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Dissociated development of growth and skeletal robustness, and motor skills of preschool children

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Abstract

Background Lack of physical activity is associated with various health risks. Yet, instead of indulging their natural urge to move, the majority of today's preschool children tends to spend a substantial portion of the day in sedentary pursuit.

Objective To investigate patterns of motor skills related to age, body size and strength, or to dexterity and movement coordination.

Sample and Methods Eight anthropometric measurements and seven motor skill tests were performed in 144 boys and 120 girls aged 2.6 to 4.5 years. Children were measured in Berlin (Germany) in 2001/2002.

Results Anthropometric variables and motor skills are multiply interrelated. Yet, there is an almost complete lack of progress in several motor skills between the age of 2.6 and 4.5 years. The indicators of dexterity, such as one-legged stance and backward balancing, show children of all age groups who performed very poorly. . Standing long jump and running speed as indicators of gross physical strength were moderately connected with height ($r=0.48$ and $r=0.41$, $p<0.001$).

Conclusion Modern German preschool children show poor motor performance. The general pattern of motor skills that are related to dexterity and movement coordination and depend on practice and training, differ from those which depend on physical strength, such as standing long jump and running. The need for cooperation and mutual promotion of motor development by parents, physicians, and teachers, and the opening up of natural spaces to give room to the physiological urge to move for young children is evident.

Take home message for students Modern German preschool children show poor motor performance. The pattern of motor skills that is related to dexterity and movement coordination and depends on practice and training, differs from that which depends on physical strength, such as standing long jump and running.

Introduction

Children of preschool age tend to grow without major growth spurts and to tightly track in height, weight, and body mass index (BMI) (Mei et al. 2004). Between the age of 24 and 60 months, only some 2% to 10% of the healthy children cross 2 major centiles in height, 1% to 5% cross 2 major centiles in weight, and 6% to 15% cross 2 major centiles in BMI. Children also improve in fundamental motor skills, but unlike physical growth, improving motor skills requires practice. Motor skills have major impact on physical activity and lifestyle (Williams et al. 2008). Lack of physical activity in youth is associated with subsequent risk of osteoporosis, bone injuries (Landry and Driscoll 2012; Rietsch et al. 2013), and bone related health problems (Ireland et al. 2016; Gunter et al. 2012), it raises the disposition for overweight and obesity (Kurth and Schaffrath Rosario 2010; Schaffrath Rosario et al. 2010), and diminishes skeletal robustness (Rietsch et al. 2013).

However, instead of parental support allowing children to indulge their natural urge to move and to freely practice and improve motor skills, the majority of today's preschool children tends to spend a substantial portion of the day in sedentary pursuit (Tucker et al. 2015). This goes hand in hand with declining motor competence as observed in recent decades (Henderson and Henderson 2003).

Of the few studies that provide modern references for motor skills of preschool children (Brown and Lalor 2009; Griffiths et al. 2018; Henderson and Geuze 2015; Henderson and Henderson 2003; Lam and Henderson 1987; Petermann et al. 2011; Petermann et al. 2015; Petermann and Kastner 2008; Schulz et al. 2011; Smits-Engelsman et al. 2011; Wagner et al. 2011; Zoia et al. 2019) the "Movement Assessment Battery for Children 2" (M-ABC-2), and in Germany, the "Entwicklungstest 6 Monate bis 6 Jahre" (developmental test for age 6 months to 6 years; ET 6–6-R) are the most preferred ones (Koglin et al. 2013; Koglin et al. 2015; Petermann and Macha 2015). Both tests focus on the "standard" development at specific ages with centiles for developmental milestones such as walking and jumping, balancing, running, climbing and skipping (Petermann et al. 2011; Petermann et al. 2015). They offer test procedures that can be carried out not only by professional assessors, but also by non-trained personnel (e.g., parents).

The aim of the present study was to analyze the development of motor skills of preschool children living in modern urban environment, to confirm the presence of obvious milestones as suggested by currently used references, and to compare the progress in dexterity with the general progress in growth and skeletal robustness. We hypothesized that the general developmental pattern of those motor skills that are related to the incremental tracking pattern of body size and strength, such as standing long jump and running, differs in modern children from those motor skills which are more related to dexterity and movement coordination, such as one-legged stance and balancing.

Sample and Methods

Eight anthropometric measurements and seven motor skill test procedures were performed in 264 healthy children (144 boys, 120 girls) aged 2.6 to 4.5 years. Details of this study cohort have been published previously (Ketelhut et al. 2004; Scheffler et al. 2004; Scheffler et al. 2007; Schilling).

In short, the anthropometric measurements of body height, weight, BMI, triceps

skinfold (skinf), elbow breadth (elbBr), mid-upper arm circumference (MUAC), upper arm muscle area (AMA=[MUAC-(skinf*π)]^2/(4*π)), and frame index (frame index = elbBr/height) (Frisancho 1993) were performed using standard routines as described by Knußmann (Knußmann 1988). Motor skills were tested by: right/left one-legged stance (given in seconds), balancing forward and backward (maximum distance reached in centimeters), standing long jump (given in centimeters), time needed for a 6-meter run (given in seconds) and the "lateral transfer" (given in number of movements) (Scheffler et al. 2004). The "lateral transfer" was used to test overall body coordination. The children were given two boards. The task was to first step onto one board. Thereafter, the child had to use both hands to lift the board next to it and put it down again on the other side of the body. The child then had to move onto the "new" board and move the board that had become free again. The children should repeat this sequence of movements as quickly as possible within 20 seconds.
The M-ABC-2 test (Petermann et al. 2015; Petermann et al. 2011) (and the ET 6–6-R (Petermann and Macha 2015) references were used to evaluate the performance of the present study population.
The interactions between the anthropometric variables and motor skill tests were analyzed by St. Nicolas House Analysis (SNHA) (Hermanussen et al. 2021). This is a parameter free approach, which finds direct interactions between multiple variables. The SNHA ranks the absolute correlation coefficients in descending order and thereby creates hierarchic, so-called, association chains. Association chains are characterized by sequences for which a reversing start and endpoint does not change the order of the elements. These sequences are used to visualize dependencies of the underlying variables as a graph by connecting them via undirected edges.
Linear regression model (lm) was used to demonstrate the regression of all motor skill tests and age.
All calculations were performed using the statistical program R "Version R 4.3.1".

Results

As the tested motor skills did not significantly differ between boys and girls, both sexes were combined. Table 1 summarizes mean values and standard deviations of seven motor skills and the anthropometric variables.
Anthropometric variables and motor skills are multiply interrelated. Applying SNHA illustrated the natural association between weight, BMI, and skinfolds, as well as skeletal robustness and muscle mass as mirrored by elbow breath, frame index and AMA (Figure 1). The figure illustrates the interactions among the anthropometric variables and its association via weight and height, with the seven motor skills that were also interconnected among themselves. Standing long jump and running speed as indicators of physical strength were moderately connected with height ($r=0.48$ and $r=0.41$, $p<0.001$), whereas backward balancing and one-legged stance that rather reflect coordination, were directly associated with age, though the latter correlations appeared weak ($r=0.25$ and $r=0.26$, $p<0.001$).
Right one-legged stance (rLeg), left one-legged stance (lLeg), forward balancing (fBal), backward balancing (rBal), standing long jump (jump), lateral transfer (transf), and the time for a 6-meter run (speed), height (heigh), weight (weigh), BMI, triceps skinfold (skinf), elbow breadth (elbBr), upper arm circumference (MUAC), upper arm muscle area (AMA), and frame index.

Two sections are visible that connect via height and weight, weight being associated with the anthropometric variables, height being associated with age and the motor skills.

Figure 2 shows the correlation matrix. The figure again highlights the two sections: anthropometric variables and motor skills, both connected via weight and height. The green rectangle emphasizes the lack of association between physical maturity (height and particularly weight) and the motor skills that require training and coordination (one-legged stance and balancing). Figure 3 provides scattergrams and visualizes the almost complete lack of progress in motor skills between the age of 2.6 and 4.5 years. Except for standing long jump (adj.$R^2 = 0.149$, $p<0.001$) that seems to slightly ameliorate with increasing age, the ability for one-legged stance, balancing, and running speed shows a bedrock of children who perform very poorly at all ages and with almost no success in these tasks up to the age 4 years. The same applies for lateral transfer with a small number of children with better results after age 3.5 (adj. $R^2 = 0.128$, $p<0.001$).

Discussion:

In general, the performance of the motor skill tests of the children in this study lacked an obvious association with age and was significantly poorer than suggested by the “Movement Assessment Battery for Children 2” (M-ABC-2), and the “Entwicklungstest 6 Monate bis 6 Jahre” (ET 6–6-R)

Table 1 Mean and median values, standard deviations (SD), minimum and maximum of seven motor skills and the anthropometric measurements of children aged 2.6 to 4.5 years (measures of motor skills: right one-legged stance (rLeg), left one-legged stance (lLeg), forward balancing (fBal), backward balancing (rBal), standing long jump (jump), lateral transfer (transf), and the time for a 6-meter run (speed); anthropometric variables: height, weight, BMI, triceps skinfold (skinf), elbow breadth (elbBr), upper arm circumference (MUAC), upper arm muscle area (AMA), and frame index.)

	Sexes combined					boys		girls	
	mean	median	SD	min	max	mean	SD	mean	SD
age (years)	3.54	3.59	0.35	2.63	4.51	3.53	0.34	3.54	0.36
rLeg (sec)	3.41	2.47	3.07	0.50	18.53	3.31	2.96	3.54	3.21
lLeg (sec)	4.15	2.61	4.36	0.50	32.69	4.01	4.54	4.31	4.14
fBal (sec)	184.23	200.00	38.01	20.00	200.00	184.85	37.47	183.44	38.84
rBal (sec)	74.82	57.50	55.26	0.00	200.00	75.66	54.39	73.80	56.65
jump (cm)	50.82	51.50	18.69	5.00	93.00	52.80	19.08	48.44	18.02
transf (n)	5.20	5.00	1.66	1.00	13.00	5.16	1.76	5.25	1.55
speed (sec)	2.79	2.70	0.50	2.00	6.01	2.75	0.50	2.84	0.51
height (cm)	100.34	99.80	4.96	89.30	113.40	101.03	4.80	99.48	5.05
weight (kg)	16.31	16.00	2.28	12.30	23.10	16.71	2.30	15.82	2.16
BMI (kg/m^2)	16.11	16.02	1.29	13.23	20.68	16.29	1.28	15.89	1.27
skinf (mm)	9.15	8.93	2.11	5.20	15.73	9.01	1.93	9.33	2.31
elbBr (cm)	4.22	4.20	0.31	3.50	5.10	4.32	0.30	4.10	0.29
MUAC (cm)	15.54	15.30	1.15	12.40	18.80	15.60	1.07	15.48	1.24
AMA (cm^2)	12.58	12.58	1.10	0.55	14.69	12.61	1.34	12.54	0.68
frame index	42.07	42.17	2.47	35.53	48.57	42.75	2.38	41.22	2.33

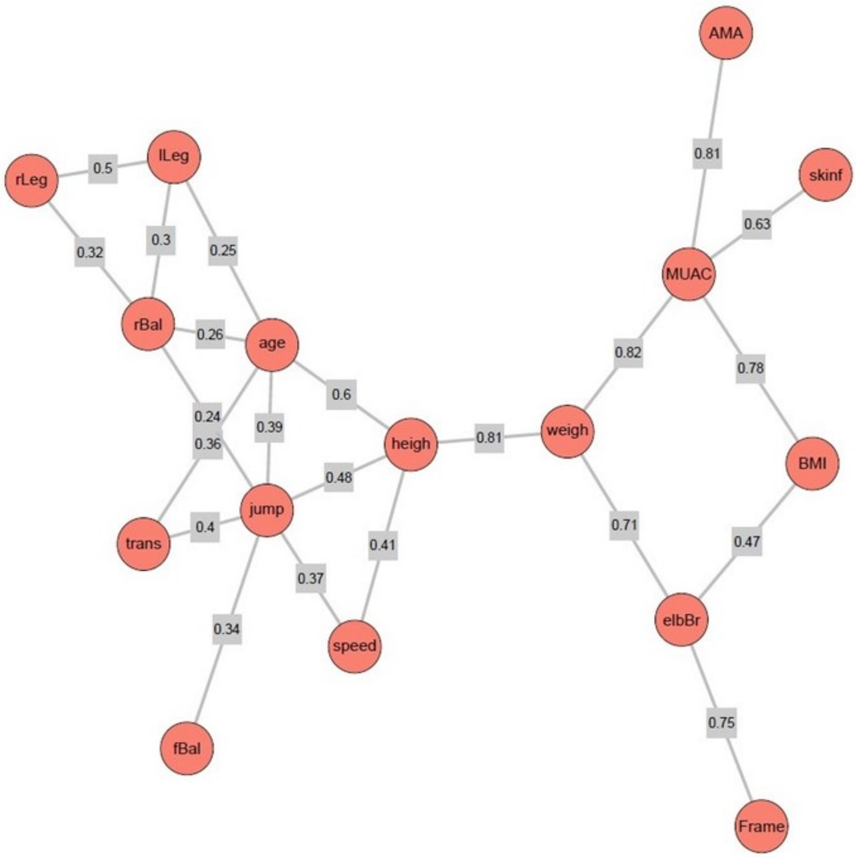

Figure 1 St. Nicolas House Analysis (SNHA) of the multiple interactions between anthropometric variables, age, and motor skills, in German children aged 2.6 to 4.5 years.

(Koglin et al. 2013; Koglin et al. 2015; Petermann and Macha 2015) (data not shown in detail).

Contrary to the basic concept of early developmental milestones that are well-known for freely sitting, crawling, and walking, the more complex motor skills of later age like balancing and one-legged stance depend on practice and exercise. None of these tasks appeared to pass a certain "milestone age" or critical developmental step after which the performance reached a new level of perfection. In a majority of children, the ability to stand on one leg and to balance backward did not occur up to the age of four years. Only balancing forward appeared easier as almost all children beyond age three years were able to do so. Only the motor skills that are related to physical strength and skeletal robustness such as running and jumping show minor associations with height and weight, but also lack an obvious age-pattern.

The data support our hypothesis that the developmental pattern of motor skills related to dexterity and movement coordination such as one-legged stance and balancing, differs from the incremental tracking pattern of body size, and also from skills such as standing long jump and running that are more related to gross physical strength and robustness.

The children in the present study showed significant failure in coordination and motor skills even below the currently used M-ABC-2 and the ET 6–6-R references. Our findings are in line with the general perception that across the Western world, coordination and motor skills have declined (Tester et al. 2014). The question is: does it matter? Coordination depends on training (Wu and Latash 2014). As the

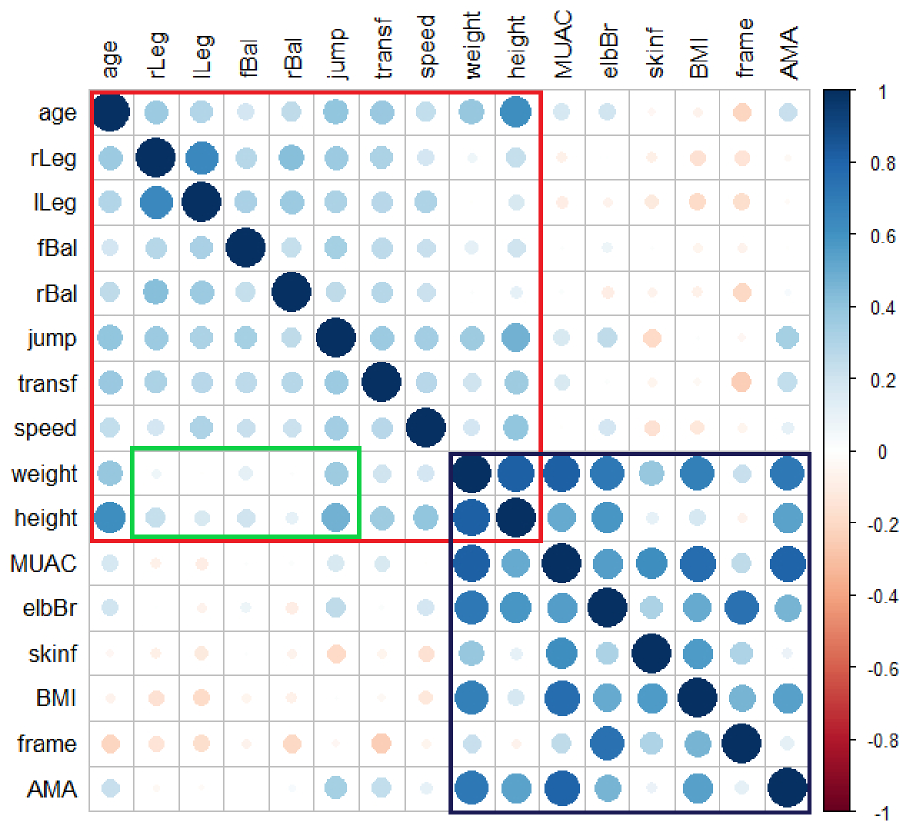

Figure 2 The correlation matrix of anthropometric measurements and motor skills of 2.6 to 4.5 year old German childrens. The three rectangles encompass (1) the section age, motor skills and the anthropometric variables weight and height (red); (2) the section weight and height, and the other anthropometric variables (blue); and (3) the lack of association [all r<0.21, and p>0.01] between weight and height on the one hand, and one-legged stance and balancing as the indicators of body coordination on the other hand (green).

M-ABC-2 and the ET 6–6-R tests are among the most frequently used tests for assessing motor deficits in children and often used for clinical purposes (Brown and Lalor 2009; Dathe et al. 2020; Schulz et al. 2011; Wagner et al. 2011; Zoia et al. 2019) the question raises: do these tests still represent the motor skills of today's children? The results of the present study certainly question that these tests are still representative. We found many children with motor performances at age four that do not differ from those at age two. The lack of congruence between expected "reference" motor performance and currently used references is obvious. But, we question any demand for updating these references as suggested by Henderson and Geuze (Henderson and Geuze 2015). Updating references would somehow "normalize" the serious lack of motor performance of today's children and will weaken the perception of their inadequate motor competence.

Possible causes for the decline in physical activity and the significant deterioration in preschool children's motor skills need to be scrutinized. Increased electronic device usage (Landry and Driscoll 2012; Moss and Gu 2022; Rietsch et al. 2013; Robinson et al. 2012) and the major increase in media consumption should be considered (Pawellek et al. 2022). But parents also need to be advised, as their exercise behaviour sets examples for their children (Landry and Driscoll 2012).

Daily physical activity is a critical factor in practicing motor function (Landry and Driscoll 2012; Musalek et al.) and secondary, in enhancing strength, and skeletal growth and robustness (Rietsch et al. 2013). Regular and long-term physical activity is needed for developing full motor

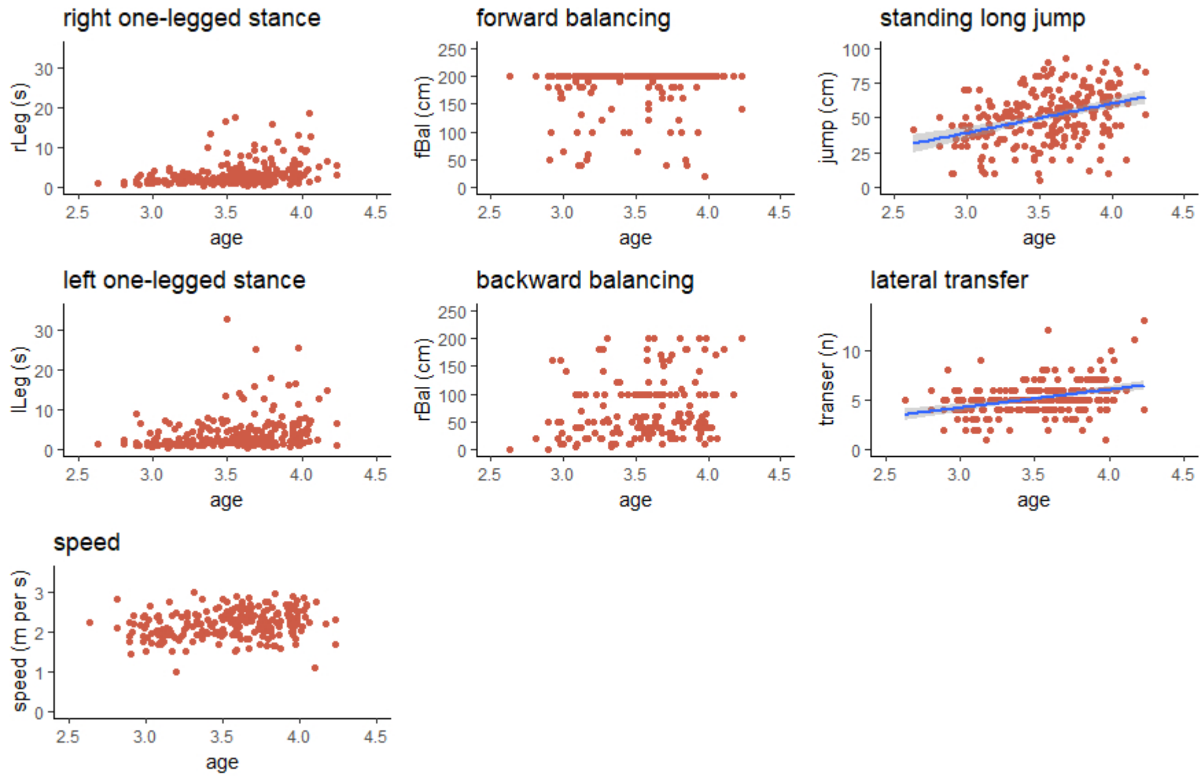

Figure 3 Scattergrams of motor skills depending on age showing the progress of one-legged stance (rLeg: adj. R^2 = 0.091, p<0.001 , lLeg: adj.R^2 = 0.056, p<0.001), balancing (fBal: adj.R^2 = 0.013, p<0.045, rBal: adj.R^2 = 0.033, p<0.006), standing long jump (jump: adj.R^2 = 0.149, p<0.001) lateral transfer (trans: adj.R^2 = 0.128, p<0.001), and the time needed for a 6-meter run (speed: adj.R^2 = 0.048, p<0.004) in German children aged 2.6 to 4.5 years.

competence and needs to be supported by parents, physicians, and teachers (Hesketh et al. 2017; Jeong et al. 2021; Lucas et al. 2016; Zeng et al. 2017). Sufficient levels of permanent physical activity are required for achieving later health and motor benefits (Twisk 2001), and have been shown to also contribute to mental health (Ferreira et al. 2020). The need for cooperation and mutual promotion of motor development and particularly the opening up of natural spaces to give room to the physiological urge to move of young children is evident (Booth et al. 2015; Tremblay et al. 2014).

Conlusion:

German preschool children show poor motor performance as early as 2001/2002. Contrary to the basic concept of developmental "milestones", motor skills related to dexterity and movement coordination, such as standing on one leg and balancing, are dependent on practice and training. Their occurrence differs from those that are more related to gross physical strength, such as standing long jump and running.

We caution against updating currently used motor references as this could "normalise" the poor motor performance of modern children and weaken the perception of their inadequate motor competence.

The need for cooperation and mutual promotion of motor development by parents, physicians, and teachers, and particularly the opening up of natural spaces to give room to the physiological urge to move of young children is evident.

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