The relationship between motor competence and physical fitness from early childhood to early adulthood: A meta-analysis

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Abstract

Background: Motor competence and physical fitness are important factors for promoting positive trajectories of health over time. In 2008, Stodden and colleagues developed a model that discussed the role of both factors in physical activity. Furthermore, the authors hypothesized that the relationship between motor competence and physical fitness is reciprocal and changes over time.

Objective: The aim of the present meta-analysis was to synthesize the evidence on the relationship between motor competence and components of physical fitness from early childhood to early adulthood and the potential influence of age.

Methods: Scientific databases Web of Science and PubMed were used for literatures search. German as well as English studies were included that assessed typically developing children. In accordance with the PRISMA guidelines, 93 studies between 2005 and June 2018 were screened in full. Nineteen studies comprising of 32 samples, 87 single data points from 15,984 participants aged 4.5 to 20.4 years (M_{age} = 11.44, SD = 4.77) were included in the analysis.

Results: A random effects model was conducted for the meta-regression with age as moderator variable. The relationship between motor competence and physical fitness was moderate to large (r = .43, p < .001) after controlling for multiple effects, including dependent samples and small sample sizes in the quantitative synthesis. Additionally, age was a small significant positive moderator of the effect size.

Conclusions and implications: The findings provide support for a moderate to large positive relationship between motor competence and physical fitness that strengthens with increasing age. However, the results also indicate that there may be an overlap in content between motor competence and physical fitness assessments, which warrants further investigation. Further research is needed that assesses the similarities and differences also in terms of the construct structures.

Key points

- There is a moderate-to-large positive relationship between motor competence and physical fitness from early childhood to early adulthood.
- The relationship between motor competence and physical fitness strengthens across age.
- Overlap in content between measures of motor competence and physical fitness warrants further investigation into content and construct validity of assessment tools.

Introduction

It has often been shown that decreased levels of physical activity are associated with increased levels of overweight and obese children and adolescents [1,2]. In view of these negative trends and the importance of physical activity in health [3], research has focused on understanding the underlying mechanisms of physical activity in order to promote an active and healthy lifestyle. Stodden et al. [4] put forth a conceptual model describing the dynamics between physical activity and other health-related factors which lead to a positive spiral of engagement or a negative spiral of disengagement in physical activity. One of these health-related factors is motor competence, which is a global term referring to an individual's degree of proficiency in performing a wide range of motor skills as well as the mechanisms underlying this performance (e.g., motor control and coordination) [5–8]. Motor competence is at the centre of Stodden and colleagues' model [4] and is also considered an important factor underlying physical activity. Prior research has shown a positive relationship between motor competence and physical activity in youth [9–12]. Longitudinal studies have also provided some evidence that motor competence levels during childhood positively influence physical activity levels in later years [13,14].

Another key factor that was described in the model of Stodden et al. [4] is physical fitness. Physical fitness is a multifaceted construct involving physical and physiological components such as cardiorespiratory fitness, musculoskeletal fitness (i.e., muscular endurance and strength), and flexibility [15–17]. It is a significant health marker that underlies physical activity performance [15,18]. In their model, Stodden et al. [4] indicated that there is a positive relationship between motor competence and health-related fitness. The authors also postulated that health-related fitness mediates the relationship between motor competence and physical activity. Although there is only limited evidence supporting the mediating role of physical fitness [19], previous studies have consistently shown that motor competence is positively associated with cardiorespiratory fitness and musculoskeletal fitness in youth [5,11,20].

Recently, Cattuzzo et al. [20] conducted a systematic review on the associations between motor competence and physical fitness in young people. Although the review has provided valuable qualitative insights into the existing literature, the authors did not statistically account for methodological issues associated with single studies, such as lack of precision and small sample size [21] or provided information regarding statistical risk of bias. Instead, they counted the number of studies and provided qualitative information which resulted in percentages of studies showing specific relationships with no empirical integration of evidence. In their conceptual model, Stodden et al. [4] also postulated that the relationship between motor competence and physical fitness strengthens across age. That is, younger children that repeatedly engage in physical activities would increase both their motor competence as well as physical fitness levels. While some studies support this hypothesis [20,22,23], the dynamic relationship between motor competence and measures of physical fitness across age has not yet been investigated comprehensively [24].

There is a need to further explore the available evidence on the association between motor competence and physical fitness. A meta-analysis of associated effect sizes could provide a possible solution to quantify this relationship [21], and provide a better understanding of the relationship between motor competence and physical fitness. Moreover, the hypothesized change in this relationship age can be investigated across various samples and measures. Therefore, the aim of the present meta-analysis is to review the existing evidence base and evaluate the relationship between motor competence and physical fitness in children and adolescents as well as the potential moderating role of age therein.

Methods

Literature Search

The literature search was conducted according to the PRISMA Guidelines [25]. One of the main aims of the PRISMA guidelines is to reduce bias from researchers. To avoid subjective selection criteria of studies, which can strongly influence the results of meta-analyses [25], we included the results as well as reference lists of two recent topic-related reviews as the basis of for this meta-analysis [5,20]. These well-known reviews investigated associations between physical fitness and motor competence qualitatively. Further, we conducted a systematic search using search engines Web of Science and PubMed using search terms of in the context of motor competence and physical fitness as well as subdomains using the logical operators available as search tools (for the specific search criteria as pasted into the search engines, see osf.io/p36rq/). Search results included studies from January 2005 to June 2018.

Study Inclusion and Exclusion Criteria

Studies published in German and English language were included in the present study. This meta-analysis includes studies with typically developing participants aged 3 to 21 years. Studies with a focus on individuals with a physical or cognitive impairment were excluded. Data was considered for studies that included interrelations between total scores of test batteries or single measures that assess motor competence and physical fitness. The question of an overall effect size for the associations between motor competence and physical fitness requires an adequate definition of both constructs. In light of this, the following definitions are used in this meta analysis.

Motor competence. Motor competence refers to the degree of proficiency in performing a wide variety of motor skills including both gross (e.g., jumping) and fine motor skills (e.g., manual dexterity or precision), as well as the underlying mechanisms including coordination, control and quality of movement [6,26]. During childhood, motor competence can also be reflected by a person's proficiency in executing fundamental motor skills, which consist of locomotor skills, object control skills and stability skills [27,28]. Locomotor skills entail movement across space and include skills such as running, jumping and hopping whereas object control skills refer to manipulation of objects and include catching, kicking, bouncing or throwing a ball. Stability skills refer to non-locomotor movement that focuses on balance and include skills such as bending and twisting [29–31]. However, as noted by Robinson et al. [5], motor competence is a global term reflecting various terminologies used in the literature.

Physical Fitness. Caspersen et al. [32] define physical fitness as "the ability to carry out daily tasks with vigor and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits" (p. 128). The authors considered physical fitness as a set of attributes which can be categorized into health-related fitness and skill-related fitness. Components of health-related fitness include cardiorespiratory fitness, musculoskeletal fitness (muscular endurance and strength), body composition and flexibility. Skill-related fitness consists of agility, balance, coordination, speed, power and reaction time. Although physical fitness is a multi-faceted construct, recent research has shown that physical fitness can be regarded as a one-dimensional construct covering a variety of different fitness components included in many fitness tests. Thus, we understand physical fitness as being interpretable as one construct, but also as multiple factors when single tasks are interpreted separately such as cardiorespiratory fitness, musculoskeletal fitness (muscular endurance and strength), and flexibility. Body composition was excluded from this meta-analysis, because it reflects no actual physical performance.

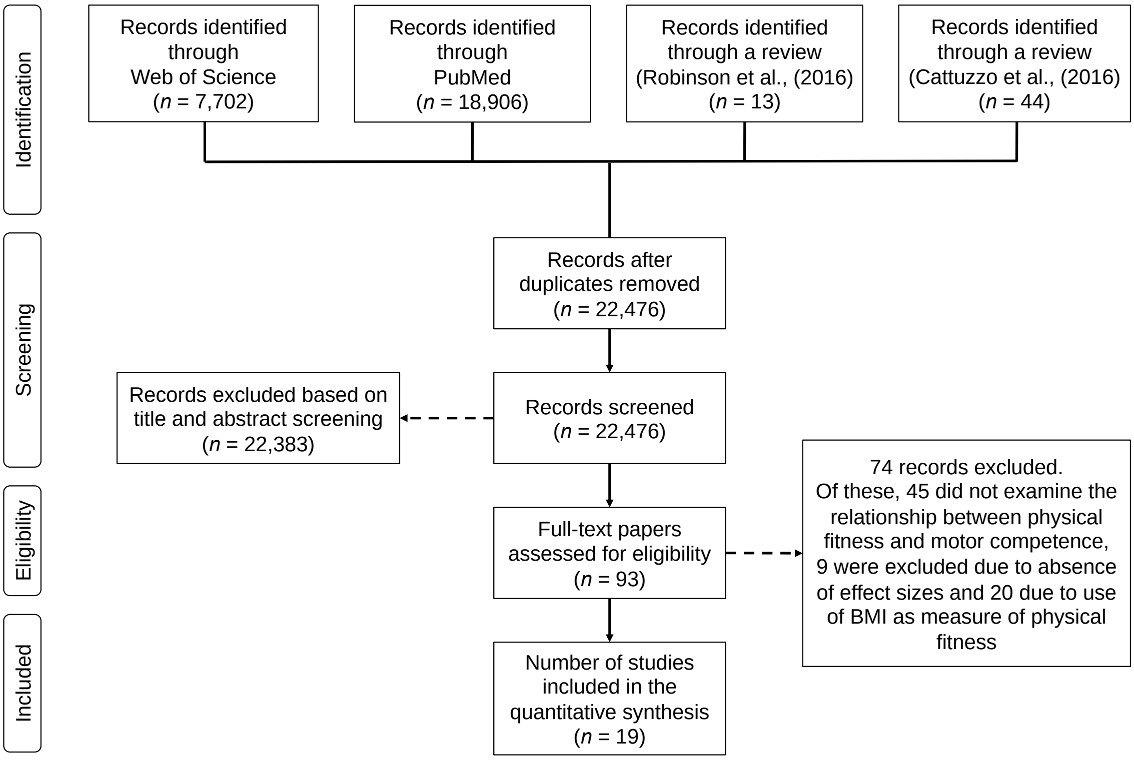

Figure 1. PRISMA flow diagram for study selection [25]. The 19 remaining studies provided a total of 32 different samples with 87 different data points.

Data Extraction

A total of 22,476 studies were screened based on title and abstract (for a BibTex file, see osf.io/p36rq/). Overall, 93 studies were identified initially that were full-text screened (see Figure 1) but only 19 studies were included in the meta-analysis [13,19,22-23,26,33–46]. Of the 74 studies that did not match the eligibility criteria based on full text screening, 45 did not examine the relationship between physical fitness and motor competence, nine did not provide effect sizes or enough information to manually calculate them, and 20 studies operationalized BMI as an aspect of fitness in previous reviews and were therefore excluded. From the included studies, we extracted all data where the results of motor competence assessments were compared to results of physical fitness assessments with whole test batteries or single items. All identified effect sizes were included in this study. All effect sizes were transformed into

Fishers *z* values. Age as a potential moderator was extracted based on mean age presented for the identified sample or subsample. Further, we extracted information regarding the specific assessments used for motor competence as well as physical fitness (cf. Table 1). These studies provided 32 different samples with 87 individual data points. Overall, 15,984 participants aged between 4.5 to 20.4 years (M_{age} = 11.44, *SD* = 4.77) were included in the data analysis (for an overview see Table 1).

Table 1
Overview of the studies and samples included into the meta-analysis.

Authors	Year	*N*	*r*	Age	Fitness	Motor Competence
Barnett et al. [13]	2008	234	.51	13.1	PACER	GSGA
Burns et al. (f) [41]	2017	730	.26	8.4	Push Ups	TGMD-3
Burns et al. (m) [41]	2017	730	.21	8.4	Push Ups	TGMD-3
Burns et al. (f) [41]	2017	730	.19	8.4	Curl-ups	TGMD-3
Burns et al. (f) [41]	2017	730	.17	8.4	PACER	TGMD-3
Burns et al. (m) [41]	2017	730	.16	8.4	PACER	TGMD-3
Burns et al. (m) [41]	2017	730	.15	8.4	Curl-ups	TGMD-3
Castelli & Valley [42]	2007	230	.57	9.49	PACER	SCPEAP
Castelli & Valley [42]	2007	230	.36	9.49	Push-Ups	SCPEAP
Castelli & Valley [42]	2007	230	.14	9.49	Sit & reach	SCPEAP
Castelli & Valley [42]	2007	230	.39	9.49	Curl-Ups	SCPEAP
Gu et al. [35]	2017	262	.25	10.87	PACER	PE Metrics
Haga [26]	2008	67	.59	9.7	TPF	MABC
Hands et al. (m) [44]	2009	814	.52	14	ACHPER	MAND
Hands et al. (f) [44]	2009	771	.44	14	ACHPER	MAND
Hardy et al. (gr4, m) [45]	2012	697	.64	9.25	PACER	Object Control
Hardy et al. (gr4, m) [45]	2012	697	.60	9.25	PACER	Locomotion
Hardy et al. (gr6, m) [45]	2012	649	.40	11.25	PACER	Object Control
Hardy et al. (gr6, m) [45]	2012	649	.47	11.5	PACER	Locomotion
Hardy et al. (grh, m) [45]	2012	1661	.31	14.35	PACER	Object Control
Hardy et al. (grh, m) [45]	2012	1661	.27	14.35	PACER	Locomotion
Hardy et al. (gr4, w) [45]	2012	699	.51	9.25	PACER	Object Control
Hardy et al. (gr4, w) [45]	2012	699	.50	9.25	PACER	Locomotion
Hardy et al. (gr6, w) [45]	2012	631	.18	11.25	PACER	Object Control
Hardy et al. (gr6, w) [45]	2012	631	.44	11.25	PACER	Locomotion
Hardy et al. (grh, w) [45]	2012	1332	.25	14.35	PACER	Object Control
Hardy et al. (grh, w) [45]	2012	1332	.29	14.35	PACER	Locomotion

Jaakkola et al. [40]	2016	333	.23	12.41	CooperTest and Situps	Flamingo Test
Khodaverdi et al. [19]	2016	352	.16	8.78	Push Ups	TGMD-2
Khodaverdi et al. [19]	2016	352	.09	8.78	Sit & Reach	TGMD-2
Khodaverdi et al. [19]	2016	352	.08	8.78	Curl-ups	TGMD-2
Lima et al. [46]	2017	46	.05	6.75	VO2max	KTK
Oberer et al. [33]	2018	162	.06	6.42	SixMinuteRun	PostingCoins
Oberer et al. [33]	2018	162	.24	6.42	SixMinuteRun	ThreadingBeads
Oberer et al. [33]	2018	162	.28	6.42	SixMinuteRun	DrawingTrial
Oberer et al. [33]	2018	162	.15	6.42	SixMinuteRun	JumpingSideway
Oberer et al. [33]	2018	162	.19	6.42	BroadJump	PostingCoins
Oberer et al. [33]	2018	162	.44	6.42	BroadJump	ThreadingBeads
Oberer et al. [33]	2018	162	.25	6.42	BroadJump	DrawingTrial
Oberer et al. [33]	2018	162	.05	6.42	BroadJump	JumpingSideway
Pereira et al. [34]	2011	3699	.005	8	Push-Ups	KTK
Pereira et al. [34]	2011	3699	.004	8	Curl-Up	KTK
Pereira et al. [34]	2011	3699	.004	8	One Mile Run	KTK
Pereira et al. [34]	2011	3699	.003	8	Trunk-Lift	KTK
Ré et al. [39]	2016	80	.60	14.6	12min run	Ballskill
Ré et al. [39]	2016	80	.57	14.6	Zigzag running	Ballskill
Ré et al. [39]	2016	80	.22	14.6	BroadJump	Ballskill
Stodden et al. [23]	2009	188	.72	20.4	Grip	Jump
Stodden et al. [23]	2009	188	.70	20.4	Leg press	Jump
Stodden et al. [23]	2009	188	.68	20.4	Grip	Kick
Stodden et al. [23]	2009	188	.67	20.4	Leg press	Throw
Stodden et al. [23]	2009	188	.64	20.4	Grip	Throw
Stodden et al. [23]	2009	188	.63	20.4	Leg press	Kick
Stodden et al. [23]	2009	188	.59	20.4	Curl up	Jump
Stodden et al. [23]	2009	188	.54	20.4	Run	Jump
Stodden et al. [23]	2009	188	.50	20.4	Run	Throw
Stodden et al. [23]	2009	188	.49	20.4	Curl up	Kick
Stodden et al. [23]	2009	188	.49	20.4	Run	Kick
Stodden et al. [23]	2009	188	.48	20.4	Curl up	Throw
Stodden et al. [23]	2009	188	-.08	20.4	Sit & reach	Jump
Stodden et al. [23]	2009	188	-.12	20.4	Sit & reach	Kick
Stodden et al. [23]	2009	188	-.17	20.4	Sit & reach	Throw
Stodden et al. (4,5) [22]	2014	68	.23	4.5	Fitnessgram	Throw
Stodden et al. (4,5) [22]	2014	68	.38	4.5	Fitnessgram	Kick
Stodden et al. (4,5) [22]	2014	68	.55	4.5	Fitnessgram	Jump
Stodden et al. (6,5) [22]	2014	82	.39	6.5	Fitnessgram	Throw

Stodden et al. (6,5) [22]	2014	82	.37	6.5	Fitnessgram	Kick
Stodden et al. (6,5) [22]	2014	82	.02	6.5	Fitnessgram	Jump
Stodden et al. (8,5) [22]	2014	84	.42	8.5	Fitnessgram	Throw
Stodden et al. (8,5) [22]	2014	84	.42	8.5	Fitnessgram	Kick
Stodden et al. (8,5) [22]	2014	84	.18	8.5	Fitnessgram	Jump
Stodden et al. (10,5) [22]	2014	143	.47	10.5	Fitnessgram	Throw
Stodden et al. (10,5) [22]	2014	143	.44	10.5	Fitnessgram	Kick
Stodden et al. (10,5) [22]	2014	143	.34	10.5	Fitnessgram	Jump
Stodden et al. (12,5) [22]	2014	79	.65	12.5	Fitnessgram	Throw
Stodden et al. (12,5) [22]	2014	79	.59	12.5	Fitnessgram	Kick
Stodden et al. (12,5) [22]	2014	79	-.006	12.5	Fitnessgram	Jump
Tveter & Holm [35]	2010	341	.68	10	Quadriceps strength 240°/s	Hop length
Tveter & Holm [35]	2010	341	.66	10	Hamstrings strength 60°/s	Hop length
Vandendriessche et al. (1) [36]	2011	187	.87	11	Eurofit	KTK
Vandendriessche et al. (2) [36]	2011	181	.79	7	Eurofit	KTK
Vandendriessche et al. (3) [36]	2011	245	.80	9	Eurofit	KTK
Vedul-Kjelsås et al. [37]	2012	67	.612	11.46	TPF	MABC
Vlahov et al. [38]	2014	140	.79	10.3	Sit-ups	TMGD-1
Vlahov et al. [38]	2014	140	.66	10.3	1,5 Mile Run	TMGD-1
Vlahov et al. [38]	2014	140	.63	10.3	Sit & Reach	TMGD-1
Vlahov et al. [38]	2014	140	.59	10.3	Skinfold	TMGD-1

Quantitative Synthesis: Data Analysis and Risk of Bias.

Literature research did not provide sufficient studies in order to model the relationship between motor competence and *each* fitness component separately. However, it was possible to model the relationship for overall physical fitness as provided by a composite score in fitness test batteries and single items (87 samples), for cardiorespiratory fitness (28 samples) and for musculoskeletal fitness (28 samples). Age was included as a moderator and was grand mean centered (M_{age} = 11.44 years).

A random effects (RE) model was used to run all models with robust variance estimation (RVE) [47] and small-sample correction [48]. In order to model the effect, all effect sizes derived from the single studies were transformed into correlations and the magnitude of effect sizes will be interpreted based on Cohen's recommendations as well as recent suggestions that compared effects sizes in correlations to Cohen's d (Cohen *r*: small (.10, .29), medium (.30, .50), large (> .50]; psychometrica *r*: small (.10, .20), medium (.21, .35), large (> .35) [49,50]. Within the meta-regression, Fisher's r-to-z transformation was used to transform correlation coefficients. A τ^2 restricted maximum-likelihood estimator was conducted. Sensitivity analyses were run to identify outliers and/or influential studies (i.e., illustrated in forest plot).

In order to check for publication bias, we examined asymmetry of the results, which would be indicative for a publication bias (i.e., trim and fill, funnel analysis) [51]. However, since this meta-analysis includes studies where a low relationship would be assumed (e.g., between motor competence and flexibility), publication bias was not expected. Further, we controlled for the influence of multiple samples in the qualitative sythesis. Age was inserted as a possible moderator reflecting the nature of developmental differentiation to investigate the hypothesized change of the association with age [24]. All analyses were conducted in *R* [52] with the packages *metafor* [53] and *robumeta* [54] (see osf.io/p36rq/ for open code).

Results

In the first step, the overall relationship between motor competence and physical fitness was modeled. A total amount of 97.69 % estimated heterogeneity ($Q(86) = 3{,}321.64$, $p < .001$) suggests that the included studies did not share a common effect size, which supports the usage of a random effects model. The overall model with 87 samples provided an estimated effect size of *z* of .435 ($p < .001$; see Figure 2). The transformation of Fisher's *z* back to Pearson's *r* revealed a summarized effect of $r = .409$ (see Table 2). Despite the large heterogeneity, one outlier study was detected ($p < .05$). The outlier was a correlation between the KTK and Eurofit for 11 year-olds [36]. However, it can be expected to find one outlier in 87 samples with a significance level of $p = .05$. Further, age was a moderator of the effect size ($r = .015$, $p = .030$;

Figure 3). Further, it was tested whether the effect was influenced by multiple dependent samples in the random effects model. Thus, a *clustered random-effects model* was conducted. After correction for multiple effects for dependent samples and small-sample (small number of samples) correction, the overall effect size and the moderating effect did not change (z = .434, *r* = .409, *p* < .001) for overall physical fitness.

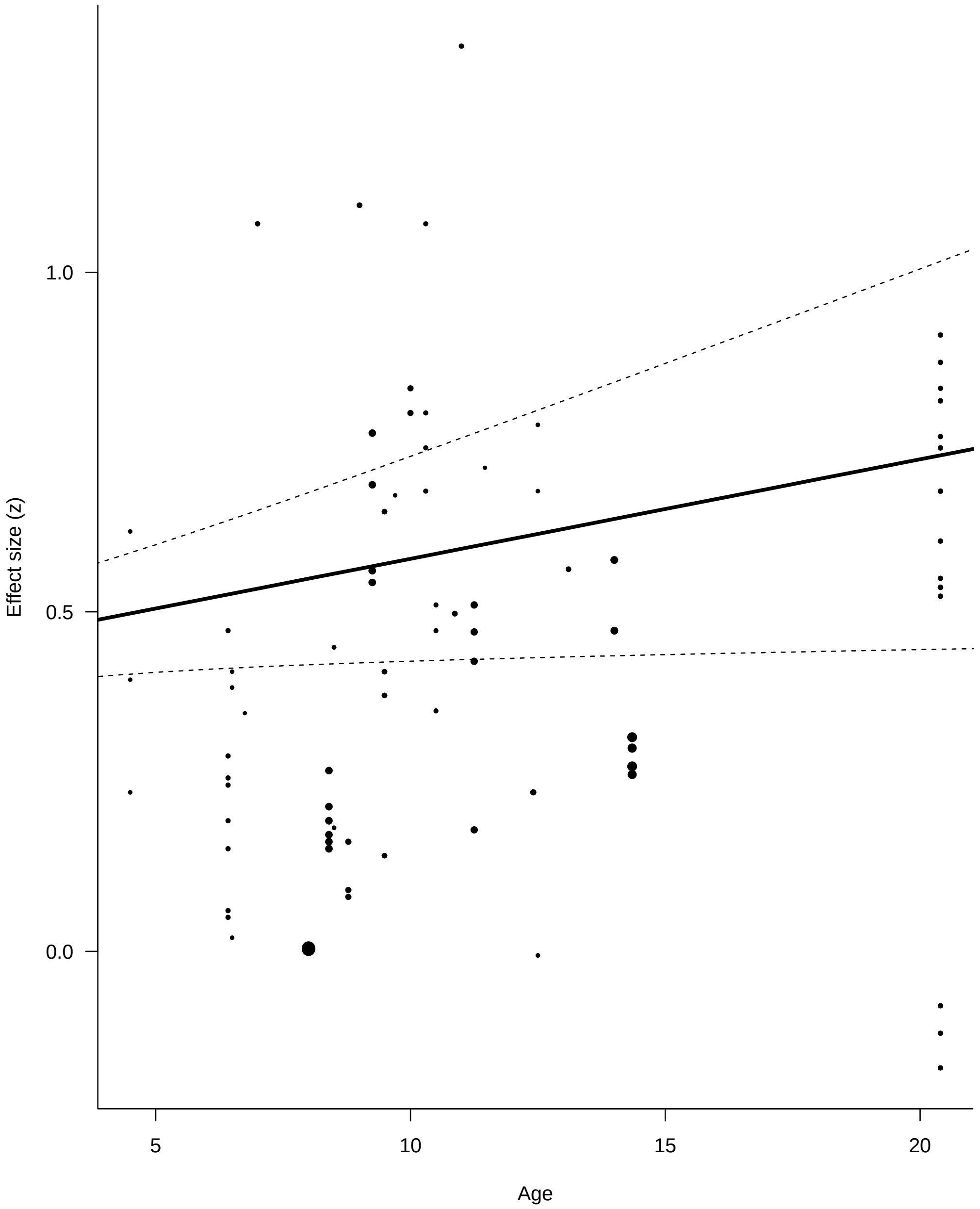

Figure 3. Illustration of the moderating effect of age in the relationship between physical fitness and motor competence. The size of the dots represent the sample size in each study.

For cardiorespiratory fitness an integrated effect size of z = .408 (r = .387, p < .001) was found while the effect size for musculoskeletal fitness was z = .445 (r = .418, p < .001). For musculoskeletal fitness, age was a significant moderator (r = .038, p = .035) while for cardiorespiratory fitness no significant moderation was found (p = .58, see Table 2).

In order to test for publication bias, Egger's regression test for asymmetry was used and showed a significant result (z = 2.03, p = .043). Further, the rank correlation test (τ = .051, p = .50) was not significant. Trim and fill method did not reveal any publication bias. Therefore, the overall model results after correction did not change and, overall, we concluded that no publication bias is present, which is supported by the funnel plot for asymmetry test (for a Figure of the funnel plot, see osf.io/p36rq/).

Table 2
Fit statistics for the random effects meta-regression. Age was grand mean centered for the moderation analysis.

Model	*z*	CI95	*r*	CI95	*p*
Overall physical fitness					
Random effects model (k = 87) for overall physical fitness					
Intercept	.435	.371 – .498	.409	.355 – .461	< .001
Age	.015	.001 – .028	.015	.001 – .028	.030
Overall physical fitness					
Clustered random-effects model for overall physical fitness with 32 clusters and 87 outcomes and small-sample correction					
Intercept	.434	. .341 – .527	.409	.329 – .483	< .001
Age	.015	-.015 – .045	.015	-.015 – .045	.182
Cardiorespiratory fitness					
Clustered random-effects model for overall physical fitness with 10 clusters and 28 outcomes and small-sample correction					
Intercept	.410	.293 – .523	.388	285. – .483	< .001
Age	.019	-.041 – .119	.019	-.019 – .058	.058

Musculoskeletal fitness					
Clustered random-effects model for cardiorespiratory fitness with 17 clusters and 28 outcomes and small-sample correction					
Intercept	.408	.246 – .570	.387	.241 – .515	< .001
Age	.038	.007 – .070	.038	.007 – .069	.035

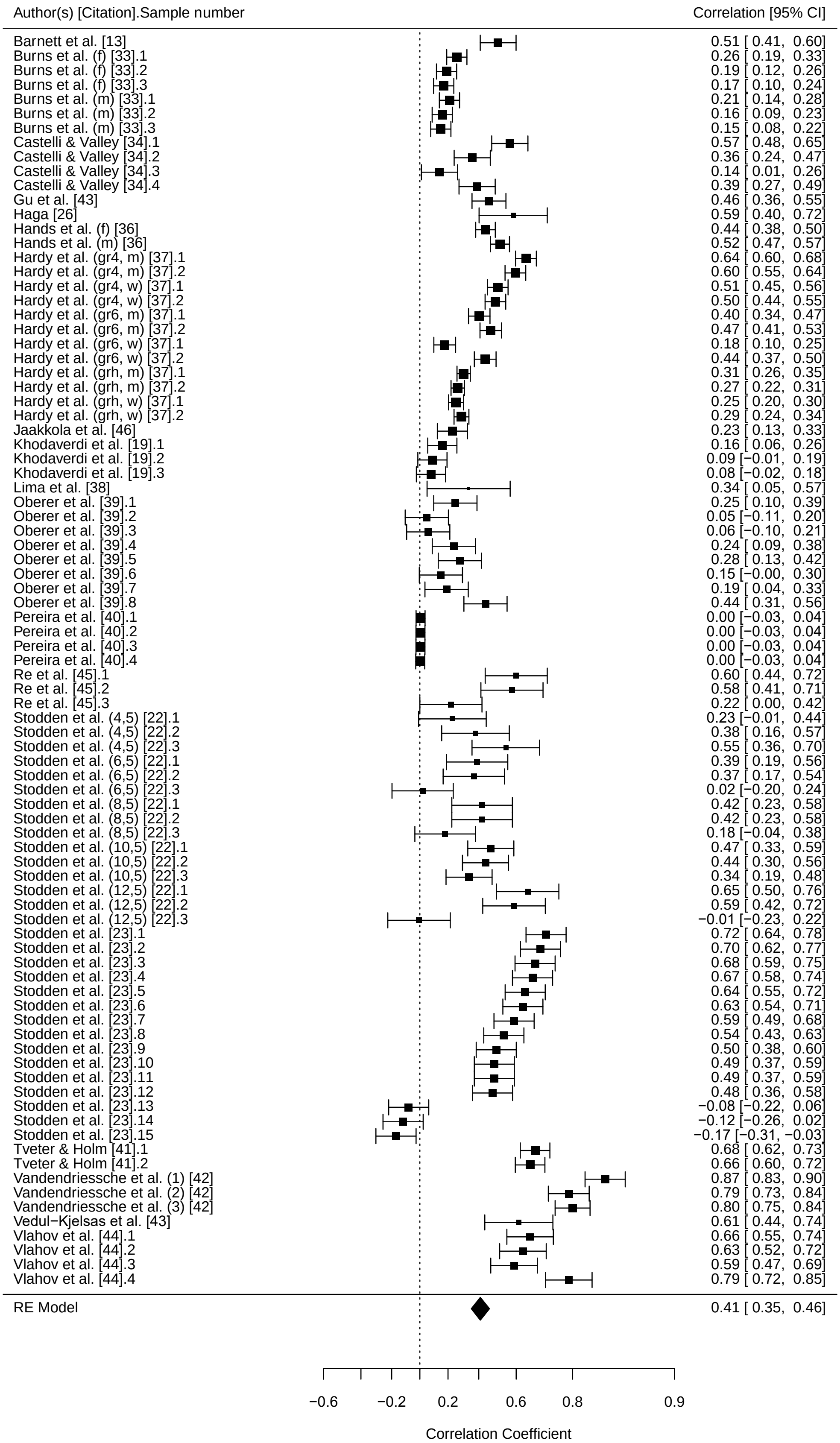

Figure 2. Forest plot of the ‘intercept meta-regression’ for associations between fitness and motor competence for k = 87 measures. ‘RE Model’ = Random Effects Model, indicating the overall effect size. The size of the black squares illustrates the sample size in each study.

Discussion

This study sought to conduct a meta-analysis on the available evidence on the relationship between motor competence and physical fitness from early childhood to early adulthood and explore the moderating role of age therein. Additionally, relationships between motor competence and subdomains of physical fitness (i.e., cardiorespiratory and musculoskeletal fitness) were examined.

The meta-analysis of 19 studies revealed moderate-to-large positive associations between motor competence and physical fitness. These findings are in line with previous literature reviews [5,11,20]. Nevertheless, there seems to be more common variance between motor competence and fitness measures than expected based on previous discussions in the literature [24]. It can be assumed that, even though motor competence and physical fitness are theoretically distinct constructs, they are closely linked. That is, numerous motor and fitness tasks require a high amount of neuromuscular control (e.g., motor unit recruitment, optimal co-activation of agonist/antagonist muscles) for efficient and coordinated movement [20]. Indeed, tests (i.e., single test items and comprehensive test batteries) included in the meta analysis are assessing complex physical performance (i.e., either motor competence or physical fitness). Furthermore, as indicated by Bardid et al. [55] and Fransen et al. [56], physical fitness can influence performance on motor competence tests to varying degrees [55,56]. For instance, musculoskeletal fitness may be measured to a greater extent in the KorperkoordinationsTest fur Kinder (KTK) [57,58] than in the Movement Assessment Battery for Children (M-ABC) [59]. It should be noted that the shared variance between motor competence and physical fitness tests may also be related to an overlap in content between these tests. Moreover, some tasks such as standing broad jump are used as either a motor competence or physical fitness measure.

The development of motor competence and physical fitness is not only linked directly via neuromuscular function, but also indirectly via participation in physical activity, as noted by

Cattuzzo et al. [20]. Engagement in physical activity positively influences both motor competence and various components of physical fitness [4]. The moderate relationship between motor competence and musculoskeletal fitness can be explained by degree of physical effort needed to perform locomotor and object control skills [60]. Performing a motor skill requires high levels of intra- and intermuscular control and coordination in order to accelerate and stop multi-joint micro movements with respect to the requested task (i.e., goal-directed movement), regardless whether it is to throw a ball or to perform a push-up. Additionally, learning and mastering any motor skill requires many repetitions, which does not only enhance musculoskeletal fitness but can also positively influence cardiorespiratory fitness [61]. This could explain the moderate to large associations between motor competence and cardiorespiratory fitness [20]. Many specific yet neuromuscular comparable skills must be performed in most sports (e.g., dribbling, kicking, striking, jumping, running and galopping). These motor skills require similar and different levels of physical fitness, as well as neuromuscular coordination and control. Thus, the results indicate a co-development of both motor skills and different aspects of physical fitness.

The present findings further showed that the relationship between motor competence and overall physical fitness is quite similar compared to the relationship between motor competence and cardiorespiratory or musculoskeletal fitness. It should be noted that current research has mainly focused on investigating associations between motor competence and cardiorespiratory or musculoskeletal fitness. In contrast, limited research has been conducted with regard to other components of physical fitness such as flexibility. It was therefore not possible to sythezise empirical evidence regarding the relationship between motor competence and flexibility in the present meta-analysis.

Stodden and colleagues [4] hypothesized that the size of the relationship between motor competence and physical fitness increases with age. In alignment with previous reviews by Cattuzzo et al. [20] and Robinson et al. [5], which support this change in a qualitative synthesis, the present meta analysis extends this finding by providing a quantitative synthesis and measure to describe the positive changes in the association across age. However, results show that there is a lack of studies investigating the relationship between motor competence and physical fitness in children younger than 7-8 years and adolecents older than 14-15 years. More research is needed in these age groups in order to ensure a more comprehensive understanding of the relationship between motor competence and physical fitness across age.

The overall findings indicate that, on average, motor competence and physical fitness share 16-20% common variance with a positive moderating effect of age. Still, the meta-analytical integration of many studies cannot reveal how much of the remaining variance is due to aspects such as non-measured effects or measurement error in the included studies. However, this statistical approximation of an overall effect size was necessary in order to refine the understanding of the relationship between motor competence and physical fitness as the original effect sizes were very heterogeneous showing that single studies used various assessments and provided different effect sizes. These findings demonstrate the importance of selecting an appropriate assessment tool in order to accurately evaluate young people's motor competence and physical fitness and to develop tailored intervention programs [62].

A strength of this meta-analysis is the large number of 15,984 participants and the variety of assessments of motor competence and physical fitness that is covered. Furthermore, test of publication bias showed that the present meta-analysis provided a solid measure of the effect size regarding the relationship between motor competence and physical fitness. However, this study is not witout limitations. For instance, the present study has mainly used cross-sectional data, which does not allow to determine causality in the co-development of motor competence and physical fitness across time. Although both cross-sectional and longitudinal data have been included in the meta-analysis, these have not been analyzed separately due to the limited number of longitudinal studies. In view of this, caution is warranted when interpreting the findings regarding the role of age in the association between motor competence and physical fitness as it does not fully reflect a developmental perspective. Aside from age, various other factors such as sex, body composition and intensity/type of physical activity can further influence the relationship between motor competence and physical fitness [63,64] and should be considered in future research. Furthermore, various tests that capture different aspects/domains of motor competence and physical fitness, have been used in the literature included in the meta-analysis. In order to better understand the dynamic relationship between motor competence and physical fitness, it will be important to reach an international consensus among researchers on how motor competence and physical fitness are defined, operationalised and measured. This also includes a clear differentiation between fine and gross motor skills. Finally, the role of performance level in the relationship between motor competence and physical fitness should also be investigated in future studies. Analogous to the study of Blum and Holling [65] on cognitive ability, the construct of motor competence may vary across performance levels and age. This will in turn influence associations between motor competence and physical fitness.

Conclusion

The present meta-analysis of 87 individual effect sizes and more than 15,000 participants revealed a moderate-to-large positive relationship between motor competence and physical fitness from early childhood to early adulthood. Additionally, there was a significant change in this relationship across age. These findings indicate that the development of motor competence and physical fitness are linked directly via neuromuscular function and indirectly via physical activity participation and other factors [20]. As such, interventions should target both motor competence and physical fitness from early childhood onwards in order to promote positive trajectories of health. The present study also underscores the need to define and operationalize motor competence and physical fitness more concisely, as shown by the large overlap in tasks included in either motor competence or physical fitness tests.

Declarations

Data Availability Statement

The data that support the findings of this study are made available on the Open Science Framework (OSF) (http://doi.org/10.17605/OSF.IO/P36RQ or https://osf.io/p36rq). This includes the final data file and R script used to conduct the meta-analysis, and the BibTex files that cover all records retrieved from the literature search.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing Interests

Till Utesch declares that he has no competing interests.

Farid Bardid declares that he has no competing interests.

Dirk Büsch declares that he has no competing interests.

Bernd Strauss declares that he has no competing interests.

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Authors' contributions

Dr. Till Utesch conceptualized the study, coordinated and supervised data collection, carried out the data analyses, drafted and revised the manuscript, and approved the final manuscript as submitted.

Dr. Farid Bardid conceptualized the study, contributed to drafting and revising the manuscript, and approved the final manuscript as submitted.

Prof. Dr. Dirk Büsch critically conceptualized the study, critically reviewed the manuscript, and approved the final manuscript as submitted.

Prof. Dr. Bernd Strauss conceptualized the study, critically reviewed the manuscript, and approved the final manuscript as submitted.

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