Author(s): Aaltonen, Sari; Latvala, Antti; Rose, Richard J.; Pulkkinen, Lea; Kujala, Urho; Kaprio, Jaakko; Silventoinen, Karri

Title: Motor Development and Physical Activity: A Longitudinal Discordant Twin-Pair Study

Year: 2015

Version: Accepted version (Final draft)

Please cite the original version:

Aaltonen, S., Latvala, A., Rose, R. J., Pulkkinen, L., Kujala, U., Kaprio, J., & Silventoinen, K. (2015). Motor Development and Physical Activity: A Longitudinal Discordant Twin-Pair Study. Medicine and Science in Sports and Exercise, 47(10), 2111-2118. https://doi.org/10.1249/MSS.0000000000000650

HHS Public Access
Author manuscript
Med Sci Sports Exerc. Author manuscript; available in PMC 2016 October 01.

Published in final edited form as:
Med Sci Sports Exerc. 2015 October ; 47(10): 2111–2118. doi:10.1249/MSS.0000000000000650.

MOTOR DEVELOPMENT AND PHYSICAL ACTIVITY: A LONGITUDINAL DISCORDANT TWIN-PAIR STUDY

Sari Aaltonen[1,2], **Antti Latvala**[1], **Richard J. Rose**[3], **Lea Pulkkinen**[4], **Urho M. Kujala**[5], **Jaakko Kaprio**[1,6,7], and **Karri Silventoinen**[2]

[1]Department of Public Health, University of Helsinki, Helsinki, Finland [2]Department of Social Research, University of Helsinki, Helsinki, Finland [3]Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN [4]Department of Psychology, University of Jyvaskyla, Jyvaskyla, Finland [5]Department of Health Sciences, University of Jyvaskyla, Jyvaskyla, Finland [6]Institute for Molecular Medicine, University of Helsinki, Helsinki, Finland [7]Department of Mental Health and Substance Abuse Services, National Institute for Health and Welfare, Helsinki, Finland

Abstract

Introduction—Previous longitudinal research suggests that motor proficiency in early life predicts physical activity in adulthood. Familial effects including genetic and environmental factors could explain the association, but no long-term follow-up studies have taken into account potential confounding by genetic and social family background. The present twin study investigated whether childhood motor skill development is associated with leisure-time physical activity levels in adulthood independent of family background.

Methods—Altogether, 1 550 twin pairs from the FinnTwin12 study and 1 752 twin pairs from the FinnTwin16 study were included in the analysis. Childhood motor development was assessed by the parents' report of whether one of the co-twins had been ahead of the other in different indicators of motor skill development in childhood. Leisure-time physical activity (MET hours/day) was self-reported by the twins in young adulthood and adulthood. Statistical analyses included conditional and ordinary linear regression models within twin pairs.

Results—Using all activity-discordant twin pairs, the within-pair difference in a sum score of motor development in childhood predicted the within-pair difference in the leisure-time physical activity level in young adulthood ($p<0.001$). Within specific motor development indicators, learning to stand unaided earlier in infancy predicted higher leisure-time MET values in young adulthood statistically significantly in both samples (FinnTwin12 $p=0.02$, FinnTwin16 $p=0.001$) and also in the pooled dataset of the FinnTwin12 and FinnTwin16 studies ($p<0.001$). Having been more agile than the co-twin as a child predicted higher leisure-time MET values up to adulthood ($p=0.03$).

Corresponding author: Sari Aaltonen Ph.D., Department of Public Health, University of Helsinki, P.O. Box 41 (Mannerheimintie 172), FIN-00014 University of Helsinki, Finland. Tel: +358 50 4480 025 Fax: +358 9 1912 7600 sari.s.aaltonen@helsinki.fi.

CONFLICTS OF INTEREST
The authors declare no conflict of interest.

Conclusions—More advanced childhood motor development is associated with higher leisure-time MET values in young adulthood at least partly independent of family background, in both men and women.

Keywords

ADOLESCENCE; EXERCISE; MOTOR SKILLS; PHYSICAL ACTIVITY; TWINS

Introduction

The benefits of physical activity include the reduced risk of several diseases and mortality (5, 21, 27). However, to obtain these health benefits, regular and consistent physical activity is needed. Proficient motor skill competence may be a prerequisite for leisure-time physical activity (3, 32, 33). Cross-sectional studies have shown that motor skills play an important role in explaining individual differences in leisure-time physical activity levels. Specifically, motor proficiency may be positively associated with physical activity levels in childhood and adolescence (10, 11, 25, 37, 38). Thus, the most coordinated children seem to be the most physically active, and children with motor problems are less likely to participate in regular physical activity (11). In contrast, a study on a large sample of Australian adolescents found that even though motor competence was highly correlated with several physical measures, such as physical fitness, it was not correlated with physical activity (14).

A 20-year follow-up study showed that motor skill proficiency at the age of 6 years is highly related to motor skill proficiency in adolescence at the age of 16 years and young adulthood at the age of 26 years (23). A longitudinal Finnish study has also revealed that early infant motor development seems to predict higher levels of physical activity in adolescence at the age of 14 years (29). Moreover, childhood motor skills seem to predict leisure-time physical activity behavior in later childhood (23) and adolescence (4, 23). This view is supported by the study of 8 061 children aged 8 years at baseline, which showed that children with suspected motor problems tend to have a higher risk of physical inactivity in adolescence (16). Early infant motor development may also be associated with higher physical performance in thirties (28).

Although some longitudinal studies have provided preliminary evidence about motor proficiency in early life as a predictor of physical activity in later life, long-term follow-ups from infancy to adulthood are few and limited in size and scope. Furthermore, family background may confound the association between motor proficiency in early life and physical activity in later life since longitudinal observational follow-up studies may be affected by unobserved confounding factors, such as the childhood environment. Many of the possible factors associated with physical activity seem to have their roots in childhood and family experiences (8, 9, 12, 34, 35, 39). Hence, familial factors could explain at least a part of the association between motor proficiency and physical activity. Importantly, possible familial influences also include genetic factors, which may underlie individual biological differences in motor development and preference for physical activity. However, no long-term follow-up studies have taken into account potential confounding by family background. The twin study design allows taking family background, not just single confounding factors e.g. parental socioeconomic position, into account. By the family background we mean all household, neighborhood and parenting factors shared by co-twins, which makes co-twins to be perfectly matched for family environment. Thus, the longitudinal Finnish twin studies provide a unique opportunity to disentangle the predictors of leisure-time physical activity from infancy to adulthood when adjusting for genetic factors and childhood family environment. Specifically, comparing co-twins discordant for motor development enables adjustment for all factors shared by co-twins.

We are not aware of previous twin studies with detailed information on the leisure-time physical activity of twin pairs discordant for motor development in childhood. Therefore, the aim of the present study is to investigate whether childhood motor skill development, reported by parents, is associated with leisure-time physical activity levels in young adulthood and adulthood, as reported by twins themselves years later independent of family background. Based on the previous studies, we hypothesize that more advanced motor development in infancy and childhood would predict higher leisure-time physical activity values in young adulthood and adulthood.

METHODS

The twins were drawn from two Finnish twin studies: the FinnTwin12 (FT12) and FinnTwin16 (FT16) studies (17). Both are longitudinal studies of health and behavior in Finnish twins, their parents and siblings. The FT12 study comprises twins born between the years 1983 and 1987, and the FT16 study twins born between the years 1974 and 1979. The twins for both studies were identified from the Central Population Registry of Finland.

The data were collected through mailed or online questionnaires. The questionnaires covered extensive medical-social topics, including several items on lifestyle and health status; the parents have also assessed aspects of the twins' behavior and development in early childhood. In addition, the parents have reported the birth weight and birth order of the twins.

In the first phase of the FT12 study, the twins and their parents completed questionnaires when the twins were 11–12 years old. After that, three follow-ups occurred when the twins were at the mean ages of 14, 17.5 and 21.9 years (18, 19). The baseline assessment of the FT16 study was conducted for all the twins within 60 days of their 16th birthday. The twins were surveyed again in adolescence at the mean ages of 17.1 and 18.6 years and again when they were young adults at the mean age of 24.5 years. The last data collection wave of the FT16 study was performed when the twins were in their mid-thirties, at the mean age of 34.0 years. The achieved response rates were 72–90% in each wave of data collection (17, 18).

Previous studies have shown no gender differences in motor competence (14), but clear gender differences seem to exist in the leisure-time physical activity levels (6, 13, 20). Thus, only monozygotic (MZ) and same-sex dizygotic (DZ) twin pairs were included in the analyses and male-female pairs were excluded. The zygosity of the twins was defined on the basis of validated questions on whether people frequently confused the twins in childhood and how similar they were in appearance. The level of agreement between blood tests and the questionnaire diagnosis of zygosity has been high among the Finnish Twin Cohort (30).

Baseline family questionnaire data was collected from 1 656 twin pairs (834 MZ, 822 same-sexed DZ) in the FT12 study and from 1 852 twin pairs (919 MZ, 933 same-sexed DZ) in the FT16 study. However, since several chronic diseases may restrict the development of motor skills and the ability to be physically active, pairs in which one or both co-twins had congenital or childhood chronic diseases were excluded. The excluded diseases included e.g. cerebral palsy, minimal brain dysfunction, mental retardation and severe hearing impairment. After the exclusion criteria were applied, 1 550 twin pairs (795 MZ, 755 same-sexed DZ) from the FT12 study and 1 753 twin pairs (882 MZ, 871 same-sexed DZ) from the FT16 study were included in the analyses. However, the number of twin pairs who fulfilled our discordance criterion was not equal in each motor development indicator. Thus, the number of pairs varies between the motor development indicators. In both cohorts, the number of MZ pairs was slightly higher than the number of same-sex DZ pairs. The percentages of men and women were nearly equal (the FT12 study men 50.3%/women 49.7% and the FT16 study men 48.8%/women 51.2%).

The present study was conducted according to accepted ethical standards. The ethics committee of the University of Helsinki and the Institutional Review Board of Indiana University approved the study protocols. The parents of the participating twins provided written informed consent for their own and their children’s participation, and the twins provided their own written informed consent for taking part in the study as adults.

Motor development differences

The term “motor development” refers to the age-related development of movements (15). In both Finnish twin studies, the parents retrospectively reported on motor developmental differences between the co-twins of a twin pair. Differences in infancy and childhood were reported at age 11–12 years (the FT12 study) or at age 16 (the FT16 study). It is important to note, that the measure of motor developmental differences is based on parent-reported perceived differences in motor skills rather than exact motor developmental differences. Since parents may not remember the exact dates of developmental milestones, they were asked to report whether one of the co-twins had been ahead of the other in motor skill development.

Seven indicators were identified for childhood motor skill development. The same indicators were used in both studies. In infancy, the motor skill development indicators assessed by questionnaire were 1) turning over from back to stomach, 2) standing unaided, 3) walking unaided and 4) climbing stairs unaided. The possible response options for parents were 1) the first born twin was ahead, 2) the second born twin was ahead, 3) there were no differences (within two months of each other) and 4) cannot say. The rest of the motor development indicators represented motor proficiency in late childhood and early adolescence. These indicators were 1) fundamental motor skills at age 6 years, 2) agility at the ages of 7–10 years (the FT12 study)/at the ages of 7–12 years (the FT16 study) and 3) physical strength at the ages of 7–10 years (the FT12 study)/at the ages of 7–12 years (the FT16 study). The response options for the question of fundamental motor skills at age 6 were the same as those used in questions related to motor development in infancy. However, the response options for agility and strength questions were slightly different. The five options used were 1) the first born twin was clearly superior, 2) the first born twin was somewhat better, 3) the co-twins were equal, 4) the second born twin was somewhat better and 5) the second born twin was clearly superior. If the parents reported that one of the co-twins was ahead of the other in a motor development indicator, the co-twins of twin pair were considered to be discordant for motor development in terms of that indicator.

In addition to the separate motor development indicators, we created a summary score for within-pair motor developmental differences in order to obtain an overall perspective on motor skill differences within twin pairs. The summary score was constructed by summing over all the motor development indicators. When the summary scores were created, each indicator was given the value 1, 0 or -1 for each twin pair. The value 1 was assigned if the first born twin was ahead in motor development, and the value -1 was assigned if the second born twin was ahead. If no difference was reported, value 0 was assigned. Thus, after summing over the indicators, the new summary variable varied between the values 7 (the first born twin was ahead in every indicator) and -7 (the second born twin was ahead in every indicator). An additional two other summary scores were constructed by summing over the first infancy motor development indicators (turning over from back to stomach, standing unaided, walking unaided and climbing stairs unaided) and the second childhood motor skill indicators at age 6 years and older (fundamental motor skills at the age of 6 years, agility at the ages of 7–10/7–12 years and strength at the ages of 7–10/7–12 years). These summary variables were constructed as described above. Thus, the values for the infancy motor development summary score were between 4 and -4 and for the childhood motor development summary score between 3 and -3.

Leisure-time physical activity

Leisure-time physical activity was assessed when the twins were young adults at the mean age of 24.2 years in the FT12 study and of 24.5 years in the FT16 study. Leisure-time physical activity was based on questionnaire data, and the activity level was assessed as leisure-time metabolic equivalent units (MET index). The MET indexes were based on a series of structured questions on leisure-time physical activity: the monthly frequency, mean duration and mean intensity of leisure-time physical activity sessions, and physical activity during journeys to and from work or school. All types of leisure-time and commuting-related physical activity were taken into account. If the twins were not working or studying, they were recorded as not having commuting-related physical activity. The indexes were calculated by assigning a multiple of the resting metabolic rate (MET score) to each activity and by calculating the product of the activity, defined as intensity × duration × frequency. The MET indexes were expressed as the sum score of leisure-time MET hours/day. The MET values for leisure-time physical activity intensity were 4 for intensity corresponding to walking, 6 for intensity corresponding to vigorous walking to jogging, 10 for intensity corresponding to jogging, and 13 for intensity corresponding to running (1). MET value 4 (walking) was used for the intensity of commuting-related physical activity. Further, it was assumed that commuting-related physical activity was done on five days per week.

Additionally, we were interested in a longer term relationship between motor skill development indicators and leisure-time physical activity habits than we were able to study during the follow-up from infancy to young adulthood. In the FT16 study, leisure-time physical activity data was available from adulthood (the mean age of the participants was 34.0 years). These data were utilized in some analyses to obtain a more precise view of the long-term association between motor skill development and leisure-time physical activity habits.

Statistical analyses

The associations between childhood motor development indicators and leisure-time physical activity levels in young adulthood (the FT12 study, the FT16 study and the pooled dataset of FT12 and FT16 studies) and adulthood (only the FT16 study) were analyzed with a conditional linear regression analysis (i.e., fixed-effects regression models) using the *xtreg* modeling command with the fixed effects (*fe*) option in Stata 12.0 (31). These models use a within estimator to compare the physical activity levels of co-twins discordant for childhood motor development, and thus adjust for all unmeasured factors shared by co-twins. The associations between summary scores for within-pair motor developmental differences and within-pair leisure-time physical activity differences were analyzed using linear regression models. When the summary scores were analyzed, the MZ and DZ twin pairs were also analyzed separately in order to determine possible genetic influences in relation to motor development and leisure-time physical activity. Because MZ twins derive from one zygote, they have the same genome sequence, whereas DZ twins on average share 50% of their segregating genes. Finding an association within the DZ pairs, but not within the MZ pairs, would suggest that the association is confounded by genetic influences. The linear regression model was also run with a dataset pooled together from the existing FT12 and FT16 studies. MET indices from adulthood were also used in the FT16 study. Birth order and birth weight were included as covariates in the analyses. The data was analyzed using Stata, version 12.0 (31).

RESULTS

The mean birth weight of the twin participants was 2 698 g (SD=506 g) in the FT12 study and 2 657 g (SD=507 g) in the FT16 study. The participants' leisure-time mean MET values in young adulthood are presented in Table 1 according to the motor developmental differences in infancy and childhood, i.e. more advanced co-twins and less advanced co-twins are presented separately. The co-twins who were more advanced in motor development in infancy and childhood consistently reported higher leisure-time MET values in young adulthood.

Conditional linear regression analysis was used to predict the association between the separate childhood motor development indicators and leisure-time MET values in young adulthood (Table 2). In both cohorts, all regression coefficients were positive (coefficients varied from 0.14 to 1.86), indicating that childhood motor development is positively associated with leisure-time physical activity level in young adulthood. Further examination revealed that in young adulthood the associations appeared to be stronger in the FT12 study (from 0.3 to 1.86) than in the FT16 study (from 0.14 to 1.06).

Although the associations between childhood motor development indicators and leisure-time physical activity levels showed a systematic pattern, only some of the associations were statistically significant. This may be due to the limited statistical power of some of the motor development indicators. In both cohorts, learning to stand unaided earlier in infancy predicted significantly higher leisure-time MET values in young adulthood (the FT12 study $p=0.02$, the FT16 study $p=0.001$ and the pooled dataset of the FT12 and FT16 studies $p<0.001$). In the FT16 study, having been ahead in climbing stairs unaided ($p=0.04$), in agility ($p=0.02$) and in fundamental motor skills ($p=0.005$) predicted significantly higher leisure-time MET values as young adults. Moreover, the co-twins who had learned to walk unaided earlier had statistically significantly higher leisure-time MET values in young adulthood in the FT12 study and in the pooled dataset of FT12 and FT16 studies (both $p=0.03$). In the pooled dataset of the FT12 and FT16 studies, all the childhood motor development indicators except “strength” showed statistically significant associations between leisure-time physical activity levels in young adulthood. The significance of the associations were robust to adjustment for birth weight and birth order with the exception of the indicators “standing unaided” in the FT12 study and “walking unaided” in the pooled dataset of FT12 and FT16 studies (Table 2).

Since physical activity data was available in adulthood (mean age 34.0 years) in the FT16 study, the conditional linear regression model was run using leisure-time MET values assessed in adulthood. Although the associations between childhood motor development indicators and leisure-time physical activity were weaker in adulthood (from 0.09 to 0.56) than in young adulthood (from 0.14 to 1.06), childhood motor development was still positively associated with the leisure-time physical activity level in adulthood. The results were also consistent with those of young adulthood in terms of agility: having been more agile as a child predicted significantly higher leisure-time MET values in adulthood ($p=0.03$). Again, the significance of this association was robust to adjustment for birth weight and birth order.

Linear regression models for the summary scores of within-pair motor developmental differences and within-pair differences in leisure-time physical activity were also carried out. The results were parallel to those found in the conditional linear regression models for separate motor development indicators (Table 3). That is, a greater within-pair difference in childhood motor development predicted a greater within-pair difference in leisure-time physical activity in young adulthood. When the MZ and DZ twin pairs were analyzed together, the regression coefficients varied from 0.34 to 0.69, and the results were statistically significant in both cohorts (the FT12 study $p=0.002$ and $p=0.003$ after birth weight adjustment; the FT16 study $p<0.001$ and $p<0.001$ after birth weight adjustment). The models were also analyzed separately for the MZ and DZ pairs, but no dramatic change was seen compared to the analyses among all pairs with the exception of the DZ twin pairs in the FT12 study: the significance of the association weakened and became non-significant after birth weight adjustment among the DZ twin pairs in the FT12 study ($p=0.07$) (Table 3). In the final stage of the summary score analysis of within-pair motor developmental differences and within-pair differences in leisure-time physical activity, we pooled the two existing datasets together. The analysis of the pooled FT12 and FT16 datasets did not change the actual results, except that the statistical significance increased to $p<0.001$ in all cases.

A linear regression model was run using leisure-time MET values assessed not only in young adulthood but also in adulthood (the FT16 study). The regression coefficient was weaker in adulthood (0.25) than it was in young adulthood (0.38) (Table 3). Nevertheless, the within-pair difference in childhood motor development predicted the within-pair difference in leisure-time physical activity in adulthood ($p=0.004$ and $p=0.004$ after birth weight adjustment). When the model was run separately in the MZ and DZ twin pairs, the significance of the association was observed only in the DZ pairs. An interaction test between zygosity (MZ vs. DZ) and within-pair difference in childhood motor development was not statistically significant ($p=0.78$), suggesting that the results are not explained by genetic influences.

DISCUSSION

The present study found a positive association between childhood motor skill development as reported by parents and self-reported leisure-time physical activity levels in young adulthood and adulthood after adjusting for family background. In other words, a within-pair difference in motor development in childhood predicted a high within-pair difference in leisure-time physical activity level in later life. Several motor development indicators showed that having been more advanced in motor development skills as a child predicts higher leisure-time physical activity levels in later life. Learning to stand unaided was the only indicator replicating statistically significant results in both study samples. In the FT16 study, having been more agile as a child was the only indicator that showed a significant association between childhood motor development and leisure-time physical activity level both in young adulthood and adulthood. In the pooled dataset of the FT12 and FT16 studies, both learning to stand unaided and having been more agile as a child were the indicators that were the most significantly associated with later physical activity level. Consequently, agility and the ability to stand unaided may be good indicators to separate children in terms of later physical activity behavior. However, the ability to stand is more likely to be a valid and reliable indicator than agility due to a possible recall bias by the parents.

The results corroborate previous findings in this field. A large volume of published studies describe the important role of motor proficiency on physical activity levels (10, 11, 25, 37, 38). Longitudinal studies have also demonstrated that early motor skill proficiency is highly related to physical activity levels in later life (4, 23, 24, 29). Our findings support these previous studies suggesting that even infant motor development may predict physical activity behavior in adulthood. Moreover, our results extend the prior studies by indicating that genetic or familial influences do not account for the association between motor proficiency in childhood and physical activity behavior in adulthood.

In general, the systematic pattern of the associations revealed by the present study, which used co-twin comparisons to adjust for unmeasured family background factors, suggests that the association between childhood motor skill development and leisure-time physical activity levels in later life is not fully explained by such confounding factors. In contrast, our results are compatible with a causal relationship. Having poor motor skills as a child may result in lower self-esteem related to physical activity and decrease enjoyment of physical activity. Thus, regular participation for physical activity may be decreased also in adulthood among those who were having poor motor skills as a child.

A longitudinal follow-up of a childhood motor skill intervention showed that once the improvement in motor skills has reached a certain point, the skills gained remain for several years (38). Based on this result, motor skill interventions in childhood are believed to be worthwhile. In contrast, a motor proficiency intervention carried out on children did not result in higher physical activity participation in adolescence (4). Although interventions have examined the association between motor proficiency and the later physical activity level, the true impact of motor skill interventions can only be examined in randomized controlled trials. However, as far as we know no randomized controlled trials exist on motor skill development with a long-term follow-up from childhood to young adulthood.

A key strength of this study lies in its longitudinal design, which enabled us to examine the associations between motor development and leisure-time physical activity over time and deepen the understanding of why some people fail to engage in regular, consistent leisure-time physical activity in adulthood. We were able to investigate the relationship between childhood motor skill development indicators and physical activity habits, not only in young adulthood but also 10 years later in adulthood.

The present study was specifically designed to evaluate familial confounders by comparing co-twins discordant for childhood motor development. Twin studies are a valuable source of information about complex traits such as physical activity, since twins are perfectly matched for age, family background if reared in the same family, and perhaps also for other social and medical variables. The MZ co-twins are also perfectly matched for genomic sequence. Hence, the co-twin control study design makes it possible to take these confounding factors into account. This is a clear strength compared to studies carried out on singletons. A further strength of the present study is its adequate sample size; the study sample was representative of the population and had a high response rate. Participants with overt chronic diseases were excluded, which should have minimized the possibility of the influence of diseases on the level of leisure-time physical activity reported by the participants.

A few limitations need to be considered. First, although the overall twin sample size was large, the sample sizes of the co-twins discordant for childhood motor development indicators were limited, which meant that the statistical power to detect small differences between the more advanced and less advanced co-twins was relatively low. Thus, pooling the datasets was an important step in the analysis. Second, the exact ages of motor development milestones were not assessed. Since the motor development indicators used in the present study provided information only on the order of the motor development between the co-twins, direct associations between absolute levels of variables could not be assessed. Third, questionnaires may not be the best possible way to measure motor development or physical activity habits. The validity of the retrospective measure of motor developmental differences in twins has not been proven, but earlier analyses of the Finnish twin studies have shown high correlations between responses to similar leisure-time physical activity questions and physical activity data obtained by interview (36). Leisure-time physical activity questions and a detailed assessment of the volume of leisure-time physical activity over the previous 12 months (12-month MET index) also correlated highly when the assessment and questionnaire were conducted at the same time point (22).

Retrospective questionnaires, such as those we used to assess childhood motor skill development in the present study, are even more complex. In our study, motor developmental differences in infancy and childhood were reported by the parents at baseline when the twins were at ages 11–12 (the FT12 study) or at age 16 (the FT16 study). The results of the study revealed that the effects in regression analyses were stronger in the FT12 study than they were in the FT16 study. This may indicate that the parents remembered their children's childhood motor development better when the questions were asked four years earlier. However, it is important to note that fewer statistically significant associations in the FT12 study compared to the FT16 study may also be due to a smaller sample size.

The present study is based on twin analyses. Twin analyses raise the question of whether twins are representative of the general population. One of the most important assumptions of the twin analysis is that the twins do not differ from the general population in terms of the trait. It is known that twins are often born premature and hence lower in weight than average singleton new-borns (7), but catch up on growth quickly. Twins share the same womb and are thus exactly the same age, and because they are the same age they tend to be in the same school and share many of the same peers. This may cause twins to be more alike than non-twin siblings. Nevertheless, there is evidence that being a twin does not affect behavior (26) or several lifestyle or disease-related characteristics (2). Representativeness is also a potential concern in this study for the reason that we included only twin pairs with differences in motor development indicators in our study. However, no evidence was found that the discordant twin pairs differed from concordant twin pairs in terms of leisure-time physical activity (results not shown). Further, a majority of twin pairs, i.e. 72%, differed in at least one motor development indicator supporting the representativeness of the study.

The higher leisure-time mean MET values for the FT12 study participants may be due to two facts. First, the assessments of leisure-time physical activity behavior in the FT12 and FT16 studies were carried out at different times: the assessment of leisure-time physical activity was carried out in 2000–2002 (mean age of the twins 24.5 years) in the FT16 study and in 2006–2009 (mean age of the twins 24.2 years) in the FT12 study. Reported leisure-time physical activity levels have slightly increased since the late 90s (6, 13). Second, the response options for the frequency of leisure-time physical activity were slightly different. In the FT16 study, the response options for the frequency of the physical activity ranged from "not at all" to "about every day". In the FT12 study, one more option was offered: the options ranged from "not at all" to "several times per day". Despite the social changes and minor differences in the questionnaires described above, the results of these two cohorts were parallel in the present study.

In the future, more research with larger sample sizes would strengthen the investigation of the topic. Longitudinal studies are still rare, although they would be ideal for investigating the significance of motor skills over time. If motor proficiency actually is among the determinants of physical activity, intervention studies could provide more information on this association. Large randomized controlled trials could offer more definitive evidence, but they are, unfortunately, restricted by time and financial resources.

In conclusion, the present study aimed to investigate whether within-pair differences in childhood motor skill development reported by parents are associated with leisure-time physical activity levels in young adulthood and adulthood reported by twins. To the best of our knowledge, this study is the first to give a picture of the association when family background is adjusted for by using within-family comparisons. Our data support a positive association between childhood motor skill development and physical activity levels in later life. Moreover, our study shows that the association is at least partly independent of family background, compatible with a causal relationship. Understanding the association between early motor development indicators and leisure-time physical activity levels in later life could help us to develop effective physical activity counseling and early targeted interventions to promote physical activity. This knowledge also helps us to tailor physical activity interventions to enhance health. Motor skill development may be one of the key strategies in childhood interventions aiming to promote long-term physical activity.

Acknowledgments

The research work has been supported by the Academy of Finland (grant 266592 to SA and KS and grants 100499, 205585 and 141054 to JK), the U.S. National Institute of Alcohol Abuse and Alcoholism (grants AA-12502, AA-00145, and AA-09203 to RJR), the Finnish Ministry of Education and Culture (to UMK), and the Juho Vainio Foundation (to SA and KS).

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

References

1. Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 compendium of physical activities: A second update of codes and MET values. Med Sci Sports Exerc. 2011; 43(8):1575–1581. [PubMed: 21681120]
2. Andrew T, Hart DJ, Snieder H, et al. Are twins and singletons comparable? A study of diseaserelated and lifestyle characteristics in adult women. Twin Res. 2001; 4(6):464–477. [PubMed: 11780939]
3. Barnett LM, Van Beurden E, Morgan PJ, Brooks LO, Beard JR. Does childhood motor skill proficiency predict adolescent fitness? Med Sci Sports Exerc. 2008; 40(12):2137–2144. [PubMed: 18981934]
4. Barnett LM, van Beurden E, Morgan PJ, Brooks LO, Beard JR. Childhood motor skill proficiency as a predictor of adolescent physical activity. J Adolesc Health. 2009; 44(3):252–259. [PubMed: 19237111]
5. Booth FW, Roberts CK, Laye MJ. Lack of exercise is a major cause of chronic diseases. Compr Physiol. 2012; 2:1143–1211. [PubMed: 23798298]
6. Borodulin K, Laatikainen T, Juolevi A, Jousilahti P. Thirty-year trends of physical activity in relation to age, calendar time and birth cohort in Finnish adults. Eur J Pub Health. 2008; 18(3):339–344. [PubMed: 17875578]
7. Buckler JM, Green M. A comparison of the early growth of twins and singletons. Ann Hum Biol. 2004; 31(3):311–332. [PubMed: 15204347]

8. Dishman RK, Sallis JF, Orenstein DR. The determinants of physical activity and exercise. Public Health Rep. 1985; 100(2):158–171. [PubMed: 3920714]
9. Eriksson M, Nordqvist T, Rasmussen F. Associations between parents’ and 12-year-old children’s sport and vigorous activity: The role of self-esteem and athletic competence. J Phys Act Health. 2008; 5(3):359–373. [PubMed: 18579915]
10. Faught BE, Cairney J, Hay J, Veldhuizen S, Missiuna C, Spironello CA. Screening for motor coordination challenges in children using teacher ratings of physical ability and activity. Hum Mov Sci. 2008; 27(2):177–189. [PubMed: 18343517]
11. Fisher A, Reilly JJ, Kelly LA, et al. Fundamental movement skills and habitual physical activity in young children. Med Sci Sports Exerc. 2005; 37(4):684–688. [PubMed: 15809570]
12. Glenmark B, Hedberg G, Jansson E. Prediction of physical activity level in adulthood by physical characteristics, physical performance and physical activity in adolescence: An 11-year follow-up study. Eur J Appl Physiol Occup Physiol. 1994; 69(6):530–538. [PubMed: 7713074]
13. Hallal PC, Andersen LB, Bull FC, et al. Global physical activity levels: Surveillance progress, pitfalls, and prospects. Lancet. 2012; 380(9838):247–257. [PubMed: 22818937]
14. Hands B, Larkin D, Parker H, Straker L, Perry M. The relationship among physical activity, motor competence and health-related fitness in 14-year-old adolescents. Scand J Med Sci Sports. 2009; 19(5):655–663. [PubMed: 18694431]
15. Haywood, KM.; Getchell, N. Life Span Motor Development. Champaign: Human Kinetics; 2009. p. 3-15.
16. Kantomaa MT, Stamatakis E, Kankaanpää A, et al. Physical activity and obesity mediate the association between childhood motor function and adolescents’ academic achievement. Proc Natl Acad Sci U S A. 2013; 110(5):1917–1922. [PubMed: 23277558]
17. Kaprio J. The Finnish twin cohort study: An update. Twin Res Hum Genet. 2013; 16(1):157–162. [PubMed: 23298696]
18. Kaprio J. Twin studies in Finland 2006. Twin Res Hum Genet. 2006; 9(6):772–777. [PubMed: 17254406]
19. Kaprio J, Pulkkinen L, Rose RJ. Genetic and environmental factors in health-related behaviors: Studies on Finnish twins and twin families. Twin Res. 2002; 5(5):366–371. [PubMed: 12537860]
20. Katzmarzyk, PT. Physical activity and fitness with age among sex and ethnic groups. In: Bouchard, C.; Blair, SN.; Haskell, WL., editors. Physical Activity and Health. Champaign: Human Kinetics; 2007. p. 37-47.
21. Kujala UM, Kaprio J, Sarna S, Koskenvuo M. Relationship of leisure-time physical activity and mortality: The Finnish twin cohort. JAMA. 1998; 279(6):440–444. [PubMed: 9466636]
22. Leskinen T, Waller K, Mutikainen S, et al. Effects of 32-year leisure time physical activity discordance in twin pairs on health (TWINACTIVE study): Aims, design and results for physical fitness. Twin Res Hum Genet. 2009; 12(1):108–117. [PubMed: 19210186]
23. Lloyd M, Saunders TJ, Bremer E, Tremblay MS. Long-term importance of fundamental motor skills: A 20-year follow-up study. Adapt Phys Activ Q. 2014; 31(1):67–78. [PubMed: 24385442]
24. Lopes VP, Rodrigues LP, Maia JA, Malina RM. Motor coordination as predictor of physical activity in childhood. Scand J Med Sci Sports. 2011; 21(5):663–669. [PubMed: 21917017]
25. Okely AD, Booth ML, Patterson JW. Relationship of physical activity to fundamental movement skills among adolescents. Med Sci Sports Exerc. 2001; 33(11):1899–1904. [PubMed: 11689741]
26. Pulkkinen L, Vaalamo I, Hietala R, Kaprio J, Rose RJ. Peer reports of adaptive behavior in twins and singletons: Is twinship a risk or an advantage? Twin Res. 2003; 6(2):106–118. [PubMed: 12723997]
27. Reiner M, Niermann C, Jekauc D, Woll A. Long-term health benefits of physical activity - A systematic review of longitudinal studies. BMC Public Health. 2013; 13:813. 2458–13–813. [PubMed: 24010994]
28. Ridgway CL, Ong KK, Tammelin T, Sharp SJ, Ekelund U, Järvelin MR. Birth size, infant weight gain, and motor development influence adult physical performance. Med Sci Sports Exerc. 2009a; 41(6):1212–1221. [PubMed: 19461546]

29. Ridgway CL, Ong KK, Tammelin TH, Sharp S, Ekelund U, Järvelin MR. Infant motor development predicts sports participation at age 14 years: Northern Finland birth cohort of 1966. PLoS One. 2009b; 4(8):e6837. [PubMed: 19718258]
30. Sarna S, Kaprio J, Sistonen P, Koskenvuo M. Diagnosis of twin zygosity by mailed questionnaire. Hum Hered. 1978; 28(4):241–254. [PubMed: 566252]
31. Stata Corp. Stata Statistical Software: Release 12. College Station, TX: StataCorp LP; 2011.
32. Stodden DF, Goodway JD. The dynamic association between motor skill development and physical activity. JOPERD. 2007; 78(8):33–34. 48–49.
33. 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.
34. Tammelin T, Näyhä S, Laitinen J, Rintamäki H, Järvelin MR. Physical activity and social status in adolescence as predictors of physical inactivity in adulthood. Prev Med. 2003; 37(4):375–381. [PubMed: 14507496]
35. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: A 21-year tracking study. Am J Prev Med. 2005; 28(3):267–273. [PubMed: 15766614]
36. Waller K, Kaprio J, Kujala UM. Associations between long-term physical activity, waist circumference and weight gain: A 30-year longitudinal twin study. Int J Obes (Lond). 2008; 32(2): 353–361. [PubMed: 17653065]
37. Williams HG, Pfeiffer KA, O'Neill JR, et al. Motor skill performance and physical activity in preschool children. Obesity (Silver Spring). 2008; 16(6):1421–1426. [PubMed: 18388895]
38. Wrotniak BH, Epstein LH, Dorn JM, Jones KE, Kondilis VA. The relationship between motor proficiency and physical activity in children. Pediatrics. 2006; 118(6):e1758–65. [PubMed: 17142498]
39. Yang X, Telama R, Leino M, Viikari J. Factors explaining the physical activity of young adults: The importance of early socialization. Scand J Med Sci Sports. 1999; 9(2):120–127. [PubMed: 10220848]

Table 1

Leisure-time physical activity levels expressed as mean MET hours/day at the mean ages of 24.2 years (the FT12 study) and 24.5 years (the FT16 study). The MET values are presented according to the childhood motor developmental differences (more advanced co-twins vs. less advanced co-twins). Only the healthy MZ and same-sexed DZ twin pairs were included in the analyses. It is important to note that the assessments of leisure-time physical activity behavior in the FT12 and FT16 studies were carried out at different times and that the response options for the frequency of leisure-time physical activity were slightly different in the FT12 and FT16 studies.

Motor skill development in infancy and childhood	**Mean MET index (MET hours/day)±SD**	
	FT12	**FT16**
Turning over from back to stomach	(N=68 pairs)	(N=309 pairs)
More advanced co-twin	8.20±9.38	5.73±5.45
Less advanced co-twin	6.59±6.86	5.11±4.68
Standing unaided	(N=81 pairs)	(N=340 pairs)
More advanced co-twin	9.68±6.22	6.12±5.70
Less advanced co-twin	7.84±5.42	5.06±4.62
Walking unaided	(N=186 pairs)	(N=563 pairs)
More advanced co-twin	7.64±9.27	5.53±5.10
Less advanced co-twin	6.26±7.53	5.30±4.82
Climbing stairs unaided	(N=38 pairs)	(N=179 pairs)
More advanced co-twin	8.87±8.32	5.90±5.90
Less advanced co-twin	7.30±8.88	5.00±4.63
Fundamental motor skills at age 6	(N=153 pairs)	(N=314 pairs)
More advanced co-twin	8.53±10.40	5.63±5.15
Less advanced co-twin	7.16±8.76	4.78±4.40
Agility at age 10 (FT12)/at age 12 (FT16)	(N=179 pairs)	(N=449 pairs)
More advanced co-twin	7.52±8.85	5.54±5.16
Less advanced co-twin	6.27±7.11	4.86±4.58
Strength at age 10 (FT12)/at age 12 (FT16)	(N=186 pairs)	(N=443 pairs)
More advanced co-twin	6.98±6.85	5.45±5.08
Less advanced co-twin	6.32±6.76	5.15±4.69

MET=metabolic equivalent, SD=standard deviation

Author Manuscript

Author Manuscript

Author Manuscript

Table 2

Conditional linear regression models for motor skill development indicators and leisure-time physical activity. The models are presented for both the FT12 and FT16 studies. Only the healthy MZ and same-sexed DZ twin pairs were included in the analyses.

	Leisure-time physical activity (MET hours/day)							
	FT12 mean age 24.2 years		FT16 mean age 24.5 years		FT16 mean age 34.0 years		Pooled FT12 and FT16 mean age 24.4 years	
	Regression coefficient (95% CI)	p-value	Regression coefficient (95% CI)	p-value	Regression coefficient (95% CI)	p-value	Regression coefficient (95% CI)	p-value
Turning over from back to stomach								
No covariates	1.61 (-0.60 to 3.82)	0.15	0.63 (-0.05 to 1.30)	0.07	0.32 (-0.29 to 0.92)	0.31	0.85 (0.22 to 1.47)	0.007
Birth weight + birth order	1.58 (-0.68 to 3.86)	0.17	0.60 (-0.08 to 1.28)	0.08	0.28 (-0.33 to 0.89)	0.37	0.81 (0.17 to 1.44)	0.01
Standing unaided								
No covariates	1.86 (0.31 to 3.40)	0.02	1.06 (0.44 to 1.67)	0.001	0.37 (-0.21 to 0.94)	0.21	1.16 (0.63 to 1.7)	<0.001
Birth weight + birth order	1.48 (-0.14 to 3.10)	0.07	1.02 (0.39 to 1.65)	0.002	0.43 (-0.16 to 1.02)	0.15	1.10 (0.55 to 1.64)	<0.001
Walking unaided								
No covariates	1.38 (0.15 to 2.62)	0.03	0.23 (-0.21 to 0.67)	0.30	0.11 (-0.33 to 0.54)	0.63	0.49 (0.05 to 0.93)	0.03
Birth weight + birth order	1.32 (0.01 to 2.62)	0.05	0.17 (-0.27 to 0.62)	0.45	0.09 (-0.35 to 0.53)	0.69	0.42 (-0.03 to 0.87)	0.07
Climbing stairs unaided								
No covariates	1.56 (-1.32 to 4.45)	0.28	0.91 (0.03 to 1.78)	0.04	0.31(-0.52 to 1.13)	0.46	1.03 (0.24 to 1.81)	0.01
Birth weight + birth order	1.09 (-1.58 to 3.76)	0.42	0.94 (0.06 to 1.82)	0.04	0.34 (-0.51 to 1.18)	0.43	1.00 (0.20 to 1.79)	0.01
Fundamental motor skills at age 6								
No covariates	1.36 (-0.20 to 2.93)	0.09	0.84 (0.26 to 1.44)	0.005	0.36 (-0.19 to 0.92)	0.2	0.96 (0.35 to 1.57)	0.002
Birth weight + birth order	1.42 (-0.13 to 2.96)	0.07	0.94 (0.35 to 1.52)	0.002	0.37 (-0.18 to 0.93)	0.19	1.02 (0.41 to 1.63)	0.001
Agility at age 10 (FT12)/at age 12 (FT16)								
No covariates	1.25 (-0.08 to 2.59)	0.06	0.68 (0.13 to 1.23)	0.02	0.50 (0.04 to 0.96)	0.03	0.85 (0.33 to 1.37)	0.001
Birth weight + birth order	1.28 (-0.04 to 2.59)	0.06	0.79 (0.25 to 1.33)	0.004	0.55 (0.06 to 1.04)	0.03	0.97 (0.44 to 1.49)	<0.001
Strength at age 10 (FT12)/at age 12 (FT16)								
No covariates	0.66 (-0.50 to 1.82)	0.26	0.31 (-0.22 to 0.82)	0.25	0.53 (0.06 to 0.99)	0.03	0.4 (-0.09 to 0.88)	0.11

	Leisure-time physical activity (MET hours/day)							
	FT12 mean age 24.2 years		FT16 mean age 24.5 years		FT16 mean age 34.0 years		Pooled FT12 and FT16 mean age 24.4 years	
	Regression coefficient (95% CI)	**p-value**	**Regression coefficient (95% CI)**	**p-value**	**Regression coefficient (95% CI)**	**p-value**	**Regression coefficient (95% CI)**	**p-value**
Birth weight + birth order	0.30 (-0.82 to 1.42)	0.59	0.14 (-0.44 to 0.73)	0.63	0.39 (-0.11 to 0.89)	0.13	0.22 (-0.3 to 0.73)	0.41

MET=metabolic equivalent, CI=confidence intervals

Table 3

Linear regression models for the summary score of within-pair motor developmental differences and within-pair differences in leisure-time physical activity. The models are presented separately for the FT12 and FT16 studies and for the pooled dataset. Only the healthy MZ and same-sexed DZ twin pairs were included in the analyses.

Summary variable for within-pair motor developmental differences	Within-pair difference in leisure-time physical activity (MET hours/day)		
	Regression coefficient	**95% CI**	**p-value**
FT12, mean age 24.2 years			
All pairs			
No covariates N=395	0.53	0.20 to 0.87	0.002
Birth weight N=394	0.51	0.17 to 0.84	0.003
Only MZ pairs			
No covariates N=238	0.69	0.17 to 1.21	0.01
Birth weight N=238	0.69	0.17 to 1.22	0.01
Only DZ pairs			
No covariates N=157	0.47	0.007 to 0.94	0.05
Birth weight N=156	0.44	-0.04 to 0.91	0.07
FT16, mean age 24.5 years			
All pairs			
No covariates N=1 189	0.38	0.20 to 0.56	<0.001
Birth weight N=1 174	0.38	0.20 to 0.57	<0.001
Only MZ pairs			
No covariates N=605	0.47	0.13 to 0.81	0.006
Birth weight N=598	0.46	0.12 to 0.80	0.008
Only DZ pairs			
No covariates N=584	0.34	0.12 to 0.57	0.003
Birth weight N=576	0.35	0.12 to 0.58	0.003
FT16, mean age 34.0 years			
All pairs			
No covariates N=1 291	0.25	0.08 to 0.42	0.004
Birth weight N=1 274	0.25	0.08 to 0.42	0.004
Only MZ pairs			
No covariates N=651	0.18	-0.14 to 0.51	0.27
Birth weight N=642	0.20	-0.12 to 0.53	0.22
Only DZ pairs			
No covariates N=640	0.27	0.06 to 0.48	0.01
Birth weight N=632	0.27	0.06 to 0.48	0.01
FT12 and FT16 pooled, mean age 24.4 years			
All pairs			
No covariates N=1 584	0.44	0.27 to 0.60	<0.001
Birth weight N=1 568	0.43	0.27 to 0.59	<0.001
Only MZ pairs			

Summary variable for within-pair motor developmental differences	Within-pair difference in leisure-time physical activity (MET hours/day)		
	Regression coefficient	**95% CI**	**p-value**
No covariates N=843	0.60	0.29 to 0.85	<0.001
Birth weight N=836	0.58	0.30 to 0.86	<0.001
Only DZ pairs			
No covariates N=741	0.38	0.18 to 0.58	<0.001
Birth weight N=732	0.38	0.17 to 0.59	<0.001

MET=metabolic equivalent, CI=confidence intervals