Reference curves for a fitness battery developed for children ages 5-12 years in England.

ELIZABETH SMITH*[1], KATE WILKINSON[1], STEVE WYATT[2], PK VAISH[2], STUART MILLER[3]

1 London Sport Institute, Middlesex University, London, UK

2 Amaven, Manchester, UK

3 Centre for Sports and Exercise Medicine, Queen Mary University of London, London, UK

Elizabeth Smith L.Y.Smith@mdx.ac.uk *corresponding author:

Kate Wilkinson - K.S.Wilkinson@mdx.ac.uk

Steve Wyatt - steve.wyatt@amaven.co.uk

PK Vaish -, M1 1FN. pk.vaish@amaven.co.uk

Stuart Miller - Stuart.Miller@qmul.ac.uk

Abstract

Purpose: Reference curves have already been created for a variety of different physical testing batteries across a number of countries. Due to results differing between countries for the same sex and age, it is important that reference curves are created specific for each country. Therefore, the aim of this study was to provide reference curves for five different fitness tests that assess the core components of health related fitness within children in England. Method: Following institutional ethics approval, parental informed consent and child assent was obtained for a total of 39,199 children aged between 5 and 12 years completed tests for explosive power, agility, hand eye coordination, lower body strength and upper body strength. To calculate reference values Generalised Additive Models for Location, Scale and Shape (GAMLSS) were used. Results: Reference curves and centiles show differences in performance levels of the fitness tests between sex and age groups. These reference curves and centiles provide age and sex comparisons to enable progress monitoring of children's physical fitness competence within England and comparisons to other countries. Conclusion: Girls are outperformed from a young age group and both upper and lower body strength decreases are seen at ages nine and ten. In physical activity and health related fitness interventions, both girls and boys in KS2 should be targeted to maintain progression and lessen the gender divide.

Introduction

The proportion of children and adults who are overweight or obese in the UK and worldwide continues to rise with no forecast of attenuation (27). Nutrition and health-related fitness (7) are both indicated as contributing factors to obesity, but recently the government focus has been directed towards increasing physical activity (PA) (15). The direct relationship shown between childhood, adolescent and then adulthood obesity and physical inactivity (18) indicates the most preventative initiatives should target obesity and activity levels in young children.

Many primary schools and educational agencies are becoming increasingly aware of obesity and physical inactivity issues leading to an increased number of new initiatives in the area (26). An important component of any PA or health promotion programme is the ability to monitor progress and draw comparisons between children of the same sex and age for health-related fitness (HRF) parameters. Reference curves have been created for a variety of different HRF tests across a variety of different countries (14, 25, 33). Despite efforts to present collective reference values across countries (i.e. 28), it has been evidenced that very different scores are produced across countries for each centile for the same age and sex (19, 25). As such, country-specific reference curves are needed for each HRF test commonly utilised.

Of the HRF factors presented within Bouchard and Shephard's model (7), cardiorespiratory fitness (CRF) and morphological factors have had the most research focus. This has culminated in reference curves being presented for multiple countries (19, 32, 44), as well as "Expert Statements" on measurement and interpretation being published. However, motor and muscular HRF have not received the same focus as CRF and morphological factors. Importantly, motor and muscular parameters are associated with increased bone mineral density and skeletal health (12, 28, 43), current and emergent cardiovascular risk factors (28) and metabolic risk factors (34). Consequently, motor and muscular HRF are important instigators of increased physical activity levels (28,35) and should be included when monitoring and developing HRF during childhood and adolescence. In fact, 2018 UK government guidelines now recommend motor and muscular HRF alongside the CRF.

Of the many motor and muscular HRF parameters, explosive strength, agility, motor coordination, and upper and lower muscular strength endurance have been well documented as the foundations to a physically active childhood, shown to continue into adulthood (38), in addition to other health benefits (3 ,8, 9, 25). Specifically, increased strength has been associated with a healthy body composition, increased bone mineral density and improved mental health. Agility is associated with improved performance in sport and PA and improved physical function (39). Childhood motor coordination competency has been reported to predict up to a quarter of the variation of future PA participation (8). As such, these components of motor and muscular HRF should be an integral part of any testing battery used in children. Lack of motor and muscular HRF have been associated with lower levels of enjoyment, confidence and motivation to engage in sport and physical activity therefore being key to activity and obesity levels.

Therefore, the aim of this study is to provide reference curves for five tests that assess the core components of motor and muscular fitness within children aged 5-12 years in England. These will provide reference for development of children in England, in addition to allow for comparisons with other countries. Comparative data would be useful when comparing the viability of interventions, physical education programmes, participation rates and obesity levels. The data presented within this paper was collected as part of a government-led Healthy Schools programme.

Method

Overview

Following institutional ethical approval from Middlesex University Ethics Sub-Committee data analysis on the pre-existing data was conducted. The data were collected in conjunction with the government-led Healthy Schools programme. Amaven (Amaven.co.uk) advertised the challenge day project to schools through Physical Education conferences. A total of 34 schools responded and parents were sent a letter to explain the challenge day and were given an opportunity to opt their child out from having any data recorded. Following this, nominal children were excluded from the data, resulting in 39,199 children aged 5-12 years from the 34 schools participating in the challenge day, including all year groups and classes. Each school's data was anonymised and uploaded onto the secure Amaven online system and organised into their regular Year groups.

Participants

Table 1 displays the number of boys and girls that were tested for each skill at each age group. Using the schools' postcodes to identify the area deprivation decile, we concluded that the children sampled are representative of the spread of deprivation within the English population. Table 2 displays the number of schools within each decile of deprivation according to the English indices of deprivation (15), with the distribution across the ten deciles being in good agreement with what is to be expected (ICC(3,1) with agreement = 0.994 [0.978-0.999]).

***insert table 1 ***

***insert table 2 ***

Procedures

The tests included in the challenge day were chosen due to their association with motor and muscular HRF, physical activity level and an enhanced health status (3, 8, 9, 25)**.** The challenge day was conducted and supervised by qualified sport coaches who all went through the same training and all followed strict standardised operating procedures to ensure validity and reliability of the data collected. The qualified sport coaches used the same equipment at the 34 schools including, space cones, tape measures and stop watches; no specialised equipment was used. All tests were conducted in the school's sports hall; a clear open space with a non-slippery floor. All marked out areas needed were measured prior to the beginning of the Challenge Day using a tape measure to the nearest millimetre. The sport coach summarised the challenge day, and the pupils were given clear instructions along with a practical demonstration and one practise trial before each test. The pupils had a chance to ask questions before starting each test. The first pupil from each group would complete the particular test before returning to their group, providing enough time to rest before attempting the next test. Tests were performed in the following order; lower body strength squats, upper body strength press ups, 5-10-5 agility, broad jump and finally throw and catch. The pupils were supervised in each test by a trained sports coach.

We fully acknowledge that the testing procedures undertaken could have been more rigid. However, due to the nature of the aim for this research being to make available reference centile curves, we believe the ecological validity of the procedures enhances the potential for meeting this aim.

Agility

Agility was tested using the 5-10-5 shuttle run (pro-agility shuttle test). Children started on a marked line, on the command 'Go' from the researcher, the children sprinted 5m to a marked line where they touched the line with their hand and changed direction by 180^{o} to sprint 10m to a marked line where they touched the line and changed direction for a second time by 180^{o} to sprint a final 5m to finish the agility run. Time of completion of the agility run was recorded in seconds using a hand held stop watch. If children did not touch each line with their hand their time was not recorded and they were given two more chances after a five minute break.

Explosive power

Explosive power was tested using the standing broad jump and stick (BJS). Children started standing with their feet shoulder width apart and their toes on a line. Children were instructed to jump as far forward as they could and then land two footed without taking a step or falling. Children were allowed to use their arms to create momentum. The distance was measured to the landing of the heel in centimetres. If children did not land correctly they were given two more chances with a five minute break.

Hand eye coordination

Hand eye coordination was tested using a throw and catch test. Children stood on a marked line 1m from a flat wall. On the command "Go" from the researcher the children completed as many throw and catch rebounds off the wall in 30 seconds. Children used two hands and a size 3 football. The children had to successfully catch the rebound from the wall for it to be counted as a successful throw and catch. If the child dropped the ball, they would run and retrieve the ball and continue with the challenge. The number of successful throws and catches were recorded. The time was recorded by the researcher using a hand held stop watch.

Lower body strength

Lower body strength was tested using body weight squats. Children stood with their feet hip width apart, bent from the knees and hips to a squat position until their thighs were parallel to the ground. Children were instructed to keep their heels on the ground, their head up and their back straight. Children could use their arms to help with balance. Children completed as many body weight squats as they could in 30 seconds. If children became fatigued they could stop and re-start within the 30 seconds. A full repetition was counted when the upper leg was parallel to the ground and back to a full standing position. The number of full repetitions completed in 30 seconds was recorded and timed using a hand held stop watch.

Upper body strength

Upper body strength was tested using press ups. Children started in a full press up position by lying face down on a flat surface, children placed their hands shoulder width apart directly underneath their shoulders and straightened their arms. Children were instructed to keep their legs straight and their back and head in a straight line. Children completed as many full press ups as they could in 30 seconds. If children became fatigued they could stop and re-start within the 30 seconds. Full press ups were counted when the children lowered their body until their elbows were flexed at 90^{o} and extended again to the start position. The number of full repetitions completed in 30 seconds was recorded and timed using a hand held stop watch.

Statistical Analysis

Data analysis was performed using two parallel approaches.

First, to calculate reference values Generalised Additive Models for Location, Scale and Shape (GAMLSS) were used. These allow the fitting of a distribution to a set of data utilising regression principles. Briefly, the variances of the distribution parameters are modelled across the range of data sets (i.e. across age) so that variations in the shape of the distribution can be accounted for across the range (i.e. age).

Two distribution models were utilised, chosen to best represent the distribution of data observed. For Agility, Squat, and Broad Jump and Stick (BJS), it was assumed the distributions of the data were loosely Gaussian, but varied in their mean, variance, skewness and kurtosis, and that these variables were not consistent across age and gender. This assumption was supported through analysis of the histograms across the ages and genders for each performance test. A Box-Cox Power Exponential distribution was fitted. This loosely follows a Gaussian distribution, but allows for the mean, variance, skewness and kurtosis aspects of the distribution to be modelled and varied. This has been used in health and exercise research previously (32, 43) to produce reference curves.

For the SQ and BJS, a recording of zero was removed. These were deemed incorrect recordings as they did not fit the overall trend that the data presented. This resulted in less than 1.5% of values being removed, with the result being a more valid fit.

It was deemed not appropriate to utilise the same Box-Cox Power Exponential distribution for the press up. and throw and catch performance tests. At the higher age groups, both presented a Gaussian distribution. However, at the younger age groups a large proportion of children scored lower, leaving a distribution that mimicked half of a Gaussian distribution (i.e. only the shape to the right of the mean), with this being truncated at zero. As such, a Gaussian distribution was fitted with this being truncated at zero. This provided centiles that were more closely aligned with the centiles of the sample collected.

Following the production of the distributions using GAMLSS, centiles were produced for each gender across all age groups using the models produced. Values for the 1st, 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th 97th and 99th percentiles were calculated. These percentiles were selected to mimic those utilised by the World Health Organisation in an analysis of size developments of children (43). Where differences between consecutive percentiles were less than one, these are not presented due to being meaningless, with only the more central percentile being retained.

Secondly, a comparison between genders at each age group was undertaken using a Mann-Whitney U test. This assesses the assumption that both distributions are taken from the same overall population and it is independent of the shape of the distribution (i.e. non-parametric). Due to the range of distributions fitted to the data, we deemed it inappropriate to use classical effect sizes that utilise the mean and standard deviation (measures associated with a Gaussian distribution) for calculation, as these require the assumption of normality within the data. Therefore, the process suggested by Fritz, Morris and Richler (2012) was used to calculate Cohen's *d* from the point biserial *r* ($d = 2r / \sqrt{[1-r^2]}$), with the point biserial *r* being calculated from the Mann-Whitney *z*-statistic (output from SPSS) using the suggested formula from Fritz *et al.* ($r = z / \sqrt{N}$; where N is the total sample size across both groups). Here, we will only present the Cohen *d* statistic along with the *p*-value calculated from the Mann-Whitney U test because the point biserial *r* and Mann-Whitney *z*-statistic can be calculated through re-arrangement of the above formulae. Finally, descriptive analysis of the regression model is used to infer changes across age.

GAMLSS analysis was performed in R (version 3.4.1) using the GAMLSS package (Rigby, & Stasinopoulos, 2005) whilst comparisons between gender were undertaken using SPSS version 24.

Results

Each of the five motor and muscular HRF tests will be described individually between sex and across age, with reference curves and centile cut offs reported. All Cohen's *d* effect sizes, along with the significance of the Mann-Whitney U test, for comparisons between boys and girls can be found in Table 3. It is important to emphasise the smaller sample size for the 12 year old age category for the agility (5-10-5) and explosive (BJS) tests, as this explains the apparent discrepancy between the effect size and null hypothesis significance test.

Agility

Boys had significantly faster agility time compared to girls at 5-11 years of age (p=0.001). The difference in agility times between boys and girls increases as children get older (Cohen's *d* increasing from 0.22 at 5 years to 0.39 at 12 years). The reference curves highlight that children progressively get faster at completing the agility test from the age of 5 to 12 years old. The curves indicate a steep improvement in agility time until the age of 8/9 years where the progression slows down (Table 4 and 5; Figure 1 and 2).

Insert table 4 and 5 here

Insert figures 1 and 2 here

Explosive power

At all ages boys could jump further than girls. However, this was only significant (p=0.001) for ages 6-11 years. Similar to agility the children progressively improve from 5-12 years in the distance achieved from the standing broad jump. However, the progression starts to slow slightly later, around 9/10 years (Table 6 and 7; Figure 3 and 4).

Insert table 6 and 7 here

Insert figures 2 and 3 here

Hand eye coordination

At age 5 years, there is minimal difference in the number of completed throw and catches between genders ($p=0.141$; Cohen's $d = 0.13$). However, from ages 6-12 years, boys complete significantly more throw and catches than girls ($p<0.005$; ES > 0.16). The centile values for girls indicate a steady increase from 5-11 years with the steepest increase between 7-10 years. However, between the ages of 11-12 years girls appear to complete the same number of throw and catches within the 30 second assessment time. Whereas the boys progressively improve from age 5-12 years with the steepest increase between 6-9 years (Table 8 and 9; Figure 5 and 6).

Insert table 8 and 9 here

Insert figures 5 and 6 here

Lower body strength

As both boys and girls get older the number of squats they can complete in 30 seconds is decreased from 8-12 years. There is no significant difference, with minimal effect size (Cohen's $d \leq 0.11$), in number of squats completed in 30 seconds between boys and girls until the age of 12, where boys performed significantly more than girls ($p=0.021$; Cohen's $d = 0.18$; Table 10 and 11; Figure 7 and 8).

Insert table 10 and 11 here

Insert figures 7 and 8 here

Upper body strength

For both boys and girls the number of press ups completed in 30 seconds remained relatively constant from ages 8-10 years, but decreased afterwards. Boys performed significantly more press ups at all ages compared to girls (p=0.001; Cohen's $d \geq 0.21$; Table 12 and 13; Figure 9 and 10).

Insert table 12 and 13 here

Insert figures 9 and 10 here

Discussion

The reference curves presented in this paper, to the authors' knowledge, are the first to be established for a motor and muscular HRF testing in English children aged 5-12 years. There have been a number of countries who have published reference curves for a number of different fitness tests, however, for a number of reasons these cannot be transferred and used on English children. The first being the accessibility or ecological validity of them; some of the tests reported, would not be able to be carried out by teachers unless they had specialised protocols and/or equipment (10, 14, 25, 37), such as a hand grip dynometer as a test for strength (10). More importantly it is the poor generalisability of other countries results to English children that limits their use. For example, standing broad jump reference curves have been published in children 6 to 12 years in Macedonia (14), Europe (excluding England; 25), Greece (37) and Australia (10). When comparing the average distance jumped all other countries jumped 11cm and 19cm further than girls and boys, respectively, from England. This was a similar finding for the number of press ups completed in 30 seconds; children from other countries completed on average 3 and 5 more press-ups than English girls and boys, respectively. From these comparisons it is clear that English children are performing poorer on these tests to the other countries stated, thus stressing the importance for English reference curves that can be used to monitor and compare children within England and allow progress to be measured against reference curves from other countries

Of the other countries that have produced fitness testing batteries, the test batteries were not consistent (25, 33, 37). They use different combinations of tests to assess strength, power, agility, aerobic capacity and flexibility; however, none of them include an assessment of hand-eye coordination. This is surprising due to the influence that object control skills have on current and future physical activity participation levels, particularly in boys (2, 8). Therefore, we would suggest that hand-eye coordination should be included in all testing batteries to give an indication, particularly in boys, of PA level and likelihood to continue PA as they age.

One of the main outcomes from the reference curves is the decline in upper and lower body strength performance between the ages of 10 to 12 years. Between these ages is the transition from primary school to secondary school in England and this has been highlighted as a critical point at which physical activity declines (29). A number of reasons have been highlighted previously, including a lack of extracurricular PA opportunities, higher cognitive ability and input in to decision making (24) and decrease in active travel to and from school (23) among others. This decline in PA and an increase in unhealthy food choices (6) that have been reported at this transition stage are indicated as being contributing factors for the increase in number of overweight and obese children also at this age (27). This progressive increase in the number of children who are overweight between the ages of 9-12 years could provide an explanation for the decrease in performance in the strength based activities. With a decline in PA and an increase in unhealthy food choices, it is likely increases in fat mass and decreases in muscle mass will be seen. If someone is carrying more fat mass, whilst having less muscle mass, power to weight ratio will decrease, as well as anaerobic capacity will decline and muscles will fatigue quicker (21), resulting in a decrease in performance. Interestingly, the other tests did not decline in performance. This could be because the maturation of the children benefits their performance above the loss due to increased obesity levels. For example; having longer limbs would require less steps to complete the agility test and therefore complete it quicker; longer leavers to propel forwards for the broad jump; and longer limbs allow the hands to be closer to the wall to rebound the ball in the throw and catch test (along with improvements in motor control discussed above). Whereas, longer limbs for the squat and press up test increases the distance needed to travel to complete one whole squat/press up, thus taking longer and the amount completed in 30 seconds will decrease. Although caution should be taken with these results, as a lower sample size was gained within the 12 year old age group, there does appear to be an intricate relationship between PA, obesity and maturation levels, and a child's ability to perform optimally across different fitness tests.

The difference in performance levels between sex and across age highlight the importance of these reference curves, so any changes in children can be compared to normative values of their age and sex and tracked effectively over time. This would allow health related fitness skills to be measured against standard scores, as well as to be tracked alongside traditional curricular development. These reference curves could therefore be a key tool in supporting the physical development of children throughout their full development.

Until the age of 10, children of both genders should be somatically the same (22), suggesting there should be no difference in test scores. However, this was only found for the number of squats completed; there was only a significant difference between boys and girls at the age of 12 years. For the broad jump and the throw and catch scores there was no difference at age five years, however, by the age of six years there was a significant difference. Furthermore, a significant sex difference in agility performance was seen at age five years. These sex differences identified prior to somatotype variation, suggest that children may be socialised at an early age into gender specific activities (4) and therefore physical development. Boys at all ages have been shown to engage in more organised and spontaneous PA utilising the space around them, particularly involving balls (5). Thus, by spending more time doing PA it enables and allows boys to develop these fundamental movement skills to a greater degree compared to girls.

Once children become pre pubertal, boys start to have more muscle mass and girls more fat mass and widening of the hips, (13) therefore differences in test scores such as agility would be expected between boys and girls at this pre pubertal age. However, this age cannot be completely objective as a more recent suggestion as to why sex differences are seen at an early age, is due to the onset of puberty becoming earlier in boys (20) and girls (11). This early onset of puberty has been linked to the increased numbers of overweight and obese children (44). Whilst this cannot explain the very early sex differences, it can provide an explanation for some sex differences seen earlier than theoretically expected.

Of the three tests that were investigated from the age of five or six years the reference curves show accelerated improvements in performance until around the age of nine years. At this age, the development of these skills is seen to slow down agreeing with previous reports (41). An explanation for this could be due to the peak period of brain maturation involving myelination of CNS axons and therefore transmission speed (36) identified between the ages of six and eight years (30). Thus, children between the ages of six and eight years, have an increased efficiency of performing motor patterns and completing tasks, explaining the rapid improvement of the task outcomes in the current data set. This age of the peak brain maturation corresponds with the 'window of opportunity' of physical skill development as suggested by the Long Term Athlete Development (LTAD) model (1,16). Further research is needed to determine if this acceleration in skill development is also a time of increased sensitivity to exercise (13) and thus an important time for intervention in children to maximise PA development.

Limitations

An indication of weight status, such as BMI (body-mass index) was not recorded in this study, thus limiting the generalizability of the reference curves. However, from the wide spread of schools across the deprivation levels, it is fair to assume that the sample of children included in this study is representative of the national levels of weight status in children ages 5-12 years (30% children classed as overweight or obese; 15). The low number of 12 year olds in this sample causes the centile cut offs for this age group to be used with caution. The data reported in this study are not indicative of health risk and future research needs to be conducted to determine performance levels associated with health related fitness.

Conclusions

The reference curves and centile cut offs reported for this comprehensive fitness battery are the first to be produced in England. Importantly, we have shown that development in all fitness tests are not as expected across ages, with performances decreasing with age in strength based tests. The curves provide benchmarks for fitness test scores across 5-12 year olds for boys and girls. Finally, the reference curves can be used to suggest targets through the child's growth to support development. The sex based differences seen from aged six should be used to further highlight the need to improve motor competence in girls in any future interventions and curriculum. A future comparative study of the reference curves available from around the world should be produced to highlight key differences to be used when applying studies to other countries.

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