utilisation of fat as a substrate during the exercise protocol between the groups in this  
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43 21 study. The levels of fat oxidation in this current study were within the range  
44  
45 22 previously reported in healthy participants of similar age<sup>38</sup>. The number of  
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47 23 individuals in this sample is relatively small, however we included a range of  
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49 24 individuals with different motor capabilities and in the sub group of HMI participants  
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3 1 that returned to the laboratory we established good reliability in the clinical exercise  
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5 2 testing in this population.

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7 3 Muscle function has been found to have an important role in long term health <sup>29</sup> and  
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9 4 considering our observation of reduced muscle capacity in individuals with HMI, it is  
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11 5 important to investigate interventions that can be implemented in childhood to  
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13 6 improve muscle function and performance <sup>39</sup>. This is further supported with the  
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15 7 significantly lower MVIC in the HMI group in comparison to LMI. The reduced  
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17 8 strength of the major locomotor muscle group in the HMI not only has implications  
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19 9 for function, with some reports of increased co-contraction <sup>40</sup>, but also for the impact  
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21 10 on health and quality of life. In a recent study by Buchan et al. <sup>41</sup>, high intensity  
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23 11 exercise has been shown to reduce cardiovascular risk and improve muscle function in  
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25 12 healthy children. As yet, this type of intensity has not been investigated in the  
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27 13 population of children included in this current study, however the evidence of their  
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29 14 willingness to push themselves maximally in this study warrants the application of  
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31 15 such intensities of exercise to measure the impact on health and movement measures.  
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36 16 Work by Cairney et.al. <sup>18</sup> suggested that reduced exercise performance of children with  
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38 17 motor impairment was partly related to the level of perceived adequacy for the task.  
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40 18 The findings of this current work suggest that the limitations to exercise in the high  
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42 19 motor impairment group had strong physiological underpinnings reflected in the  
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44 20 criteria for a maximal effort being attained in all but one of the participants.  
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50 22 The findings from this work highlight the significant relationship between motor  
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52 23 impairment level and health status. The reduced exercise capacity and muscular  
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54 24 performance demonstrated by the participants with greater motor impairment  
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56 25 highlight the need for any exercise interventions to target the development of  
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3 1 muscular function. Research has shown that exercise interventions play a possible  
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5 2 role in improving motor competence levels in children with movement difficulties <sup>42</sup>  
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7 3 however, how these changes relate to alterations in markers of cardiovascular and  
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9 4 muscular health and the long term involvement in physical activity have yet to be  
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11 5 elucidated.  
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### 30 **Contributorship statement**

31  
32 14 Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design,  
33  
34 15 acquisition of data or analysis and interpretation of data, and drafting the article or  
35  
36 16 revising it critically for important intellectual content.  
37  
38 17 Dr Ken Howells - Conception and design and drafting the article or revising it critically  
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40 18 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<sub>2</sub> 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.

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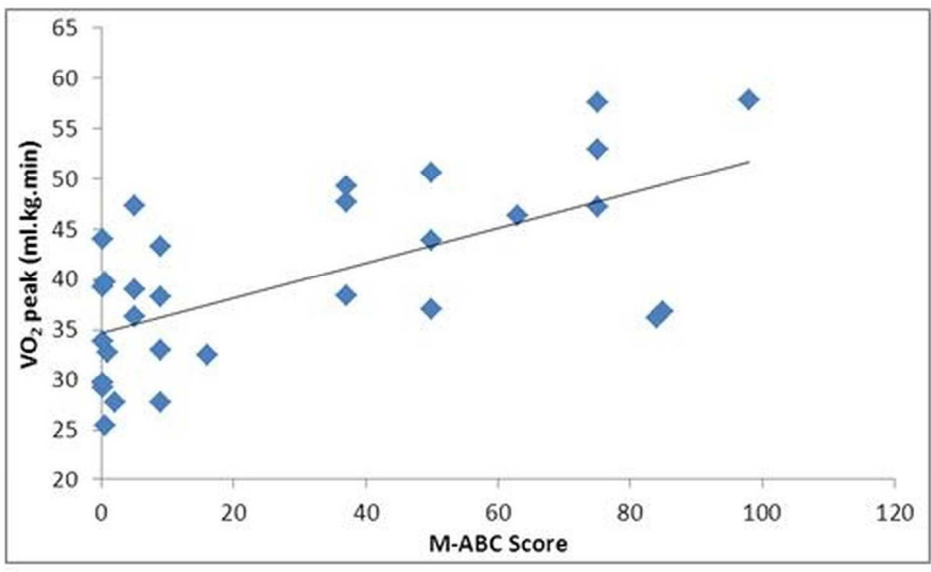


Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.

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

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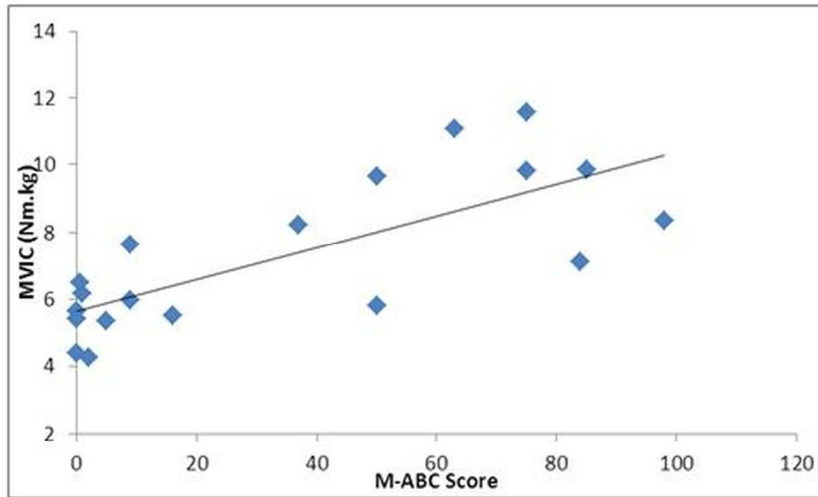


Figure 2. Relationship between M-ABC score andMVIC.

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

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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 <sub>2</sub> max (ml.kg.min)	34.9 (6.3)	48.5 (7.9)*
VO <sub>2</sub> /Workload (ml.W)	12.5 (3.9)	10.0 (1.3)*
O <sub>2</sub> 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)*

For peer review only



## Motor Impairment and its relationship to fitness in children

Journal:	<i>BMJ Open</i>
Manuscript ID:	bmjopen-2013-002909.R2
Article Type:	Research
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3 1 **Motor Impairment and its relationship to fitness in children**  
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38 17 **Key words:** Motor impairment,  $\dot{V}O_2$  max, fitness, muscle  
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40 18 **Word count: 2621**  
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## 1 ARTICLE SUMMARY

### 2 Article Focus

- 3 • Exercise tolerance was not limited by the HMI group not willing to push  
4 themselves maximally, with the level of motor impairment significantly  
5 related to VO<sub>2</sub> peak and muscular strength.
- 6 • Children with HMI have a reduced movement economy during cycling  
7 exercise.

### 8 Key Messages

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

### 16 Strengths and Limitations

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

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

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

7 **Methods:** 35 boys aged 12-15yrs completed the Movement ABC test for the  
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assessment of motor impairment, followed by an incremental cycle ergometer test to  
exhaustion for the assessment of maximal oxygen uptake ( $\dot{V}O_{2peak}$ ), 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.

14 **Results:** 18 boys were classified as having high motor impairment. All but one  
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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<sup>-1</sup>),  $\dot{V}O_2$  workload (12.5 v 10.0ml.W), maximal heart rate (176 v 188  
beats.min<sup>-1</sup>), 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.

21 **Conclusion:** When performing cycling ergometry, perceived exertion was not a  
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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

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3 1 maximal heart rate values attained during the exercise test and reduced maximal  
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5 2 strength. Perception of effort is not heightened in children with high motor  
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7 3 impairment and future exercise interventions should be focused on improving  
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10 4 muscular condition in participants with high motor impairment to enable them to be  
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12 5 better prepared to engage in physical activity for health.  
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## 1 Introduction

2 Physical activity levels in childhood have been shown to predict adult activity  
3 behavior<sup>1,2</sup>, affecting life expectancy and quality of life years. As such, successfully  
4 achieving an active lifestyle in childhood is critical. Children with movement  
5 difficulties and poor coordination tend to have lower levels of physical activity  
6 participation than their typically developing peers<sup>3-5</sup>. Further, this group of children,  
7 with reduced motor coordination and low activity levels, have been found to have  
8 significantly higher metabolic syndrome indicators<sup>6</sup>, including: abdominal adiposity,  
9 blood pressure and triglyceride levels compared to their typically developing peers<sup>7</sup>  
10<sup>8</sup>. Of added concern is that such motor impairments are known to persist into  
11 adulthood, further impacting on the ability of these individuals to achieve a physically  
12 active lifestyle as adults<sup>9-11</sup>. The number of people with some form of motor  
13 impairment in the UK population is 2.6 million<sup>12</sup> and as such this group is an  
14 important proportion of society who should be considered within public health policy.  
15 Understanding factors particularly affecting the exercise experience in these  
16 individuals is essential if higher physical activity levels are to be achieved.  
17 In a series of interviews with adolescents with Developmental Coordination Disorder  
18 (DCD)<sup>13,14</sup> and with children with cerebral palsy<sup>15</sup>, exercise-induced symptoms of  
19 muscle fatigue, poor physical tolerance and low energy levels have also been  
20 reported as major factors reducing enjoyment, tolerance and participation. However,  
21 as yet, the underpinning physiological limits have not been fully explored. We know  
22 that individual's judge and limit effort during exercise from symptoms arising from  
23 muscles, joints and the cardiovascular system; choosing to reduce how hard they are  
24 exercising when symptoms become too strong<sup>16,17</sup>. Children with increased motor  
25 impairment are known to perform poorly in sport and exercise fitness screening tests

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3 1<sup>18 19</sup>, but the physiological and perceptual responses limiting exercise performance  
4  
5 2 have not been explored in these individuals<sup>18 20 21</sup>.  
6

### 7 **Aims**

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10 4 The study set out to explore, in individuals with different levels of motor impairment,  
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12 5 physiological and perceptual measures during and limiting maximal exercise  
13  
14 6 performance.  
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### 16 **Methods**

#### 17 *Procedure*

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20 9 The study was approved by the University Research Ethics Committee (UREC).  
21  
22 10 Participants were recruited through two routes, either through a database of those who  
23  
24 11 had taken part in our previous research or through advertisements and posters.  
25  
26 12 Families indicating that they were interested in taking part were sent separate child  
27  
28 13 and parent information sheets and gave their written consent prior to the study.  
29  
30 14 Participants attended the Human Performance Laboratory for testing, with parents  
31  
32 15 attending only to help complete a health screening questionnaire for their child. The  
33  
34 16 testing session consisted of the participant completing the Movement ABC-2 Test  
35  
36 17 (MABC-2)<sup>22</sup> for a measure of motor impairment, followed by the exercise testing.  
37  
38 18 Details of these measures can be found below.  
39  
40 19 Participants were asked to refrain from eating, performing exercise or drinking  
41  
42 20 caffeine in the 2-hour period before attending the sessions.  
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48

#### 49 *Participants*

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52 23 Thirty five males aged 12 to 15 years with no known neurological condition were  
53  
54 24 recruited. Individuals were classified on the level of motor ability using the  
55  
56 25 Movement ABC-2 test.  
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3 1 *Measures*

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5 2 Movement ABC-2 Test (MABC-2)<sup>22</sup>.

6  
7 3 This standardised test of motor skill was used to confirm the presence of significant  
8  
9 4 movement difficulties. Eight age appropriate items were individually administered as  
10  
11 5 described in the test manual. Raw scores for each task were converted to standard  
12  
13 6 scores, summed across three sub-sections to obtain a standard score for Manual  
14  
15 7 Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was  
16  
17 8 also obtained. For the diagnosis of motor impairment, it has been recommended that  
18  
19 9 scores below the 5<sup>th</sup> percentile indicate definite motor impairment while scores  
20  
21 10 between the 5<sup>th</sup> and 15<sup>th</sup> percentile indicate borderline scores<sup>23</sup>. Therefore, any child  
22  
23 11 scoring below the 15<sup>th</sup> percentile in this current study was classed as having high  
24  
25 12 motor impairment (HMI). Children scoring above the 15<sup>th</sup> percentile were classified  
26  
27 13 as having no motor impairment (NMI).  
28  
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31  
32 14 *Exercise testing*

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34 15 Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were  
35  
36 16 recorded prior to the exercise test. After resting for 6 minutes participants underwent  
37  
38 17 an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen,  
39  
40 18 Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling.

41  
42 19 Workload was progressed based on the Godfrey protocol<sup>24</sup> (increasing workload by  
43  
44 20 15-20 Watts from unloaded cycling based on the height of the participant). The test  
45  
46 21 ended at volitional exhaustion or if the participant was unable to maintain a cadence  
47  
48 22 of 60 rpm, with verbal encouragement given throughout.

49  
50 23 Pulmonary gas exchange was measured breath-by-breath using an automated  
51  
52 24 metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was  
53  
54 25 calibrated prior to each test in accordance with manufacturer's instructions. All  
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1 participants wore a face mask covering the nose and mouth connected to a low-  
2 resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was  
3 recorded continuously throughout the testing protocol using short-range telemetry  
4 (Polar S810, Finland). Oxygen uptake ( $\dot{V}O_2$ ) was calculated as the average  $\dot{V}O_2$  in the  
5 last 30s of each stage, whilst  $\dot{V}O_2$  peak was recorded as the highest 60s average before  
6 the termination of the test. The respiratory exchange ratio (RER) was calculated from  
7 the ratio of  $\dot{V}CO_2$  to  $\dot{V}O_2$  at each workload level throughout the exercise test.

8 Maximal fat oxidation was calculated using the equations of Frayn<sup>25</sup> in equation 1  
9 below:

$$10 \quad \text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

11 The relationship between the amount of oxygen utilised for a given work rate was  
12 calculated from the linear slope of the relationship between  $\dot{V}O_2$  and Watts ( $\dot{V}O_2/W$ )  
13 and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive  
14 indicator of cardiac function, was calculated by dividing the  $\dot{V}O_2$  by heart rate  
15 ( $\dot{V}O_2/HR$ ). Maximum workload ( $Workload_{max}$ ) was calculated as the final completed  
16 workload. Rating of perceived exertion (RPE) was measured at the end of each stage  
17 using the Cart and Load scale (CALER), which has previously been used to assess  
18 children's perception of effort during exercise<sup>26</sup>. The CALER has a scale from 1 to  
19 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'.  
20 Illustrations of a child pulling a cart behind their bicycle, which was progressively  
21 laden with bricks, accompanied the scale.  
22 The criteria for true maximal effort included a plateau in  $\dot{V}O_2$  max, maximal heart rate  
23  $\geq 95\%$  of age predicted maximum and RER  $>1.06$ <sup>27</sup>. All children were fully  
24 familiarised with the testing protocol prior to commencing the session.

1

2 MVIC Protocol

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

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

### 15 **Data Analysis**

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

25

26



## Results

### *Movement ABC-2 Test*

Eighteen participants obtained total scores considered to be HMI, i.e. below the M-ABC 15<sup>th</sup> percentile, with 5 at or below the 5<sup>th</sup> percentile, and 17 classified as no motor impairment (NMI) (M-ABC > 15<sup>th</sup> 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<sup>-1</sup>),  $\dot{V}O_2$ /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<sup>28</sup> 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

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2  
3 1 difference in the perception of effort throughout the exercise trial and at exercise  
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5 2 termination, with all participants reporting an RPE rating of 9 or 10 at the end of the  
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7 3 test, despite individuals in the HMI group having significantly lower maximum HR  
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10 4 values at the end of the cycle ergometer test.  
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14 6 There were significant relationships between the MABC score and  $\dot{V}O_2$  peak ( $r = 0.36$ ,  
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16 7  $p < 0.05$ ) (figure 1) and MVIC ( $r = 0.76$ ,  $p < 0.01$ ) (figure 2).  
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23 10 Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.

24  
25 11 Table 2 below displays the characteristics of the participants who undertook the  
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27 12 MVIC testing

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32 14 >>>>>>insert table 2 here  
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36 16 Figure 2. Relationship between M-ABC score and MVIC.  
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### 39 18 *Test re-test reliability of exercise measures*

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42 19 10 HMI participants returned to the laboratory to complete a second maximal exercise  
43  
44 20 test for the assessment of reliability in this population. The maximal exercise data  
45  
46 21 demonstrated good reliability with ICC scores for  $\dot{V}O_2$  peak 0.75 (CI 0.23-0.94; t 0.39,  
47  
48 22 bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98; t -0.86, bias 7.8,  
49  
50 23 random error 15.4) and maximal RER 0.89 (CI 0.59-0.98; t -0.14, bias 0.07, random  
51  
52 24 error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05  
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54 25 (CI -0.60-0.66), but had a low bias (t -2.14, bias 0.86, random error 1.68).  
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## 1 Discussion

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

16  
17 Despite children with HMI demonstrating a linear  $\dot{V}O_2$ / workload response, the value  
18 of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise<sup>30</sup>.  
19  $\dot{V}O_2$  normally rises at a rate of about 8.5-11 ml.min.watt and is independent of sex,  
20 age, body weight or height<sup>31</sup>. Thus, in children with HMI, exercise participation may  
21 be limited by the impaired ability of the muscle to work aerobically. The reduced  
22 muscular strength of the quadriceps reported in this study further supports the main  
23 limiting factor being at the muscular level and this finding supports the findings from  
24 previous studies citing a reduced strength in other muscle groups in children with  
25 greater motor impairment<sup>32</sup>.

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5 2 In comparison to the NMI group, the HMI group had a reduced exercise capacity,  
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7 3 with a mean  $\dot{V}O_2$  peak of 34.9 ml.kg.min<sup>-1</sup>. The  $\dot{V}O_2$  peak was below the cardiovascular  
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9  
10 4 fitness threshold in the HMI children<sup>33</sup> and as such associated with an increased risk  
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12 5 of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood  
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14 6<sup>34</sup>. Considered alongside the low maximum heart rates demonstrated by these  
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16 7 children (mean 176 beats.min<sup>-1</sup>) in comparison to NMI participants (188 beats.min<sup>-1</sup>)  
17  
18 8 and those reported in normal healthy children at the end of a similar cycling protocol  
19  
20 9<sup>35</sup>, our findings suggest that a low level of aerobic muscle performance was limiting  
21  
22 10 the ability of children with HMI to push themselves hard enough to maximally tax the  
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24 11 cardiovascular system. Despite a significantly lower oxygen pulse level between the  
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26 12 groups (12.1 (3.7) v 15.9 (4.0)ml.beat, p<0.05), the HMI group was not different to  
27  
28 13 those in healthy individuals reported previously<sup>36</sup>. This further supports the findings  
29  
30 14 that the limiting factor is of peripheral, and not central, origin. Given the emerging  
31  
32 15 role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic  
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34 16 capability in the muscles of children with poor motor control may impact on their  
35  
36 17 long-term health and may prevent them from increasing their heart rate to the level  
37  
38 18 required to achieve an aerobic training stimulus and attain fitness, health and  
39  
40 19 wellbeing benefits according to current guidelines for physical activity in children<sup>37</sup>.  
41  
42 20 Interestingly, despite the reduced aerobic fitness there was no difference in the  
43  
44 21 utilisation of fat as a substrate during the exercise protocol between the groups in this  
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46 22 study. The levels of fat oxidation in this current study were within the range  
47  
48 23 previously reported in healthy participants of similar age<sup>38</sup>. The number of  
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50 24 individuals in this sample is relatively small, however we included a range of  
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52 25 individuals with different motor capabilities and in the sub group of HMI participants  
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3 1 that returned to the laboratory we established good reliability in the clinical exercise  
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5 2 testing in this population.  
6

7 3 Muscle function has been found to have an important role in long term health<sup>29</sup> and  
8  
9 4 considering our observation of reduced muscle capacity in individuals with HMI, it is  
10  
11 5 important to investigate interventions that can be implemented in childhood to  
12  
13 6 improve muscle function and performance<sup>39</sup>. This is further supported with the  
14  
15 7 significantly lower MVIC in the HMI group in comparison to NMI. The reduced  
16  
17 8 strength of the major locomotor muscle group in the HMI not only has implications  
18  
19 9 for function, with some reports of increased co-contraction<sup>40</sup>, but also for the impact  
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21 10 on health and quality of life. In a recent study by Buchan et al.<sup>41</sup>, high intensity  
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23 11 exercise has been shown to reduce cardiovascular risk and improve muscle function in  
24  
25 12 healthy children. As yet, this type of intensity has not been investigated in the  
26  
27 13 population of children included in this current study, however the evidence of their  
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29 14 willingness to push themselves maximally in this study warrants the application of  
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31 15 such intensities of exercise to measure the impact on health and movement measures.  
32  
33 16 Work by Cairney et.al.<sup>18</sup> suggested that reduced exercise performance of children with  
34  
35 17 motor impairment was partly related to the level of perceived adequacy for the task.  
36  
37 18 The findings of this current work suggest that the limitations to exercise in the high  
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39 19 motor impairment group had strong physiological underpinnings reflected in the  
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41 20 criteria for a maximal effort being attained in all but one of the participants.  
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49 22 The findings from this work highlight the significant relationship between motor  
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51 23 impairment level and health status. The reduced exercise capacity and muscular  
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53 24 performance demonstrated by the participants with greater motor impairment  
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55 25 highlight the need for any exercise interventions to target the development of  
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3 1 muscular function. Research has shown that exercise interventions play a possible  
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5 2 role in improving motor competence levels in children with movement difficulties <sup>42</sup>  
6  
7 3 however, how these changes relate to alterations in markers of cardiovascular and  
8  
9 4 muscular health and the long term involvement in physical activity have yet to be  
10  
11 5 elucidated.  
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14 6

#### 7 **Data sharing**

8 No additional data available.

#### 9 **Contributorship statement**

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

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

#### 15 **Competing Interests**

16 None

#### 17 **Funding**

18 None

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3 Table 1. Participant characteristics and outcome measures.  
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	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 <sub>2</sub> max (ml.kg.min)	34.9 (6.3)	48.5 (7.9)*
VO <sub>2</sub> /Workload (ml.W)	12.5 (3.9)	10.0 (1.3)*
O <sub>2</sub> 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)

5 Table 2. M-ABC and MVIC for the HMI and NMI participants.  
6

	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)*

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3 1 **Motor Impairment and its relationship to fitness in children**  
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7 3 Martyn Morris  
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9 4 Helen Dawes  
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11 5 Ken Howells  
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13 6 Roel Janssen  
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38 17 **Key words:** Motor impairment,  $\dot{V}O_2$  max, fitness, muscle  
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3 **Abstract**

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

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

7 **Methods:** 35 boys aged 12-15yrs completed the Movement ABC test for the  
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8 assessment of motor impairment, followed by an incremental cycle ergometer test to  
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9 exhaustion for the assessment of maximal oxygen uptake ( $\dot{V}O_{2peak}$ ), respiratory  
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10 exchange ratio (RER), heart rate (HR) and rating of perceived exertion (RPE).

11 10 participants classified as having either high or no motor impairment also  
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12 performed a maximal voluntary isometric contraction (MVIC) for the assessment of  
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13 lower limb extensor strength.

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

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

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3 1 maximal heart rate values attained during the exercise test and reduced maximal  
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5 2 strength. Perception of effort is not heightened in children with high motor  
6  
7 3 impairment and future exercise interventions should be focused on improving  
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10 4 muscular condition in participants with high motor impairment to enable them to be  
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12 5 better prepared to engage in physical activity for health.  
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## 1 Introduction

2 Physical activity levels in childhood have been shown to predict adult activity  
3 behavior<sup>1,2</sup>, affecting life expectancy and quality of life years. As such, successfully  
4 achieving an active lifestyle in childhood is critical. Children with movement  
5 difficulties and poor coordination tend to have lower levels of physical activity  
6 participation than their typically developing peers<sup>3-5</sup>. Further, this group of children,  
7 with reduced motor coordination and low activity levels, have been found to have  
8 significantly higher metabolic syndrome indicators<sup>6</sup>, including: abdominal adiposity,  
9 blood pressure and triglyceride levels compared to their typically developing peers<sup>7</sup>  
10<sup>8</sup>. Of added concern is that such motor impairments are known to persist into  
11 adulthood, further impacting on the ability of these individuals to achieve a physically  
12 active lifestyle as adults<sup>9-11</sup>. The number of people with some form of motor  
13 impairment in the UK population is 2.6 million<sup>12</sup> and as such this group is an  
14 important proportion of society who should be considered within public health policy.  
15 Understanding factors particularly affecting the exercise experience in these  
16 individuals is essential if higher physical activity levels are to be achieved.  
17 In a series of interviews with adolescents with Developmental Coordination Disorder  
18 (DCD)<sup>13,14</sup> and with children with cerebral palsy<sup>15</sup>, exercise-induced symptoms of  
19 muscle fatigue, poor physical tolerance and low energy levels have also been  
20 reported as major factors reducing enjoyment, tolerance and participation. However,  
21 as yet, the underpinning physiological limits have not been fully explored. We know  
22 that individual's judge and limit effort during exercise from symptoms arising from  
23 muscles, joints and the cardiovascular system; choosing to reduce how hard they are  
24 exercising when symptoms become too strong<sup>16,17</sup>. Children with increased motor  
25 impairment are known to perform poorly in sport and exercise fitness screening tests

1 18<sup>19</sup>, but the physiological and perceptual responses limiting exercise performance  
2  
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4  
5 have not been explored in these individuals<sup>18 20 21</sup>.

### 3 **Aims**

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

### 7 **Methods**

#### 8 *Procedure*

9 The study was approved by the University Research Ethics Committee (UREC).

10 Participants were recruited through two routes, either through a database of those who  
11 had taken part in our previous research or through advertisements and posters.

12 Families indicating that they were interested in taking part were sent separate child  
13 and parent information sheets and gave their written consent prior to the study.

14 Participants attended the Human Performance Laboratory for testing, with parents  
15 attending only to help complete a health screening questionnaire for their child. The  
16 testing session consisted of the participant completing the Movement ABC-2 Test  
17 (MABC-2)<sup>22</sup> for a measure of motor impairment, followed by the exercise testing.

18 Details of these measures can be found below.

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

21

#### 22 *Participants*

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

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3 1 *Measures*

4  
5 2 Movement ABC-2 Test (MABC-2)<sup>22</sup>.

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7 3 This standardised test of motor skill was used to confirm the presence of significant  
8  
9 4 movement difficulties. Eight age appropriate items were individually administered as  
10  
11 5 described in the test manual. Raw scores for each task were converted to standard  
12  
13 6 scores, summed across three sub-sections to obtain a standard score for Manual  
14  
15 7 Dexterity, Aiming & Catching and Balance. A total test score and percentile rank was  
16  
17 8 also obtained. For the diagnosis of motor impairment, it has been recommended that  
18  
19 9 scores below the 5<sup>th</sup> percentile indicate definite motor impairment while scores  
20  
21 10 between the 5<sup>th</sup> and 15<sup>th</sup> percentile indicate borderline scores<sup>23</sup>. Therefore, any child  
22  
23 11 scoring below the 15<sup>th</sup> percentile in this current study was classed as having high  
24  
25 12 motor impairment (HMI). Children scoring above the 15<sup>th</sup> percentile were classified  
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27 13 as having no motor impairment (NMI).

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32 14 *Exercise testing*

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34 15 Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were  
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36 16 recorded prior to the exercise test. After resting for 6 minutes participants underwent  
37  
38 17 an incremental cycle ergometer exercise test (Lode Excalibur Sport, Gronigen,  
39  
40 18 Netherlands) of 1 minute stages after an initial 2 minutes of unloaded cycling.

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42 19 Workload was progressed based on the Godfrey protocol<sup>24</sup> (increasing workload by  
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44 20 15-20 Watts from unloaded cycling based on the height of the participant). The test  
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46 21 ended at volitional exhaustion or if the participant was unable to maintain a cadence  
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48 22 of 60 rpm, with verbal encouragement given throughout.

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50 23 Pulmonary gas exchange was measured breath-by-breath using an automated  
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52 24 metabolic analysis system (Cortex Metalyzer, Leipzig Germany). The system was  
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54 25 calibrated prior to each test in accordance with manufacturer's instructions. All  
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1 participants wore a face mask covering the nose and mouth connected to a low-  
2 resistance volume transducer (Triple V, Hoechberg, Germany). Heart rate was  
3 recorded continuously throughout the testing protocol using short-range telemetry  
4 (Polar S810, Finland). Oxygen uptake ( $\dot{V}O_2$ ) was calculated as the average  $\dot{V}O_2$  in the  
5 last 30s of each stage, whilst  $\dot{V}O_2$  peak was recorded as the highest 60s average before  
6 the termination of the test. The respiratory exchange ratio (RER) was calculated from  
7 the ratio of  $\dot{V}CO_2$  to  $\dot{V}O_2$  at each workload level throughout the exercise test.

8 Maximal fat oxidation was calculated using the equations of Frayn<sup>25</sup> in equation 1  
9 below:

$$10 \quad \text{Eq. 1 Fat oxidation (g.min)} = 1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$$

11 The relationship between the amount of oxygen utilised for a given work rate was  
12 calculated from the linear slope of the relationship between  $\dot{V}O_2$  and Watts ( $\dot{V}O_2/W$ )  
13 and was used as a measure of muscular efficiency. Oxygen pulse, a non-invasive  
14 indicator of cardiac function, was calculated by dividing the  $\dot{V}O_2$  by heart rate  
15 ( $\dot{V}O_2/HR$ ). Maximum workload ( $Workload_{max}$ ) was calculated as the final completed  
16 workload. Rating of perceived exertion (RPE) was measured at the end of each stage  
17 using the Cart and Load scale (CALER), which has previously been used to assess  
18 children's perception of effort during exercise<sup>26</sup>. The CALER has a scale from 1 to  
19 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'.  
20 Illustrations of a child pulling a cart behind their bicycle, which was progressively  
21 laden with bricks, accompanied the scale.

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

1

2 MVIC Protocol

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

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

### 15 **Data Analysis**

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

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## Results

### *Movement ABC-2 Test*

Eighteen participants obtained total scores considered to be HMI, i.e. below the M-ABC 15<sup>th</sup> percentile, with 5 at or below the 5<sup>th</sup> percentile, and 17 classified as no motor impairment (NMI) (M-ABC > 15<sup>th</sup> 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<sup>-1</sup>),  $\dot{V}O_2$ /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<sup>28</sup> 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

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3 1 difference in the perception of effort throughout the exercise trial and at exercise  
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5 2 termination, with all participants reporting an RPE rating of 9 or 10 at the end of the  
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7 3 test, despite individuals in the HMI group having significantly lower maximum HR  
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10 4 values at the end of the cycle ergometer test.  
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14 6 There were significant relationships between the MABC score and  $\dot{V}O_2$  peak ( $r = 0.36$ ,  
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16 7  $p < 0.05$ ) (figure 1) and MVIC ( $r = 0.76$ ,  $p < 0.01$ ) (figure 2).  
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23 10 Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.

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25 11 Table 2 below displays the characteristics of the participants who undertook the  
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27 12 MVIC testing

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32 14 >>>>>>insert table 2 here  
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36 16 Figure 2. Relationship between M-ABC score and MVIC.  
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### 39 18 *Test re-test reliability of exercise measures*

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42 19 10 HMI participants returned to the laboratory to complete a second maximal exercise  
43  
44 20 test for the assessment of reliability in this population. The maximal exercise data  
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46 21 demonstrated good reliability with ICC scores for  $\dot{V}O_2$  peak 0.75 (CI 0.23-0.94;  $t$  0.39,  
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48 22 bias 3.54, random error 6.93), maximal heart rate 0.93 (CI 0.73-0.98;  $t$  -0.86, bias 7.8,  
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50 23 random error 15.4) and maximal RER 0.89 (CI 0.59-0.98;  $t$  -0.14, bias 0.07, random  
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52 24 error 0.14). Maximal RPE ICC scores were all rated 9-10 thus affecting the ICC 0.05  
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54 25 (CI -0.60-0.66), but had a low bias ( $t$  -2.14, bias 0.86, random error 1.68).  
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## 1 Discussion

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

16  
17 Despite children with HMI demonstrating a linear  $\dot{V}O_2$ / workload response, the value  
18 of 12.5 (3.9) ml.W reflects a reduced movement economy throughout the exercise<sup>30</sup>.  
19  $\dot{V}O_2$  normally rises at a rate of about 8.5-11 ml.min.watt and is independent of sex,  
20 age, body weight or height<sup>31</sup>. Thus, in children with HMI, exercise participation may  
21 be limited by the impaired ability of the muscle to work aerobically. The reduced  
22 muscular strength of the quadriceps reported in this study further supports the main  
23 limiting factor being at the muscular level and this finding supports the findings from  
24 previous studies citing a reduced strength in other muscle groups in children with  
25 greater motor impairment<sup>32</sup>.

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5 2 In comparison to the NMI group, the HMI group had a reduced exercise capacity,  
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7 3 with a mean  $\dot{V}O_2$  peak of 34.9 ml.kg.min<sup>-1</sup>. The  $\dot{V}O_2$  peak was below the cardiovascular  
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10 4 fitness threshold in the HMI children<sup>33</sup> and as such associated with an increased risk  
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12 5 of obesity, Type II diabetes and cardiovascular and metabolic disorders in adulthood  
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14 6<sup>34</sup>. Considered alongside the low maximum heart rates demonstrated by these  
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16 7 children (mean 176 beats.min<sup>-1</sup>) in comparison to NMI participants (188 beats.min<sup>-1</sup>)  
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18 8 and those reported in normal healthy children at the end of a similar cycling protocol  
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20 9<sup>35</sup>, our findings suggest that a low level of aerobic muscle performance was limiting  
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22 10 the ability of children with HMI to push themselves hard enough to maximally tax the  
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24 11 cardiovascular system. Despite a significantly lower oxygen pulse level between the  
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26 12 groups (12.1 (3.7) v 15.9 (4.0)ml.beat, p<0.05), the HMI group was not different to  
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28 13 those in healthy individuals reported previously<sup>36</sup>. This further supports the findings  
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30 14 that the limiting factor is of peripheral, and not central, origin. Given the emerging  
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32 15 role of mitochondrial dysfunction in many neuromuscular disorders, a lack of aerobic  
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34 16 capability in the muscles of children with poor motor control may impact on their  
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36 17 long-term health and may prevent them from increasing their heart rate to the level  
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38 18 required to achieve an aerobic training stimulus and attain fitness, health and  
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40 19 wellbeing benefits according to current guidelines for physical activity in children<sup>37</sup>.  
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42 20 Interestingly, despite the reduced aerobic fitness there was no difference in the  
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44 21 utilisation of fat as a substrate during the exercise protocol between the groups in this  
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46 22 study. The levels of fat oxidation in this current study were within the range  
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48 23 previously reported in healthy participants of similar age<sup>38</sup>. The number of  
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50 24 individuals in this sample is relatively small, however we included a range of  
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52 25 individuals with different motor capabilities and in the sub group of HMI participants  
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3 1 that returned to the laboratory we established good reliability in the clinical exercise  
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5 2 testing in this population.  
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7 3 Muscle function has been found to have an important role in long term health <sup>29</sup> and  
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9 4 considering our observation of reduced muscle capacity in individuals with HMI, it is  
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11 5 important to investigate interventions that can be implemented in childhood to  
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13 6 improve muscle function and performance <sup>39</sup>. This is further supported with the  
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15 7 significantly lower MVIC in the HMI group in comparison to NMI. The reduced  
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17 8 strength of the major locomotor muscle group in the HMI not only has implications  
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19 9 for function, with some reports of increased co-contraction <sup>40</sup>, but also for the impact  
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21 10 on health and quality of life. In a recent study by Buchan et al. <sup>41</sup>, high intensity  
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23 11 exercise has been shown to reduce cardiovascular risk and improve muscle function in  
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25 12 healthy children. As yet, this type of intensity has not been investigated in the  
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27 13 population of children included in this current study, however the evidence of their  
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29 14 willingness to push themselves maximally in this study warrants the application of  
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31 15 such intensities of exercise to measure the impact on health and movement measures.  
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33 16 Work by Cairney et.al. <sup>18</sup> suggested that reduced exercise performance of children with  
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35 17 motor impairment was partly related to the level of perceived adequacy for the task.  
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37 18 The findings of this current work suggest that the limitations to exercise in the high  
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39 19 motor impairment group had strong physiological underpinnings reflected in the  
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41 20 criteria for a maximal effort being attained in all but one of the participants.  
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50 22 The findings from this work highlight the significant relationship between motor  
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52 23 impairment level and health status. The reduced exercise capacity and muscular  
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54 24 performance demonstrated by the participants with greater motor impairment  
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56 25 highlight the need for any exercise interventions to target the development of  
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3 1 muscular function. Research has shown that exercise interventions play a possible  
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5 2 role in improving motor competence levels in children with movement difficulties <sup>42</sup>  
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7 3 however, how these changes relate to alterations in markers of cardiovascular and  
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9 4 muscular health and the long term involvement in physical activity have yet to be  
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11 5 elucidated.  
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### 13 Contributorship statement

31  
32 14 Dr. Martyn Morris, Prof. Helen Dawes and Roel Janssen - Conception and design,  
33  
34 15 acquisition of data or analysis and interpretation of data, and drafting the article or  
35  
36 16 revising it critically for important intellectual content.

37  
38 17 Dr Ken Howells - Conception and design and drafting the article or revising it critically  
39  
40 18 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.

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For peer review only

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 <sub>2</sub> max (ml.kg.min)	34.9 (6.3)	48.5 (7.9)*
VO <sub>2</sub> /Workload (ml.W)	12.5 (3.9)	10.0 (1.3)*
O <sub>2</sub> 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)*

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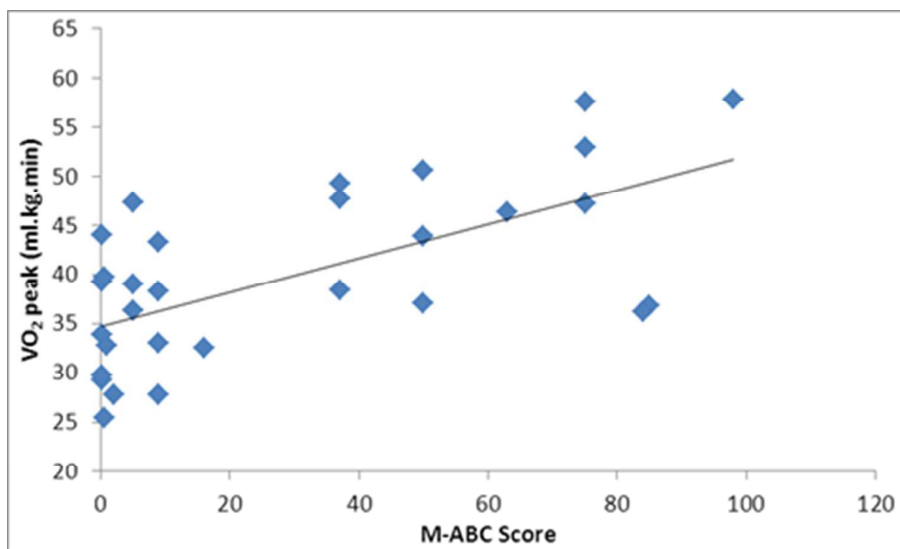


Figure 1. Relationship between M-ABC score and  $\dot{V}O_2$  peak.

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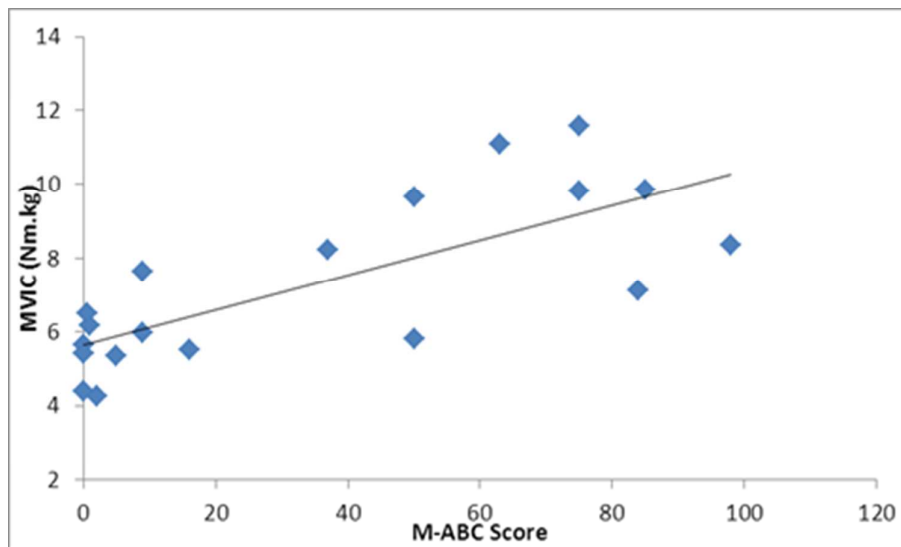


Figure 2. Relationship between M-ABC score and MVIC.

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