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Neuromotor development in children. Part 4: new norms from 3 to 18 years

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Abstract: AIM The aim of this cross-sectional study was to provide normative data for motor proficiency (motor performance and contralateral associated movements [CAMs]) in typically developing children between 3 years and 18 years of age using an updated version of the Zurich Neuromotor Assessment (ZNA-2). METHOD Six-hundred and sixteen typically developing children between 3 years and 18 years of age were enrolled from day-care centres, kindergartens, and schools, and were tested using the ZNA-2 with improved items of the original battery. Motor proficiency was assessed on five components (fine motor tasks, pure motor tasks, static balance, dynamic balance, and CAMs) as a function of age and sex to determine centile curves for each task. Intraobserver, interobserver, and test-retest reliabilities were evaluated. RESULTS Most ZNA-2 tasks featured a marked developmental trend and substantial interindividual variability. Test-retest reliability was generally high (e.g. static balance 0.67; CAMs 0.81; and total scores 0.84). INTERPRETATION The ZNA-2 is a reliable and updated test instrument to measure motor proficiency in children from 3 to 18 years with improved properties for assessing motor performance. It allows continuous measurement without changing items for the entire age range; this feature of the ZNA-2 is unique and makes the instrument suitable for clinical purposes. The reduction of CAMs scoring simplifies the clinical procedure and increases its reliability. WHAT THIS PAPER ADDS The Zurich Neuromotor Assessment, Second Edition (ZNA-2) provides new norms for motor proficiency in children between 3 years and 18 years. High reliabilities suggest that the revised test battery is a useful tool for assessing neuromotor development. Integration of a 'not able to perform' category makes the ZNA-2 suitable for clinical purposes.

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Neuromotor development in children. Part 4: new norms from 3 to 18 years

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ABBREVIATIONS

CAMs	Contralateral associated movements
DCD	Developmental coordination disorder
ZNA-2	Zurich Neuromotor Assessment, Second Edition
ZNA	Zurich Neuromotor Assessment

AIM The aim of this cross-sectional study was to provide normative data for motor proficiency (motor performance and contralateral associated movements [CAMs]) in typically developing children between 3 years and 18 years of age using an updated version of the Zurich Neuromotor Assessment (ZNA-2).

METHOD Six-hundred and sixteen typically developing children between 3 years and 18 years of age were enrolled from day-care centres, kindergartens, and schools, and were tested using the ZNA-2 with improved items of the original battery. Motor proficiency was assessed on five components (fine motor tasks, pure motor tasks, static balance, dynamic balance, and CAMs) as a function of age and sex to determine centile curves for each task. Intraobserver, interobserver, and test–retest reliabilities were evaluated.

RESULTS Most ZNA-2 tasks featured a marked developmental trend and substantial interindividual variability. Test–retest reliability was generally high (e.g. static balance 0.67; CAMs 0.81; and total scores 0.84).

INTERPRETATION The ZNA-2 is a reliable and updated test instrument to measure motor proficiency in children from 3 to 18 years with improved properties for assessing motor performance. It allows continuous measurement without changing items for the entire age range; this feature of the ZNA-2 is unique and makes the instrument suitable for clinical purposes. The reduction of CAMs scoring simplifies the clinical procedure and increases its reliability.

In 2001, the Zurich Neuromotor Assessment (ZNA) was presented in this journal to describe the developmental course and interindividual variation for timed performance and the quality of movements (intensity of contralateral associated movements [CAMs]) for a set of motor tasks of variable complexity in typically developing children between 5 years and 18 years.[1,2] This test battery has since been successfully used both in clinical and in research settings and to address specific questions related to motor development in infants and adolescents.[3–5]

However, this long experience with the ZNA showed that there was room for improvement. As in other comparable test batteries, some tasks were changed between age bands, thus preventing continuous evaluation and comparison between ages.[6–8] This was especially true for static and dynamic balance; several tasks were used for this over the entire age range. Furthermore, only a few tasks related to fine motor abilities as well as static and dynamic balance were included in the original battery, and these were then varied to comprehensively assess underlying functions in a differentiated way. Additionally, the assessment of movement quality by scoring CAMs was time-consuming, and the reliability of such scoring was not proportionate to the effort that it involved.[9] Finally, assessment of motor proficiency in children below the age of 5 years was only possible with another version of the test battery,[10] which contained substantially different tasks from the original ZNA.

Thus, we developed a revised version of the ZNA, the ZNA-2, to address the main shortcomings of the original test battery. Our aim was to develop a unified test which reliably describes the variability and evolution of motor proficiency in typically developing children continuously from 3 to 18 years. Unlike the previous ZNA and other test batteries, the ZNA-2 now incorporates tasks whose definition remains strictly identical throughout the entire age range. Only the number of repetitions of a task is varied to accommodate increased motor proficiency with age; the tasks themselves remain unchanged. Moreover, unlike tests that quantify motor proficiency by comparing the motor performance of a child with that of peers in the same age group – thus averaging the performance of

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children of possibly different ages[6–8] – the ZNA-2 models motor proficiency as a continuous function of age. Such modelling allows the comparison of the motor performance of a child with that of peers of exactly the same age. Normative data may then be used in the clinical setting to assess motor proficiency of children and identify those with motor difficulties.

In fact, motor problems frequently occur during childhood. For example, about 5% to 6% of all children are estimated to suffer from developmental coordination disorder (DCD).[11,12] The European Academy for Childhood Disability stresses using a reliable, valid, standardized, and norm-referenced motor test to determine the extent of the movement problems of children.[13] According to these guidelines, the acquisition and execution of motor skills must be substantially below the expected level given the individual's chronological age and sufficient opportunities to acquire motor skills.[13] A comparison of the ZNA with the Movement Assessment Battery for Children, Second Edition (a classic motor instrument for the diagnosis of DCD) has been provided for children with DCD from 5 to 7 years, indicating that the ZNA can also be used for the identification of DCD.[14] However, unlike the Movement Assessment Battery for Children, Second Edition, which quantifies motor skills, the ZNA focuses on motor abilities, a concept that more directly reflects the child's neurological development.[10,15]

The greatest challenge to provide normative measures for all ages was to integrate the data of the children who were not yet able to do the tasks because of their age. To overcome this disadvantage, a variant of the poor man's data augmentation algorithm was used[16] which integrates missing data into the estimation of the outcome model.[10] In this way, we were able to take account of the high variability in motor proficiency in children younger than 6 years and to provide normative measures even for 3-year-olds.

Furthermore, the ZNA-2 was slightly simplified to improve its feasibility in clinical practice. Some tasks were dropped, and new ones were incorporated to increase the test–retest reliability of components. The aim of the current study was to present a new ZNA battery that continuously and reliably describes motor proficiency in typically developing children and adolescents from 3 to 18 years.

What this paper adds

- The Zurich Neuromotor Assessment, Second Edition (ZNA-2) provides new norms for motor proficiency in children between 3 years and 18 years.
- High reliabilities suggest that the revised test battery is a useful tool for assessing neuromotor development.
- Integration of a 'not able to perform' category makes the ZNA-2 suitable for clinical purposes.

METHOD

Participants

A total of 616 children (304 males, 312 females) between the ages of 3 years and 18 years participated in this cross-sectional study (see Table I for sample characteristics). They were enrolled from day-care centres, kindergartens, and primary, secondary, and vocational schools in the greater Zurich area. Children with evident medical or behavioural conditions (e.g. physically/mentally challenged) were excluded from the analysis. All the children lived in the Zurich area and together constituted a representative sample of the general population of typically developing children. In Switzerland, 25% of the population is of foreign extraction. Although most of our data sample were white, we did not identify the racial or ethnic backgrounds of the children for ethical reasons; neither did we ask whether they were foreigners or not. Special attention was given to sampling from districts with low, medium, and high socio-economic backgrounds. The study was approved by the institutional review board of the Canton of Zurich (KEK-ZH-Nr StV-40/07) and performed according to the Declaration of Helsinki. All families received a study description and provided written informed consent.

Test battery

The original ZNA is a standardized procedure that was specifically designed to describe neuromotor development in children from 5 to 18 years of age.[1,2,9] Motor proficiency is measured on five components: fine motor tasks, pure motor tasks, dynamic balance, static balance, and movement quality (CAMs). The assessment of motor proficiency was later extended to children between 3 years and 5 years of age using a customized version of the test.[10]

In the updated version of the ZNA, the ZNA-2, we used essentially the same items and components as in the original.[9] To take account of improvements with age in performance of fine motor tasks, static balance, and dynamic balance tasks, the original ZNA changed the difficulty of the tasks over age. These changes made comparisons between age groups and longitudinal evaluations difficult. Our aim with the ZNA-2 was to apply essentially the same motor test for all ages. Weaker performance in younger children was adjusted for by reducing the number of repetitions for children between 3 years and 6 years (Table II).

Items were added to the test for all children. For fine motor tasks,[10] a turning bolt and stringing beads (bimanual) task were added. The static balance component now consists of a one-leg stand with eyes open and another with eyes closed for all age groups. In the dynamic balance

Table I: Study population and median age at testing

Age range (y:mo)	Median age (y:mo) at testing (interquartile range)	Females (*n*)	Males (*n*)	All (*n*)
All ages	7:9 (6:7)	312	304	616
3:0–5:11	4:4 (1:3)	113	103	216
6:0–8:11	7:1 (1:1)	59	61	120
9:0–11:11	10:2 (1:3)	72	64	136
12:0–14:11	13:6 (1:11)	26	26	52
15:0–17:11	16:0 (1:3)	42	50	92

Table II: The Zurich Neuromotor Assessment, Second Edition

			3–6 y	6–18 y
Fine motor tasks	Pegboard (+CAMs)		1 try (s), D, ND	1 try (s), D, ND
	Bolts (+CAMs)		1 try (s), D, ND	1 try (s), D, ND
	Beads		1 try (s)	1 try (s)
Pure motor tasks	Repetitive movements	Fingers	10 times (s), D, ND	20 times (s), D, ND
		Hand	10 times (s), D, ND	20 times (s), D, ND
		Foot	10 times (s), D, ND	20 times (s), D, ND
	Alternating movements	Hand (pro-/supination) (+CAMs)	5 times (s), D, ND	10 times (s), D, ND
		Foot (heel–toe alternation) (+CAMs)	5 times (s), D, ND	10 times (s), D, ND
	Sequential movements	Fingers (+CAMs)	2 times (s), D, ND	5 times (s), D, ND
Static balance	Standing on one leg (eyes open)		2 tries (s), D, ND	2 tries (s), D, ND
	Standing on one leg (eyes closed)		2 tries (s), D, ND	2 tries(s), D, ND
Dynamic balance	Jumping sidewards		10 times (s)	20 times (s)
	Chair-rise		5 times (s)	10 times (s)
	Standing long jump		2 tries, distance (m)	2 tries, distance (m)

New items are set in bold type; differences in the number of repetitions are indicated in the table. CAMs, contralateral associated movements; s, seconds; D, dominant hand; ND, non-dominant hand; m, metres.

component, the two sideward jumping tasks are reduced to one, but they are adapted to all ages and supplemented by a chair-rise task and a standing long-jump task.

An overview of all items and the times in which the children had to perform the exercise is provided in Table II. Items newly added to the previous version of the ZNA are indicated in bold type. For an exact description of the items, see Appendix S1 (online supporting information). Time and distance are always measured to an accuracy of one decimal place. Total time allowed to perform the test is between 20 minutes and 30 minutes, depending on the motor proficiency of the child. Components in the ZNA-2 were defined as they had been in the original ZNA. Furthermore, two total scores summarizing the motor performance across all components are calculated (with and without CAMs) in the ZNA-2.

Socio-economic status

Socio-economic status is calculated by coding the occupational status of both parents and transforming this into an International Socio-Economic Index value.[17] The maximal socio-economic status is then determined by the selection of the highest of the maternal and paternal International Socio-Economic Index values. In our trials, the mean Index value of the mothers was 55 (SD 20.7; range 16–89) and of the fathers 57 (SD 19.9; range 10–89), comparable to the earlier cohort[1,2] and to the general population of Switzerland, which has a mean score of 55 and standard deviation of 17.[18]

Procedure

Participants were tested in their own day-care centre, kindergarten, or school and recorded individually on digital video. Examiners were experienced ZNA testers who had all been trained by THK and JC. In total, five people were trained for the ZNA-2 assessment; all testing and scoring were supervised by THK and JC. Tests always took place individually in a separate room. Before testing began, children were measured for height and weight. All tasks were performed in the same order by all children. First, the child performed all exercises on the table (fine motor tasks), then the child sat on a height-adjustable chair for the repetitive, alternating, and sequential movements (pure motor tasks). Then, static balance and dynamic balance were tested (Fig. 1). The examiner explained verbally and demonstrated how to perform the tasks. If the child did not understand the task and did something different, a repeat demonstration was provided. If they failed again, the examiner scored the task as 'failed' and continued with another item. Total administration time of the test was about 25 minutes. CAMs during pure motor and fine motor tasks were scored subsequently from video recordings.

Interobserver reliability was assessed on 20 children tested by two examiners (THK and SE). Intraobserver reliability was assessed by SE, who retested 20 video recordings 1 year after their first assessment. Test–retest reliability was assessed by EK and SE, who together tested 105 children twice with exactly 1 week between tests. For example, a child who was tested on a Monday was retested 1 week later, also on a Monday, at approximately the same time of day. No individual child participated in more than one reliability measurement. The video recordings used to estimate interobserver and intraobserver reliability were chosen randomly. For the test–retest reliability, we approached three schools and two child-care centres.

Statistical analysis

Data from the dominant and non-dominant hands were modelled separately. Age was treated as a continuous variable as it covered the whole interval between 3 years and 18 years (Fig. 2 and Table I). For a given task j, the motor performance y_{ij} of child i was measured as the duration (in seconds) needed for that child to complete the task, with the exception of standing long jump; in this case, y_{ij} referred to the distance in centimetres over which the child

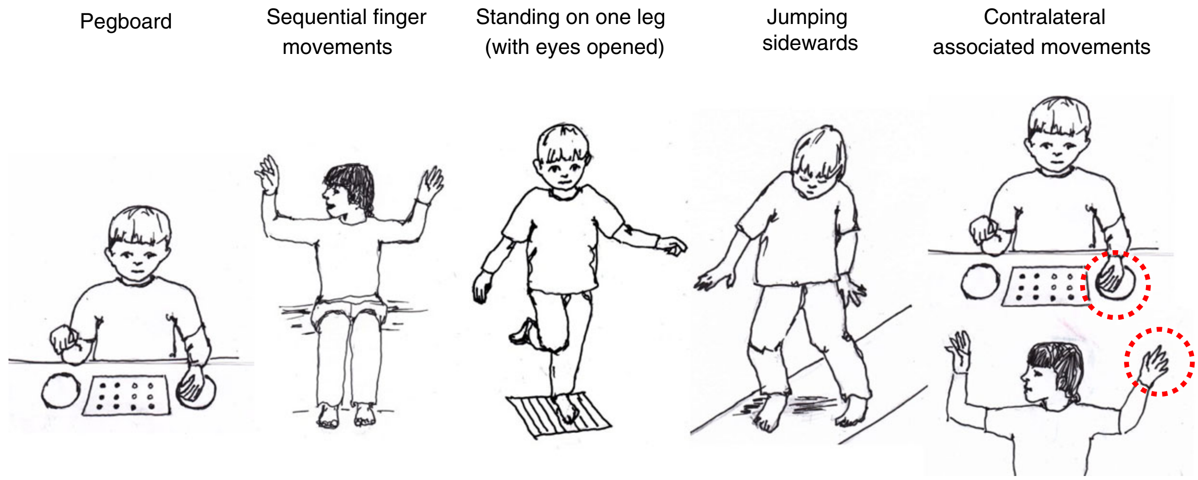

Figure 1: Example of starting positions for one task of every component. From left to right: pegboard task, sequential finger movements, one-leg stand with eyes open, jumping sidewards, and contralateral associated movements (in dashed single circle) during the pegboard and sequential movements tasks. [Colour figure can be viewed at wileyonlinelibrary.com].

was able to jump. The duration $d_{ij} \in \{0; 1; 2; \ldots; 10\}$ and extent $e_{ij} \in \{0; 1; 2; 3\}$ of CAMs measured on the opposite hand from that used to perform task j were combined into an index $w_{ij} = [d_{ij}(e_{ij}-0.5)]^{1/2}$ called the intensity of CAMs.[19] This index contains 24 values ranging from 0 (no CAMs) to 5 (maximum number of CAMs), with the square root being used to make w_{ij} approximately normal. The motor performance y_{ij} and the intensity of CAMs w_{ij} were modelled as a function of age and sex using the LMS method,[20] implemented in the framework of generalized additive models for location, scale, and shape.[21] This framework allows the flexible modelling of the mean, variance, and possible skewness of the outcomes y_{ij} and w_{ij} as smooth functions of covariates, which in turn allows the calculation of centile curves.

Floor and ceiling effects induced by those children achieving the minimal value of 0 or the maximal value of 5 for the intensity of CAMs were treated as left-censored or right-censored observations respectively, as done when modelling ZNA.[19] Similarly, children younger than 6 years who were not able to perform a given task – a situation that mostly occurred during alternating and sequential movements and jumping sidewards – were treated as right-censored observations for timed performance (see Appendix S2 for more details [online supporting information]) and as missing observations for intensity of CAMs. To fit such models, an approach equivalent to the poor man's data augmentation algorithm was used.[16]

For any given task, the model for centile curves was used to convert the motor performance or intensity of CAMs of a child into a standard deviation (SD) score. An SD score (also called z-score) is a continuous and standardized measure of motor performance (adjusted for age and sex) that is normally distributed in the population of typically developing children with a mean of 0 and an SD of 1. An SD score of 0 refers to average performance, and positive and negative values refer to above-average and below-average performances respectively. For a given child, the SD scores calculated on individual items belonging to the same component were then summed (and standardized to have an SD of 1) to calculate an SD score for that component. The two total scores were calculated in a similar fashion using a standardized sum of SD score values from the individual components after either including or excluding CAMs.

The interobserver, intraobserver, and test–retest reliabilities for individual tasks and components were estimated using the intraclass correlation coefficient.[22] As when assessing the reliability of ZNA,[14] and as recommended,[23] the systematic error (i.e. bias) between two SD score values measured on the same child was penalized when quantifying interobserver and intraobserver reliability, but it was not penalized when investigating test–retest reliability. More details on the statistical procedure are given in Appendix S2 (online supporting information).

RESULTS

Developmental course and interindividual variation

Centile curves for motor performance and CAMs for a selection of tasks are presented in Figures 2 to 5. A strong increase in speed could be observed for the pegboard task until about age 10, with females remaining slightly faster than males at all ages (Fig. 2a). However, the decrease in CAMs seemed more continuous and spread over a longer age period, with fewer CAMs seen in females than in males of the same age (Fig. 2b). We observed a moderate but continuous increase in speed of alternating movements of the hands over age, with a shift after 6 years resulting from children being required to perform twice the number of movements (Fig. 3a). The intensity of CAMs seemed stable up to the age of 10 years, after which it quickly decreased, with females consistently showing fewer CAMs than males

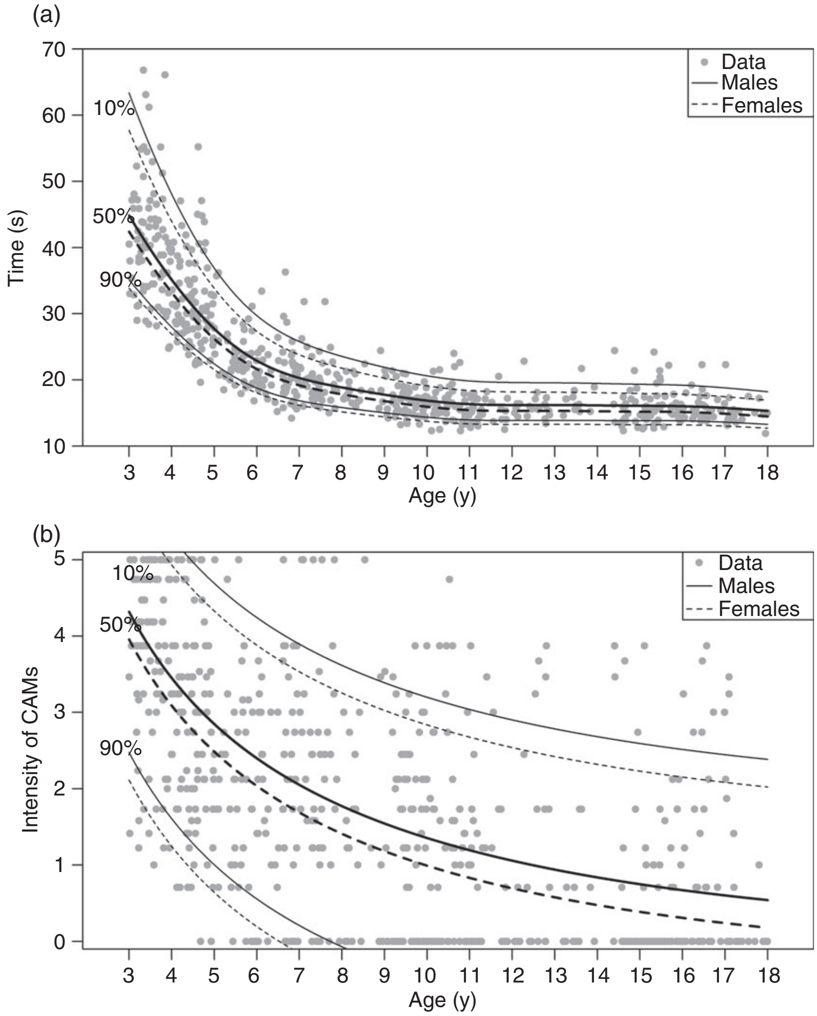

Figure 2: Centile curves (a) of timed performance for the pegboard task for the dominant hand (b) for the intensity of the contralateral associated movements of the non-dominant hand occurring at the same time. CAMs, contralateral associated movements.

(Fig. 3b). The time over which a child could stand on one leg with eyes opened (Fig. 4a) increased quickly; half of the females reached the upper threshold of 30 seconds at 6-years-old, while half of the males required approximately an additional year to reach the same threshold. This task differentiates well between younger children but appears to be too easy for older children. Therefore, the same test performed with eyes closed was introduced to allow better differentiation of older children and adolescents (Fig. 4b). With the new, eyes-closed test, the improvement over age was less marked, but the variability was clearly apparent up to the age of 18, with females performing better than males of the same age. The combination of these two tasks is therefore a very useful addition to the ZNA-2. When the curves for the standing long jump were examined (Fig. 5a), a stagnation of the distances jumped by females became clearly apparent after age 10 to 11 years. The 10% weakest males jumped just as far as 50% of the females. Finally, the time required to jump sidewards (Fig. 5b) decreased with age before flattening out around age 13, with no difference seen between males and females. Note that large proportions of children below 6-years-old were not able to perform this task (99%, 90%, and 43% of failure at ages 3 years, 4 years, and 5 years respectively). Consequently, centile curves are plotted only up to the right-censoring threshold, above which the time of those children unable to perform is expected to lie.

Reliability

Intraobserver, interobserver, and test–retest reliability of all tasks are provided in Table III. Interobserver and intraobserver reliabilities were estimated from the data on 20 children while test–retest reliability was estimated from the data on 105 children (from 3–18y). For the individual tasks, test–retest reliability varied considerably, from 0.33 to 0.73, while interobserver reliability varied from 0.72 to 1.00 and intraobserver reliability was at least 0.96. Results on components were much better; test–retest reliability

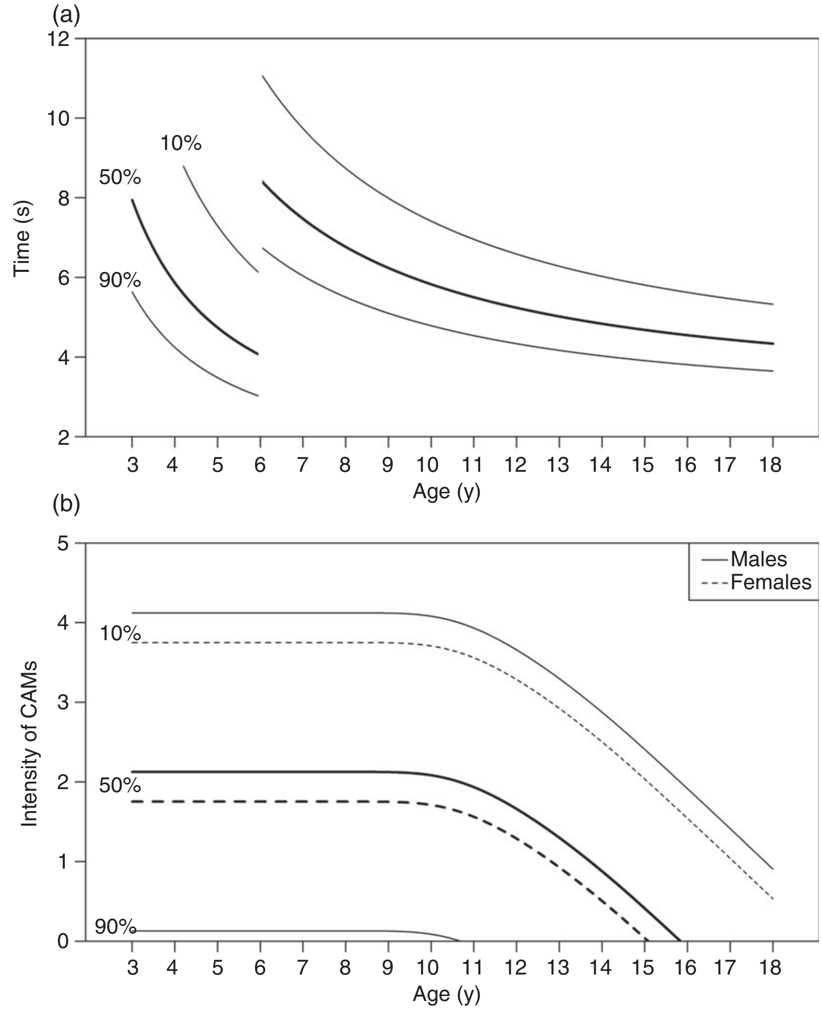

Figure 3: Centile curves (a) of timed performance for the alternating movements of the dominant hand and (b) for the intensity of the contralateral associated movements of the non-dominant hand occurring at the same time. Because some young children are not able to perform alternating hand movements, centile curves in (a) are plotted only for times falling below the right-censoring threshold (above which the time of those children unable to perform is supposed to lie). CAMs, contralateral associated movements.

ranged between 0.67 and 0.84, interobserver reliability was equal to or greater than 0.92, and intraobserver reliability was consistently estimated at 1.00. In particular, the test–retest reliability of the two total scores was remarkably high at 0.84.

DISCUSSION

In this paper, we provide new norms for the updated version of the ZNA, the ZNA-2. New normative data for motor proficiency in typically developing children were required, and 20 years' experience had highlighted some problematic test items that needed to be replaced. In line with other updated versions of motor tests,[6–8] we also adapted our test to the most recent requirements for reliable motor testing. The norms that we present here enable us to show that interindividual variation is still a major feature among typically developing young children. The new norms now include children between 3 years and 5 years, an age range known for its fluctuations in motor behaviour. In addition, we had to deal with the fact that not all young children are able to perform some of the more complex coordinative tasks, such as sequential finger movements. Our statistical modelling approach allows the integration into the normative data of those items that could not be performed by all children.[10] Now, nearly all test items remain the same from 3 years up to 18 years; this unique feature of the ZNA-2 allows the comparison of younger and older children on the same test and, thus, makes the instrument ideal for research purposes. It also enables us to distinguish children with delayed or aberrant motor development from those whose motor development is typical.

In fact, early identification of children with motor disorders is recommended by the clinical community, because

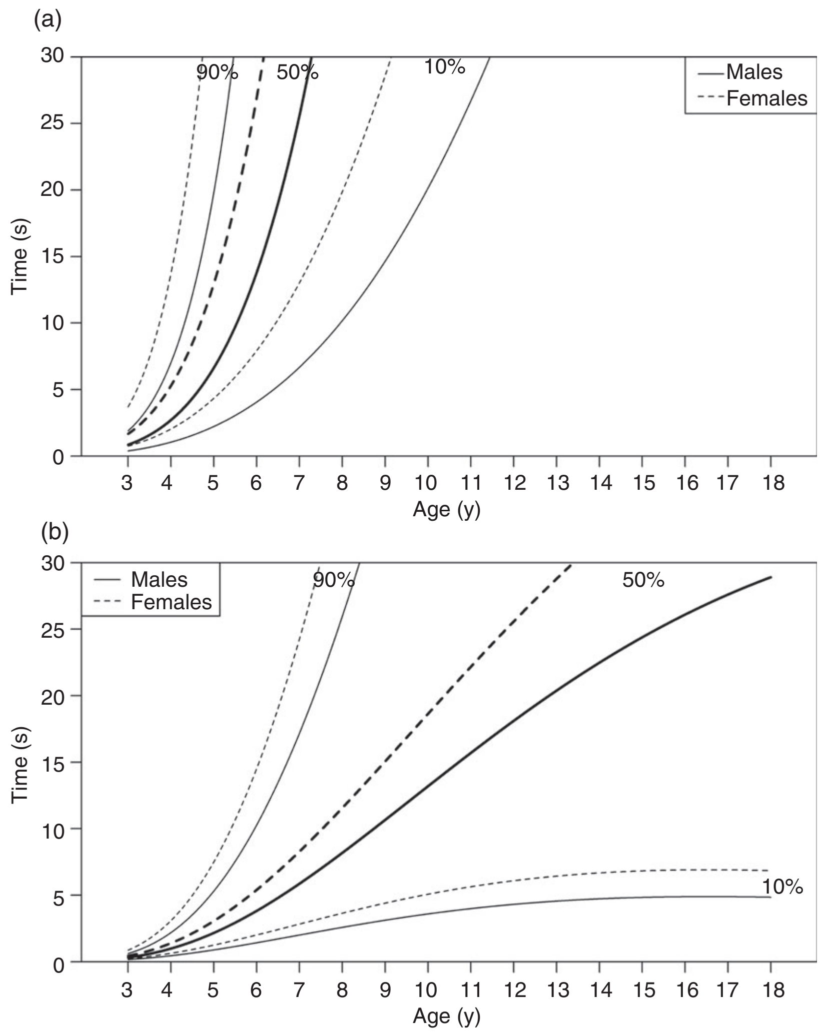

Figure 4: Centile curves of timed performance for static balance for the dominant leg, eyes (a) open and (b) closed.

aberrant motor development is considered to have a major impact on psychological, emotional, and cognitive development.[24] As the ZNA-2 focuses on the general traits or capacities of the child that underlie its motor proficiency, it may be most suitable for identifying motor disorders such as DCD (although validity studies still need to be done). In the ZNA-2, most of the tasks are not influenced by practice beforehand. The test is close to a 'neurological' test (and therefore called neuromotor) because the neurological prerequisites of the typically developing motor system are assessed. Unlike the Movement Assessment Battery for Children, Second Edition, the ZNA-2 does not measure proficiencies in motor skills that may be, for example, practised during sports.

The validity of the data is demonstrated by the strong link between motor proficiency and age on nearly all items, which also highlights the test's suitability for describing typical neuromotor development. Although it is generally known that children younger than 5 years are less competitive, the ZNA-2 and its continuous items allow observation of improvement over age from as young as 3-years-old. Preschool children are more variable in their performance because of their emotional immaturity. A small change in their daily routine may have a strong impact on their current mood,[25] and these mood changes clearly influence their motor performance. However, we have been able to demonstrate the continuity of data and improvement of motor performance from 3 to 18 years.

Although the previous version of the ZNA was used in clinical populations such as children born preterm, children with congenital heart disease or children with DCD,[3,14,26] the ZNA-2 has not yet been applied in these populations, although it offers appropriate psychometric properties as a motor test. We hope that others will examine test validity for the identification of children with motor problems in the future.

The ability of the instrument to provide an SD score for children even when they are unable to perform the task is a new feature of the ZNA-2 that can be valuable in the

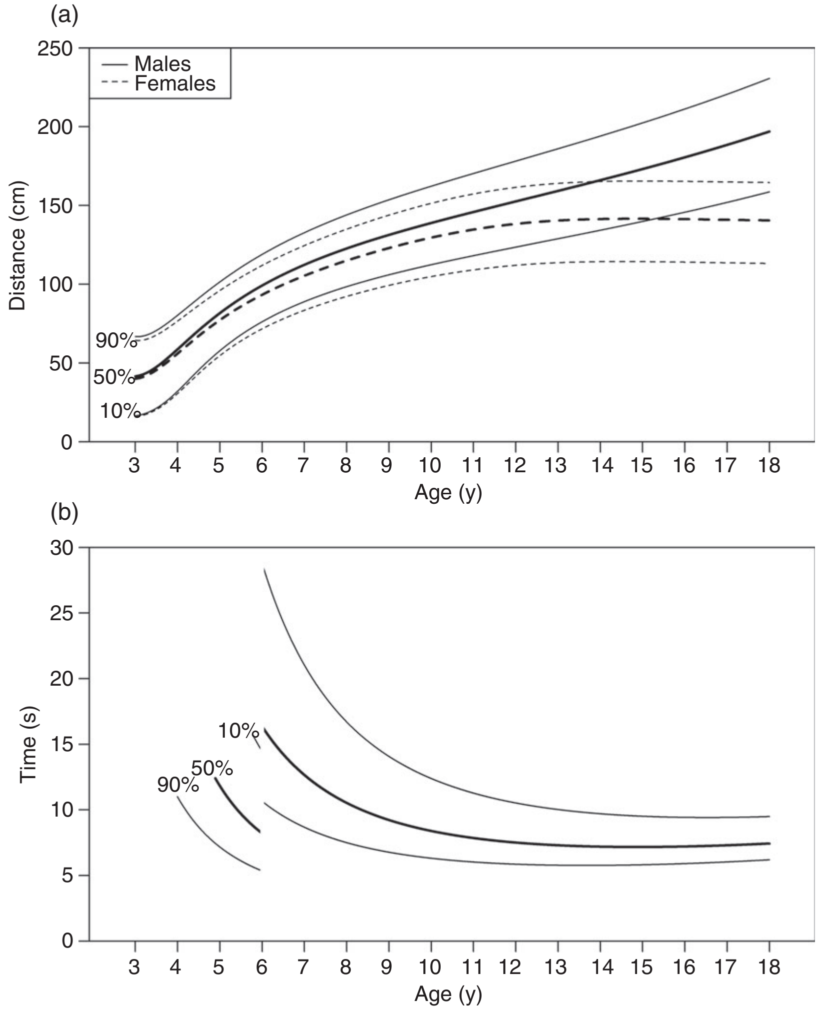

Figure 5: Centile curves (a) of distances jumped on the standing long jump (mean of two values) and (b) time required to jump sidewards. Because a significant proportion of young children are not able to jump sidewards, centile curves in (b) are plotted only for times falling below the right-censoring threshold (above which the time of those children unable to perform is supposed to lie).

clinical setting. This new feature of the ZNA-2 enables practitioners to identify young children with motor problems so long as the proportion of task failures at any given age remains reasonable. Indeed, when that proportion grows too large (e.g. >50%), it becomes 'normal' for a child to be unable to perform. Consequently, the ability of the test to detect young children with motor disorders is reduced, as for any other test. However, we note that, except for the tasks 'jumping sidewards and sequential finger movements', the probability of failures at age 4 years was always below 30%. Moreover, because of a moderate test–retest reliability at the individual task level, motor disorders are best detected at the component level, with a component encompassing several tasks that the child is capable of achieving.

Test–retest values in the ZNA were always the lowest (interobserver and intraobserver values were always higher), reflecting not only differences within observers but also changes in the state of the participant.[25] This instability in mood may explain the lower values. However, the creation of composite scores for our items, in which test parts are grouped according to their nature, improved the reliability of our test considerably.[4] Test–retest values for the five components (fine motor tasks, pure motor tasks, static balance, dynamic balance, CAMs) varied between 0.67 and 0.84, while the test–retest reliability of the two total scores was 0.84.

We replaced forward jumping in the dynamic balance category by two new items that have proved to be more reliable in other tests; they are used for tests in sports (standing long jump)[27] and in the elderly (chair-rise task).[28] The standing long jump, an Olympic discipline until 1912, is used to test the muscular strength and power of the lower body.[27] The chair-rise task is designed to quantify lower-extremity muscle strength too, but it is also suitable for those participants who cannot hop.[28] For children

Table III: Intraobserver, interobserver, and test–retest reliabilities for the different tasks and components of the Zurich Neuromotor Assessment, Second Edition

	Reliability		
	Intraobserver (*n*=20)	Interobserver (*n*=20)	Test–retest (*n*=105)
Individual tasks			
Pegboard (D)	1.00 (1.00; 1.00)	1.00 (1.00; 1.00)	0.47 (0.31; 0.61)
CAMs (ND)	1.00 (0.99; 1.00)	0.94 (0.86; 0.98)	0.63 (0.49; 0.73)
Pegboard (ND)	1.00 (1.00; 1.00)	1.00 (1.00; 1.00)	0.47 (0.30; 0.60)
CAMs (D)	0.99 (0.99; 1.00)	0.91 (0.79; 0.96)	0.63 (0.50; 0.73)
Bolts (D)	1.00 (1.00; 1.00)	1.00 (0.99; 1.00)	0.66 (0.54; 0.76)
CAMs (ND)	1.00 (0.99; 1.00)	0.92 (0.81; 0.97)	0.68 (0.56; 0.77)
Bolts (ND)	1.00 (1.00; 1.00)	1.00 (0.99; 1.00)	0.64 (0.51; 0.74)
CAMs (D)	1.00 (1.00; 1.00)	0.91 (0.79; 0.96)	0.68 (0.56; 0.77)
Beads	1.00 (1.00; 1.00)	0.99 (0.97; 1.00)	0.57 (0.43; 0.69)
Repetitive foot movements (D)	0.99 (0.96; 0.99)	0.84 (0.64; 0.93)	0.49 (0.33; 0.62)
Repetitive foot movements (ND)	1.00 (1.00; 1.00)	0.91 (0.79; 0.96)	0.64 (0.51; 0.74)
Alternating foot movements (D)	1.00 (0.99; 1.00)	0.98 (0.96; 0.99)	0.63 (0.49; 0.73)
CAMs (ND)	1.00 (1.00; 1.00)	0.92 (0.81; 0.97)	0.52 (0.36; 0.64)
Alternating foot movements (ND)	1.00 (0.99; 1.00)	0.99 (0.98; 1.00)	0.63 (0.50; 0.73)
CAMs (D)	1.00 (1.00; 1.00)	0.91 (0.79; 0.97)	0.37 (0.19; 0.52)
Repetitive hand movements (D)	0.99 (0.97; 0.99)	0.74 (0.46; 0.89)	0.54 (0.38; 0.66)
Repetitive hand movements (ND)	0.98 (0.95; 0.99)	0.80 (0.56; 0.91)	0.60 (0.47; 0.71)
Alternating hand movements (D)	1.00 (0.99; 1.00)	0.98 (0.96; 0.99)	0.61 (0.47; 0.71)
CAMs (ND)	1.00 (0.99; 1.00)	0.94 (0.84; 0.98)	0.53 (0.38; 0.65)
Alternating hand movements (ND)	0.99 (0.98; 1.00)	0.98 (0.94; 0.99)	0.67 (0.54; 0.76)
CAMs (D)	0.98 (0.95; 0.99)	0.92 (0.79; 0.97)	0.53 (0.37; 0.65)
Repetitive finger movements (D)	0.96 (0.91; 0.99)	0.74 (0.46; 0.89)	0.59 (0.45; 0.70)
Repetitive finger movements (ND)	0.99 (0.97; 1.00)	0.72 (0.42; 0.88)	0.65 (0.52; 0.75)
Sequential finger movements (D)	1.00 (1.00; 1.00)	0.99 (0.97; 1.00)	0.68 (0.55; 0.77)
CAMs (ND)	1.00 (1.00; 1.00)	0.92 (0.79; 0.97)	0.45 (0.28; 0.59)
Sequential finger movements (ND)	0.99 (0.97; 1.00)	1.00 (0.99; 1.00)	0.67 (0.56; 0.77)
CAMs (D)	1.00 (1.00; 1.00)	0.82 (0.58; 0.93)	0.54 (0.38; 0.66)
Standing on one leg (eyes open) (D)	1.00 (1.00; 1.00)	0.99 (0.98; 1.00)	0.48 (0.30; 0.60)
Standing on one leg (eyes open) (ND)	1.00 (1.00; 1.00)	1.00 (0.99; 1.00)	0.44 (0.27; 0.58)
Standing on one leg (eyes closed) (D)	1.00 (1.00; 1.00)	0.96 (0.90; 0.98)	0.33 (0.15; 0.49)
Standing on one leg (eyes closed) (ND)	1.00 (1.00; 1.00)	1.00 (1.00; 1.00)	0.47 (0.31; 0.61)
Jumping sidewards	0.99 (0.99; 1.00)	0.99 (0.98; 1.00)	0.68 (0.56; 0.77)
Chair-rise	1.00 (1.00; 1.00)	0.99 (0.97; 0.99)	0.59 (0.44; 0.70)
Standing long jump	N/A	N/A	0.73 (0.61; 0.80)
Components			
Fine motor	1.00 (1.00; 1.00)	1.00 (0.99; 1.00)	0.78 (0.70; 0.85)
Pure motor	1.00 (1.00; 1.00)	0.93 (0.83; 0.97)	0.84 (0.77; 0.89)
Static balance	1.00 (1.00; 1.00)	0.99 (0.98; 1.00)	0.67 (0.54; 0.76)
Dynamic balance	1.00 (1.00; 1.00)	0.99 (0.99; 1.00)	0.78 (0.70; 0.85)
CAMs	1.00 (1.00; 1.00)	0.92 (0.82; 0.97)	0.81 (0.73; 0.86)
Total score (excluding CAMs)	1.00 (1.00; 1.00)	0.98 (0.94; 0.99)	0.84 (0.77; 0.89)
Total score (including CAMs)	1.00 (1.00; 1.00)	0.97 (0.92; 0.99)	0.84 (0.78; 0.89)

The reliability is quantified using the intraclass correlation (with 95% confidence intervals in brackets). D, dominant hand; CAMs, contralateral associated movements; ND, non-dominant hand; N/A, not applicable.

younger than 5 years, new tasks (turning bolts and threading beads) were added, and these are now integrated in the ZNA-2 for all children. Through these additions, we achieved a more challenging and reliable group of fine motor tasks.

The quantification of the duration and extent of CAMs, and therefore their intensity, is less objective than a time or distance measurement. Further, the decrease in CAMs with age is not the same for all items. Finally, CAMs are nearly non-existent in older children, thus creating a floor effect and causing unreliable test–retest measures. The CAMs component to be scored during some fine motor and pure motor tasks improved considerably on the earlier version of this component in the ZNA: test–retest reliability went from 0.66 to 0.81.[4] Additionally, when the CAMs are integrated in a summary score, test–retest reliability remains stable, with an intraclass correlation coefficient of 0.84.

In conclusion, the ZNA-2 provides new norm data for neuromotor development in children from 3 to 18 years of age. The ZNA-2 is able to grasp the large interindividual variation in motor proficiency. Children with superior motor performance and those with motor problems such as DCD may be detected. However, future studies should now be performed to examine its validity in clinical populations.

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SUPPORTING INFORMATION

The following additional material may be found online:

Appendix S1: Exact description of testing procedure and items.

Appendix S2: Statistical appendix.

REFERENCES

1. Largo RH, Caflisch JA, Hug F, et al. Neuromotor development from 5 to 18 years. Part 1: timed performance. *Dev Med Child Neurol* 2001; **43**: 436–43.
2. Largo RH, Caflisch JA, Hug F, et al. Neuromotor development from 5 to 18 years. Part 2: associated movements. *Dev Med Child Neurol* 2001; **43**: 444–53.
3. Seitz J, Jenni OG, Molinari L, Caflisch J, Largo RH, Latal Hajnal B. Correlations between motor performance and cognitive functions in children born <1250 g at school age. *Neuropediatrics* 2006; **37**: 6–12.
4. Rousson V, Gasser T, Caflisch J, Largo R. Reliability of the Zurich neuromotor assessment. *Clin Neuropsychol* 2008; **22**: 60–72.
5. Jenni OG, Chaouch A, Caflisch J, Rousson V. Correlations between motor and intellectual functions in normally developing children between 7 and 18 years. *Dev Neuropsychol* 2013; **38**: 98–113.
6. Henderson SE, Sugden DA, Barnett AL, Petermann F, Bös K, Kastner J. Movement Assessment Battery for Children - Second Edition (Movement ABC-2) - Deutschsprachige Adaptation. London, UK: Harcourt Assessment, 2007.
7. Folio M, Fewell R. Peabody Developmental Motor Scales-2. Austin, TX: PRO-ED, 2000.
8. Bruininks RH, Bruininks BD. Bruininks-Oseretsky Test of Motor Proficiency - Second edition (BOT-2). Minneapolis, MN: Pearson, 2005.
9. Largo RH, Rousson V, Caflisch JA, Jenni OG. Zurich Neuromotor Assessment. Zürich, Switzerland: AWE, 2007.
10. Kakebeeke TH, Caflisch J, Chaouch A, Rousson V, Largo RH, Jenni OG. Neuromotor development in children. Part 3: motor performance in 3- to 5-year-olds. *Dev Med Child Neurol* 2013; **55**: 248–56.
11. Lingam R, Hunt L, Golding J, Jongmans M, Emond A. Prevalence of developmental coordination disorder using the DSM-IV at 7 years of age: a UK population-based study. *Pediatrics* 2009; **123**: e693–700.
12. American Academy of Pediatrics. Developmental surveillance and screening infants and young children. *Pediatrics* 2001; **108**: 192–6.
13. Blank R, Smits-Engelsman B, Polatajko H, Wilson P, European Academy for Childhood Disability. European Academy for Childhood Disability (EACD): recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version). *Dev Med Child Neurol* 2012; **54**: 54–93.
14. Kakebeeke TH, Egloff K, Caflisch J, et al. Similarities and dissimilarities between the movement ABC-2 and the Zurich neuromotor assessment in children with suspected developmental coordination disorder. *Res Dev Disabil* 2014; **35**: 3148–55.
15. Kakebeeke TH, Knaier E, Köchli S, et al. Comparison between the Movement ABC-2 and the Zurich Neuromotor Assessment in preschool children. *Percept Mot Skills* 2016; **123**: 687–701.
16. Wei G, Tanner M. A Monte Carlo implementation of the em algorithm and the poor man's data augmentation algorithms. *J Am Stat Assoc* 1990; **85**: 699–704.
17. Ganzeboom HBG. A new international socio-economic index [ISEI] of occupational status for the international standard classification of occupation 2008 [ISCO-08] constructed with data from the ISSP 2002-2007, with an analysis of quality of occupational measurement in ISSP. Annual Conference of International Social Survey Programme; Lisbon, Portugal, 2010.
18. Konsortium PISA. OECD-PISA Programme for International Student Assessment. Bern and Neuchâtel, Switzerland: SBF/EDK, 2014.
19. Gasser T, Rousson V. Modelling neuromotor ratings with floor-effects. *Stat Med* 2004; **23**: 3641–53.
20. Cole TJ, Green PJ. Smoothing reference centile curves - the LMS method and penalized likelihood. *Stat Med* 1992; **11**: 1305–19.
21. Rigby RA, Stasinopoulos DM. Generalized additive models for location, scale and shape. *J Roy Stat Soc C* 2005; **54**: 507–44.
22. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull* 1979; **86**: 420–8.
23. Rousson V, Gasser T, Seifert B. Assessing intrarater, interrater and test-retest reliability of continuous measurements. *Stat Med* 2002; **21**: 3431–46.
24. Stodden DF, Goodway JD, Langendorfer SJ, et al. A developmental perspective on the role of motor skill competence in physical activity: an emergent relationship. *Quest* 2008; **60**: 290–306.
25. Holodynski M. The internalization theory of emotions: a cultural historical approach to the development of emotions. *Mind Cult Act* 2013; **20**: 4–38.
26. Naef N, Liamlahi R, Beck I, et al. Neurodevelopmental profiles of children with congenital heart disease at school age. *J Pediatr* 2017; **188**: 75–81.
27. Clark J, Philips SJ. A developmental sequence of the standing long jump. In: Clark J, Humphrey J, editors. Motor Development (volume 1). Princeton, NJ: Princeton Books, 1985: 73–85.
28. Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. *Am J Med* 1985; **78**: 77–81.