

Longitudinal Association of Motor Development and Body Weight in Elementary School Children—A 4-Year Observational Study

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Abstract

The inverse association between body weight and physical fitness has been well documented but there remains limited information on the association of weight change with the development of physical fitness, particularly in elementary school children. The present study, therefore, examined the association between change in weight status and the development of physical fitness from the ages 6 to 10 years in 301 Austrian children (55.1% male). Body weight and height were measured according to standard procedures and physical fitness was assessed via the German motor test (DMT 6 - 18) at baseline and 4-year follow-up. Overweight/obesity was determined using the 90th BMI percentile at each measurement time and children were classified as always normal weight, always overweight/obese, weight gainers (transition from normal weight to overweight/obese) and weight losers (transition from overweight/obese to normal weight). The majority of children (80.1%) maintained normal weight while 7.9% were considered overweight/obese throughout the observation period. A total of 10.3% were classified as weight gainers and only 1.7% were considered weight losers. Weight gainers and those who were overweight/obese throughout the observation period displayed lower improvements in physical fitness, except for flexibility, compared to those who maintained normal weight. Of particular concern is the lack of improvement in cardiorespiratory fitness in weight gainers and overweight/obese children during the elementary school years. Given the detrimental effects of excess body weight on the development of physical fitness,

preventive measures that emphasize a healthy body weight and facilitate physical activities that enhance physical fitness should start at young age.

Keywords

Physical Fitness, Overweight, Obesity, Weight Change, Cardiorespiratory Endurance, Muscular Strength, Youth

1. Introduction

Physical activity and motor development are considered key determinants of health and general well being during childhood and adolescence (Andersen et al., 2017; Dencker et al., 2006; Janssen & Leblanc, 2010). Available evidence, however, indicates a decline in motor competence and physical fitness (Bös, 2003; Roth et al., 2010; Tomkinson & Olds, 2007), which is associated with low physical activity as well as excess body weight (Graf et al., 2004; Hardy, Reinten-Reynolds, Espinel, Zask, & Okely, 2012; Morgan, Okely, Cliff, Jones, & Baur, 2008). Motor competence and physical fitness during childhood and adolescence has also been associated with physical activity levels across the life course, and is considered an important component in the promotion of an active and healthy lifestyle (Loprinzi, Davis, & Fu, 2015). The school years, therefore, represent an important sensitive time window to establish a healthy and active lifestyle with the elementary school years appearing particularly important for motor development (Augste & Jaitner, 2010).

Despite the importance of physical activity for general development and well-being, a majority of children is considered insufficiently active (Greier, Drenowatz, Ruedl, & Riechelmann, 2019; Kaiser-Jovy, Scheu, & Greier, 2017; Strong et al., 2005; Tremblay et al., 2016), which may have contributed to the high prevalence of overweight and obesity along with low physical fitness in youth (Blüher et al., 2011; Ng et al., 2014). Various studies also reported an inverse association between body weight and physical fitness, but these studies were predominantly cross-sectional in nature (Barnett et al., 2016; Castetbon & Andreyeva, 2012; Fogelholm, Stigman, Huisman, & Metsämuuronen, 2008; Greier, Riechelmann, & Burtscher, 2014; Ruedl, Greier, Kirschner, & Kopp, 2016). Longitudinal studies showed lower physical fitness and impaired motor development with excess body weight, particularly in dynamic tasks that require the management of the own body weight (Albrecht, Hanssen-Doose, Oriwol, Bös, & Worth, 2016; Ruedl et al., 2018). Most studies, however, focused predominantly on the association between cardiorespiratory endurance and body weight while the association with other aspects of physical fitness, including strength, power, speed, agility, balance and flexibility, is less studied. Longitudinal studies also focused predominantly on adolescents (Augste, Lämmle, & Künzell, 2015; Drenowatz & Greier, 2019; Greier & Drenowatz, 2018) while data on the prospective association between body weight and physical fitness as well

as motor competence during the elementary school years remains sparse, particularly in Austria. The intention of the present study, therefore, was to provide longitudinal data that examines the interaction between change in body weight and the development of various components of physical fitness and motor competence over a 4-year period in Austrian elementary school children.

2. Materials and Methods

A total of 15 elementary schools in the federal state of Tyrol, Austria were randomly selected for participation and received information about this 4-year longitudinal study. One school declined to participate due to organisational problems, resulting in a final sample of 14 schools. Due to the longitudinal nature of the study, only 1st grade students were eligible for participation, which resulted in 392 potential participants. Written informed consent was obtained from parents of participating children. Children provided oral assent at the time of data collection. The study protocol was approved by the Institutional Review Board of the University of Innsbruck, the school authorities of the federal state of Tyrol and by the school board of each participating school. All study procedures were performed according to the ethical standards of the 2008 Declaration of Helsinki.

Baseline data collection occurred during the school entry evaluation in October 2014 in first grade students of the participating schools. Follow-up measurements were taken towards the end of the elementary school time in June 2018 in children attending 4th grade. All measurements were performed by trained technicians in the participating schools gymnasium during regular class time.

Body weight (kg) and height (cm) were measured with children wearing gym clothes and barefoot. Specifically, body weight was measured with a calibrated digital scale (SECA® 803, Hamburg, Germany) to the nearest 0.1 kg and height was measured with a portable stadiometer (SECA® 217, Hamburg, Germany) to the nearest 0.1 cm. Body mass index (BMI) was calculated (kg/m^2) and weight status was determined based on German reference values using the 90th BMI percentile as cutpoint for overweight/obesity (Kromeyer-Hauschild et al., 2001). Subsequently children were stratified based on change in weight status from baseline to follow-up in 4 weight development groups. Children who were normal weight at baseline and overweight/obese at follow-up were considered weight gainers, while those who changed from overweight/obese to normal weight were considered weight losers. Those who maintained their weight status were classified as either normal weight or overweight/obese (Figure 1).

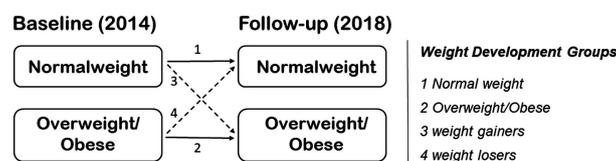


Figure 1. Establishment of “weight development groups”; based on Albrecht et al. (2016).

The German motor test (DMT 6 - 18) was used to assess physical fitness (Bös et al., 2009). The DMT is a widely used and validated fitness test that assesses major components of physical fitness. It consists of 8 test items that assess muscular strength, muscular endurance, cardiovascular endurance, speed, power, agility, balance and flexibility. Specifically, participants performed a 20 m sprint, sideways jumping, backward balance, pushups, standing long-jump, sit ups, stand-and-reach tests and a 6-minute run after a standardized 5-minute warm up. Tests were performed in random order over a 90-minute period, except for the 20 m sprint, which was performed at the beginning and the 6-minute run, which was performed at the end of the test session. Participants received specific instructions and performed practice trials prior to measuring raw performance scores as specified by the test manual (Bös et al., 2009). The 20 m sprint was performed from a standing position at the starting line. Sideways jumping consisted of jumping back and forth across a line at maximum speed for 15 seconds. Backwards balance was performed across a 6 cm, 4.5 cm and 3 cm wide bar with children trying to complete as many steps as possible. Pushups and sit ups were performed over a period of 40 seconds. During sit ups hands were placed at the shoulders and the upper body needed to be lifted until the elbows touched the knees. For Pushups, participants started lying on the ground with hands on their back; in order to ensure complete extension of the elbow during each attempt one hand had to be removed from the floor at the end of each push up. The standing long jump was performed using a counter-movement jump motion (including the arms) with children being required to land on their feet and not reaching back with their hands. The stand-and-reach test was conducted with children standing on a bench and slowly moving their fingers along a measurement scale, while keeping their knees fully extended. Distance from the toes was measured with positive values indicating reaching beyond the toes and negative values indicating not reaching the toes. For the 6-minute run children completed as many laps as possible within the time given. Children were allowed to walk in case of fatigue and received information on the time remaining every minute.

Change in physical fitness was calculated as the difference between follow-up and baseline measurements in order to evaluate individual change throughout the observation period.

Statistical Analysis

Data was checked for normal distribution and data is shown as means with standard deviation. Differences in change in physical fitness across weight development groups were examined via ANCOVA, adjusting for school and baseline performance with Bonferroni adjustment for post-hoc tests. A second analysis included sex as additional covariate. All statistical tests were performed using SPSS 26.0 (Armonk, NY, USA) with the significance level set at $\alpha < 0.05$ and Bonferroni adjustment for multiple comparisons.

3. Results

Of the 392 participants measured at baseline, 301 children (55.1% male) provided data at 4-year follow-up. There were no significant differences in baseline characteristics between children with missing follow-up measurements and those included in the analysis. There were also no differences in age, sex distribution, BMI, weight status and weight change across participating schools. Children were 6.4 ± 0.5 years of age at baseline and 9.9 ± 0.6 years at follow-up. No sex differences were observed for age, but boys were significantly taller and heavier at each measurement time ($p < 0.05$). Nevertheless, BMI and prevalence of overweight/obesity did not differ between boys and girls. A total of 17 and 19 children were considered underweight at baseline and follow-up, respectively. Of those considered underweight at baseline 5 were classified as normal weight at follow-up while 7 participants changed from normal weight at baseline to being underweight at follow-up. There was no transition from underweight to overweight/obese in either direction over the 4-year observation period. The prevalence of overweight/obese, however, almost doubled from 9.6% at baseline to 18.3% at follow-up (Table 1).

Of the total sample 80.1% of the participants maintained normal body weight throughout the observation period and 7.9% were considered overweight/obese at both measurement times. A change from normal weight to overweight/obese occurred in 10.3% of the participants while only 1.7% of overweight/obese participants at baseline changed to normal weight at follow-up. There was no significant sex difference across the weight development groups (Table 2).

Table 1. Anthropometric characteristics at baseline and follow-up for the total sample and separately for boys and girls. Values are Mean \pm standard deviation ($n = 301$).

	Baseline (2014)			Follow up (2018)		
	boys	girls	total	boys	girls	total
Age (years)	6.4 \pm 0.5	6.4 \pm 0.5	6.4 \pm 0.5	9.9 \pm 0.6	9.8 \pm 0.6	9.9 \pm 0.6
Height (cm) ^{1,2}	123.4 \pm 5.8	121.2 \pm 5.3	122.4 \pm 5.7	143.4 \pm 6.8	141.5 \pm 7.0	142.6 \pm 6.9
Weight (kg) ^{1,2}	24.8 \pm 4.5	23.5 \pm 4.2	24.2 \pm 4.4	38.2 \pm 9.1	36.1 \pm 8.5	37.3 \pm 8.9
BMI (kg/m ²)	16.2 \pm 2.0	15.9 \pm 2.0	16.1 \pm 2.0	18.4 \pm 3.5	17.9 \pm 3.2	18.2 \pm 3.4
OW/OB, n (%)	19 (11.4)	10 (7.4)	29 (9.6)	32 (19.3)	23 (17.0)	55 (18.3)

Table 2. Description of the 4 “weight development groups” ($n = 301$).

Weight development groups	boys n (%)	girls n (%)	total n (%)
normal weight	132 (79.5)	109 (80.7)	241 (80.1)
overweight	17 (10.2)	7 (5.2)	24 (7.9)
weight gainer	15 (9.0)	16 (11.9)	31 (10.3)
weight loser	2 (1.2)	3 (2.2)	5 (1.7)

Normal weight children at baseline performed significantly better at balancing and the 6-minute run than their overweight/obese peers ($p < 0.01$). Further, it was shown that normal weight children at baseline, who gained weight throughout the 4-year observation period had a lower performance at the 6-minute run compared to those who maintained normal weight (**Table 3**). These results remained essentially unchanged after controlling for school and sex.

Table 3. Motor performance at baseline across the 4 weight development groups. Values are Mean \pm standard deviation (n = 301).

	Normal Weight	Weight Gainer	Weight Loser	Overweight
Sit ups (reps in 40 sec)	15.1 \pm 5.6	16.2 \pm 5.1	11.4 \pm 6.8	13.9 \pm 6.5
Pushups (reps in 40 sec)	11.8 \pm 3.7	11.4 \pm 3.5	9.6 \pm 3.0	11.0 \pm 3.4
Side Jumps (reps in 15 sec)	23.1 \pm 5.8	22.9 \pm 6.2	19.7 \pm 4.0	22.8 \pm 5.6
Balance (steps) ^{1,2}	27.0 \pm 9.9	29.0 \pm 9.1	26.4 \pm 10.1	20.8 \pm 8.5
6 minute Run (m) ^{1,3}	874 \pm 132	791 \pm 150	782 \pm 148	745 \pm 134
20 m Sprint (sec)	4.8 \pm 0.5	4.8 \pm 0.5	4.7 \pm 0.6	4.9 \pm 0.4
Longjump (cm)	114.4 \pm 17.9	111.3 \pm 17.1	109.8 \pm 19.1	109.8 \pm 17.9
Stand-Reach (cm)*	0.7 \pm 5.6	2.2 \pm 5.9	1.0 \pm 3.2	-0.1 \pm 5.5

Even though performance at the individual fitness tests improved in the total sample, except for flexibility, which remained stable, there were significant differences in the development of physical fitness across weight development groups. In general, mean improvement over time was more pronounced in participants who maintained normal weight throughout the observation period and those who lost weight compared to participants who were overweight/obese throughout the observation period or weight gainers. There was no difference in change in physical fitness between weight gainers and always overweight/obese participants. Both, weight gainers and those who were overweight/obese throughout the observation period had significantly lower improvement than those who maintained normal weight for sit ups, pushups, standing long jump, sideways jumping ($p < 0.01$) as well as the 6-minute run and balance ($p < 0.05$) (**Figure 2** and **Figure 3**). It was further shown that 6-minute run performance improved significantly only in participants who maintained normal weight or lost weight, while weight gainers and those who were always overweight/obese maintained their baseline performance throughout the elementary school years.

Weight gainers also showed a significantly lower improvement in the 20 m sprint compared to participants who were always normal weight ($p = 0.03$). No significant differences across weight development groups were observed for flexibility (**Figure 3**). The results remained essentially unchanged after additionally adjusting for sex.

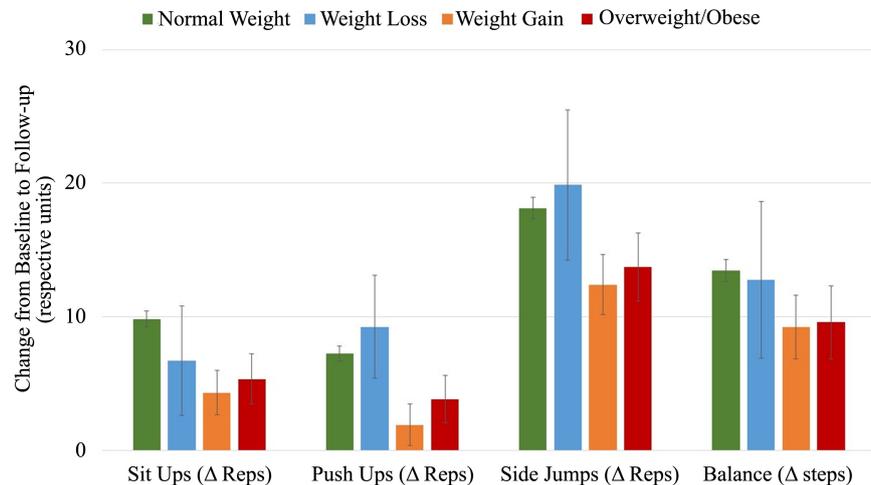


Figure 2. Change in physical fitness from baseline to follow-up across weight development groups. Values are Mean change, adjusted for school and baseline performance with 95% Confidence Interval. Reps... repetitions; Δ ... Change over 4-year observation period.

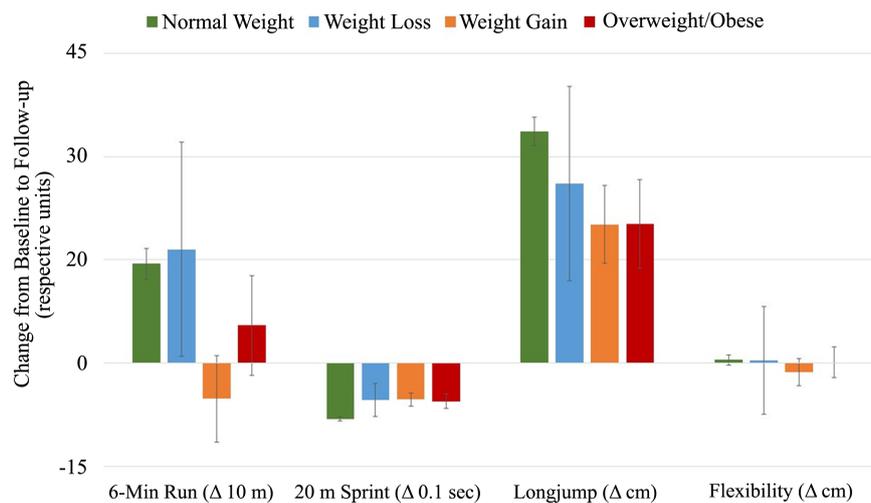


Figure 3. Change in physical fitness from baseline to follow-up across weight development groups. Values are Mean change, adjusted for school and baseline performance with 95% Confidence Interval. Δ ... Change over 4-year observation period.

4. Discussion

This study evaluated the influence of body weight on the development of various components of physical fitness in 301 elementary school children in Tyrol, Austria. Data showed that almost 10% of children entering elementary school were considered overweight/obese and the prevalence of overweight/obesity almost doubled during the elementary school years. In addition, this study showed that increased body weight and excessive weight gain impair the development of cardio-respiratory endurance, strength, power, speed, agility, and balance during the elementary school years. While performance across various fitness tests is expected to increase during the elementary school years as a result of physical growth and biological maturation (Malina, Bouchard, & Bar-Or, 2004), children

with excess weight gain and those who were always overweight/obese displayed significantly lower improvements in physical fitness compared to normal weight children. Participants, who lost weight and transferred from being overweight/obese to normal weight, on the other hand, showed a comparable development of physical fitness as children with normal body weight throughout the study period. Weight loss was further associated with a significantly greater improvement in push-ups compared to children with excess weight gain. Only the development of flexibility was not associated with weight development during the elementary school years.

Of particular concern is that there was no significant improvement in cardiorespiratory endurance in children with excess weight gain and those who were overweight/obese throughout the observation period. Due to the association with various health risk factors, independent of socio-demographic factors, diet and physical activity, cardiorespiratory fitness is a key contributor to general health and well-being (Andersen et al., 2006; Hurtig-Wennlöf, Ruiz, Harro, & Sjöström, 2007). Accordingly, cardiorespiratory fitness has been suggested to be included as a health indicator in children and adolescents (Andersen et al., 2015). Due to growth and biological maturation cardiorespiratory fitness should increase during childhood and into adolescence (Eisenmann, Laurson, & Welk, 2011; Malina et al., 2004). Nevertheless, adequate stimuli, such as physical activities of sufficient intensity, are necessary to ensure biological adaptations associated with increased cardiorespiratory fitness (Rowland, 1996). Physical activities of higher intensity have also been associated with greater benefits for various health outcomes compared to total physical activity (Strain et al., 2020). Excess body weight, however, potentially limits the motivation or hinders the ability to engage in physical activities of higher intensity. Accordingly, available evidence suggests that weight status influences efforts to increase cardiorespiratory fitness (Peralta, Henriques-Neto, Gouveia, Sardinha, & Marques, 2020).

Previous studies also showed an inverse association between excess weight gain and other components of physical fitness (Aires et al., 2010; Albrecht et al., 2016; Graf et al., 2007; Graf et al., 2004; Greier & Drenowatz, 2018). This may at least partially be attributed to lower physical activity levels and higher sedentary time in overweight/obese children compared to their normal weight peers (Abbott & Davies, 2004; Gillis, Kennedy, & Bar-Or, 2006; Page et al., 2005), which may hinder their development of physical fitness. As low physical fitness most likely impairs engagement in sports and other forms of physical activity, there is a high risk of a vicious cycle of weight gain and low physical fitness that starts already at a young age (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). During the elementary school years children with overweight or obesity are at increased risk to be outperformed by their normal weight peers (Augste & Jaitner, 2010), which may lead to withdrawal from physical activities and increase the risk for various chronic diseases (Martins et al., 2010). Low physical fitness along with withdrawal from physical activities also increases the risk for depression and anxiety (Biddle & Asare, 2011; Lang et al., 2018; Ortega, Ruiz, Castillo, & Sjöström,

2008) and affects cognitive and academic performance (Haapala, 2013; Santana et al., 2017). This detrimental association of insufficient physical activity, low physical fitness and poor motor competence has also been referred to as physical inactivity triad, which represents a major threat to future public health (Faigenbaum, Rebullido, & MacDonald, 2018).

The results of the present study in a previously understudied population of Austrian children, therefore, emphasize the importance of early preventive measures to avoid excess weight gain during childhood, which should incorporate physical activities that promote the development of physical fitness and motor competence. Even though environmental facilitation is an important aspect in the promotion of physical activity (Kaiser-Jovy et al., 2017), physical fitness and motor competence are also crucial components in the promotion of an active lifestyle (Drenowatz & Greier, 2018b). Accordingly, a recent study reported that almost 90% of children with low motor competence are insufficiently active (De Meester et al., 2018). As childhood physical activity forms the foundation for a sustainable engagement in various activities throughout adolescence and into adulthood (Telama et al., 2014), schools provide an ideal setting in addition to club sports to enhance physical fitness that facilitates participation in a wide range of physical activities. Physical education, therefore, has been suggested to be an important contributor to the development of physical fitness, particularly in children (Chen, Kim, & Gao, 2014; Institute of Medicine (IOM), 2013; Peralta et al., 2020). An improvement in physical fitness and motor competence, however, requires deliberate practice in addition to free play. Of particular importance for the improvement of physical fitness is to ensure sufficient intensity and it has been shown that traditional PE relying predominantly on free play may lack the necessary intensity increase physical fitness (Peralta et al., 2020). In addition, children should engage in age-adequate exercises targeting muscular strength, which also emphasizes the need for well-trained personnel (Faigenbaum & Bruno, 2017). Physical activities targeting muscular strength may also be more appealing to children with excess body weight compared to prolonged exercises targeting cardiorespiratory endurance (Drenowatz & Greier, 2018a). These initial positive experiences with physical activity may subsequently lead to other activities that will promote engagement in a variety of activities that also stimulate cardiorespiratory endurance. Participation in physical activities has also been shown to minimize the risk for emotional and social problems that potentially lead to isolation, particularly in children with increased body weight (Leyk et al., 2008).

Some limitations of this study, however, should be considered when interpreting the results of this study. Due to the observational nature of the study there was a large variability in participant number across the four weight development groups with a low number of participants in the overweight/obese group, weight gainers and, particularly, weight losers. Further, there was no information on changes in dietary pattern or physical activity as well as participation in organized sports that potentially affect body weight. Additionally, it is

not possible to determine whether any weight fluctuations occurred during the 4-year observation period as data was only collected when children entered elementary school and at 4-year follow-up, prior to transitioning into middle school. The longitudinal design with an observation period that covered the entire elementary school years in an understudied population, on the other hand, is a considerable strength of this study.

5. Conclusion

In conclusion, results of the present study along with previous research show the detrimental effects of excess body weight and excess weight gain on the development of physical fitness during childhood. The large increase in overweight/obesity during the elementary school years also indicates that this age is a critical period in the development of health behaviors related to body weight and physical fitness. Accordingly, physical activities that promote physical fitness and a healthy body weight should be key components in the elementary school curriculum in order to promote an active and healthy lifestyle.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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