

# School Children's Physical Activity, Motor Competence, and Corresponding Self-Perception: A Longitudinal Analysis of Reciprocal Relationships

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**Background:** The relationship between engagement in physical activity and the development of motor competence (MC) is considered to be reciprocal and dynamic throughout childhood and adolescence. The 10-month follow-up study aimed to explore this reciprocal relationship and investigated whether the relationship is mediated by the corresponding self-perception of MC (PMC). **Methods:** A total of 51 children aged between 10 and 11 years ( $M = 10.27 [0.45]$ ) participated in the study (52.9% boys, 47.1% girls). As an indicator for physical activity, the average vigorous physical activity (VPA) per day was measured by ActiGraph accelerometers. Two aspects of MC and PMC were recorded: self-movement and object movement. Saturated pathway models in a cross-lagged panel design with 2 measurement points were analyzed. **Results:** Reciprocal and direct relationships between VPA and MC object movement respectively MC self-movement were not found in longitudinal analyses with PMC as a mediator. Indirect effects of MC at t1 on VPA at t2 via PMC were identified (self-movement:  $\beta = 0.13$ , 95% confidence interval, 0.04 to 0.26; object movement:  $\beta = 0.14$ , 95% confidence interval, 0.01 to 0.49). **Conclusion:** The results highlight the importance of MC and PMC in promoting children's VPA. However, VPA does not drive the development of MC.

**Keywords:** MOBAK, SEMOK, fundamental movement skills, motor proficiency

Physical activity (PA) is considered to be important for health and well-being.<sup>1,2</sup> The promotion of PA is therefore a priority for public health agencies, as well as one of the central objectives of interventions in the field of disease prevention and health promotion.<sup>3,4</sup> While interventions can improve PA, it remains to be clarified which correlates should be targeted to ensure that interventions for children and adolescents are optimized.<sup>5</sup>

Theoretical frameworks and empirical studies regarding children's motor development have focused on the association between motor competence (MC) and PA.<sup>6,7</sup> Stodden et al<sup>8</sup> assumed that the development of MC is a primary underlying causal mechanism that is partially responsible for commitment and persistence in PA. They described the relationship between PA and MC as reciprocal and developmentally dynamic throughout an individual's lifespan. It is hypothesized that the relationship among variable levels of MC and PA is weak in early childhood and will strengthen with the transition to late childhood. In addition, Stodden et al<sup>8</sup> assumed that, in early childhood, PA is mainly responsible for the development of MC, whereas this relationship changes with the transition to later childhood, and MC increasingly drives PA.

In their theoretical concept, Stodden et al<sup>8</sup> highlighted perceived MC (PMC) as a mediator (besides health-related fitness) that differentially influences the relationship between PA and MC over time. PMC refers to an individual's perception of his or her actual

MC. This self-perception of MC may be understood as a latent construct based on subjective self-assessments of single instances of performing specific motor tasks (eg, catching or throwing a ball). It is a result of continually assessing one's performance in terms of meeting specific demands and combining these assessments into a general self-perception of MC.<sup>9</sup> Estevan and Barnett<sup>10</sup> proposed a hierarchical and multidimensional structure of a global self-concept, with PMC considered to be a subdomain of perceived sport/athletic competence, and subdivided it into different subdomains (eg, locomotion, object control). Stodden et al<sup>8</sup> hypothesized that children can increasingly assess their actual MC more realistically with the transition from middle to late childhood. At these stages of development, actual MC drives PA not only directly but also indirectly via PMC.

Recent reviews have provided support for the theoretical concept developed by Stodden et al,<sup>8</sup> mainly based on cross-sectional studies involving children.<sup>7,11-15</sup> Key points of these reviews are the following: (1) evidence indicates positive associations between MC, PMC, PA, and health-related physical fitness (HRF); (2) there is preliminary support for PMC as a mediator; (3) the results on the relationships between the variables of interest do appear to depend on the mode of their operationalization and the age or developmental stage of the study participants; (4) whether and how the strength of associations changes over the course of development remains largely unclear; (5) also, questions on the reciprocity and causality of the relationship between MC and PA (antecedent/consequent mechanisms) remain unanswered.

Since the publication of these reviews, a growing number of longitudinal studies investigating the causal or reciprocal relationship between MC and PA, as well as the potential mediators of this relationship in childhood and adolescence, have been noted.<sup>16-20</sup> The results of the Copenhagen School Children Intervention Study<sup>18</sup> indicated a reciprocal relationship between MC and PA over 7 years from early to late childhood. The level of MC achieved

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in late childhood was predicted by PA in early childhood. Conversely, young children's level of MC proved to be a significant predictor of their PA level 7 years later. This relationship was mediated in both directions by HRF. Mediation via PMC was not tested. Vigorous PA (VPA) was directly and indirectly associated with MC, but moderate-to-vigorous PA (MVPA) and MC are only indirectly connected via HRF mediation.<sup>18</sup> In addition, cross-sectional studies provided preliminary support for the reciprocal nature of the relationship between PA and MC, taking into account PMC or HRF.<sup>16,21,22</sup> In a study with older Finnish children, Jaakkola et al<sup>16</sup> tested the longitudinal association between MC and MVPA in both directions, including PMC and HRF as mediators. They interpreted their results as almost fully consistent with the Stodden et al<sup>8</sup> concept. The data suggest MVPA as a stronger predictor (directly and indirectly) of MC, as opposed to MC predicting MVPA. PMC and HRF mediated the relationship between MVPA and MC in both directions.<sup>16</sup> Recent longitudinal studies examining only one direction of the PA–MC relationship also supported the theoretical concept.<sup>17,19,23</sup> It should be noted that the direct or indirect effects identified in these studies are of small to medium size.

Barnett et al<sup>12(p1684)</sup> recommended further investigating the nuances of the PA–MC relationship “to be able to tease out exactly what sorts of activity better contribute to what sort of MC (and the reverse) at different ages.” Several studies have demonstrated that subdomains of MC could be of different relevance.<sup>21,22,24</sup> Furthermore, longitudinal studies have suggested that the causal relationship between PA and MC becomes empirically evident with the transition from middle childhood to adolescence.<sup>17–19</sup>

It is also recommended to investigate the importance of different PA intensity levels for the development and promotion of MC, fitness, and health.<sup>24</sup> Longitudinal studies have shown that the relationship between PA and MC becomes empirically evident in late childhood and early adolescence, particularly when objectively measured VPA is considered.<sup>17–19</sup> Furthermore, studies with children and adolescents found that VPA is more closely connected to health-related fitness and health benefits than lower PA intensity levels.<sup>25</sup>

It is noticeable that each of the 2 directions of the hypothesized reciprocal relationship between PA and MC has so far only been tested in isolation. Also, limited studies with a focus on the reciprocal nature of the PA–MC relationship in middle to late childhood have considered PMC, VPA, or subdomains of MC. In the present study, these shortcomings were taken into account. The purpose of this study was to investigate (1) the reciprocal relationship between VPA and MC and (2) the mediating influence of corresponding self-perceptions of MC on the relationship between VPA and MC.

## Methods

### Participants

The study was conducted in 2 similar schools, located in small towns in rural eastern Germany. A convenience sample of 51 fifth graders (52.9% boys, 47.1% girls) aged between 10 and 11 years ( $t_1$ :  $M = 10.27$ ,  $SD = 0.45$ ) participated voluntarily in the study. None of them met the following exclusion criteria: regular drug intake, absence of upper/lower extremity, prevalence of chronic or acute diseases that could possibly restrict PA during everyday life.

### Measures

VPA was measured objectively by triaxial accelerometers (ActiGraph wGT3X-BT, ActiGraph, Pensacola, FL). The devices were

worn on the wrist of the nondominant hand during waking and sleeping hours for 7 consecutive days (except during water-based activities). Prior work has suggested that children's compliance is higher when accelerometers are worn on the wrist compared with on the hip.<sup>26</sup> One conclusion of this finding was that the use of ActiGraph accelerometers on the wrist can encourage increased wear time, which may provide a more accurate assessment of PA under everyday conditions.<sup>27</sup> Chandler et al<sup>28</sup> recommended placement on the nondominant wrist because it may improve user compliance with regard to wear time and monitor position and decrease counts during sedentary activity. To determine the non-wear time, the Troiano algorithm<sup>29</sup> was used. If the wear time was at least 70% per day, the measurements were considered valid on those days. In the following data analyses, only students with valid measurements for at least 5 days (with  $\geq 1$  weekend day and  $\geq 3$  weekdays) were included.<sup>30</sup> An algorithm proposed by Mattocks et al<sup>31</sup> and the cut point of 6130 threshold counts per minute were used to calculate VPA per day (in minutes) with the ActiGraph data analysis software ActiLife (ActiGraph).

MC was recorded with the MOBAK-5-6 test instrument for fifth and sixth graders aged between 10 and 12 years.<sup>32</sup> The MOBAK-5-6 provides an approach for diagnosing and evaluating context-dependent performance dispositions and enables curricularly valid and grade-specific MC measurements in physical education classes.<sup>33,34</sup> This instrument focuses on the functional mastery of motor demands and achievement of the movement goal by means of general MC. The operationalization of actual MC is based on the consideration of what a child should be able to perform at a certain age level in order to participate actively in the culture of sport and exercise. With 8 items (Table 1), MOBAK-5-6 depicts 2 factors that can be understood as MC: self-movement (MC-SM; balancing, rolling, jumping, and running) and object movement (MC-OM; throwing, catching, bouncing, and dribbling). Each test item must be explained by a test leader (including a one-time demonstration of correct performance) immediately before the children perform it. The children had several attempts each (no trial run) to complete the test items. MC-OM and MC-SM are sum scores (with a value range of 0–8) calculated from results on each of the 4 content-related MOBAK-5-6 test items. High scores indicate well-developed MC. A more accurate description of the assessment procedure is provided in Table 1 and the test manual.<sup>32</sup> Herrmann and Seelig<sup>34</sup> reported initial evidence for the construct and criteria validity of MOBAK-5-6. This study confirms that the test items represent a 2-factor structure with a satisfactory overall factor reliability (MC-OM:  $FR = 0.85$ ; MC-SM:  $FR = 0.59$ ).

PMC was measured with the SEMOK (Selbstwahrnehmung der motorischen Kompetenz) questionnaire for fifth-grade students and older.<sup>9</sup> The 8 items of the SEMOK are designed to complement the 8 items of the MOBAK-5-6 (Table 1). They refer to children's self-assessment of whether they are capable of meeting the basic motor demands formulated from physical education curriculum standards. Equivalent to the 2-factor structure of MOBAK-5-6, SEMOK items also depict 2 factors: self-movement (PMC-SM; based on self-perceptions regarding balancing, rolling, jumping, and running) and object movement (PMC-OM; based on self-perceptions regarding throwing, catching, bouncing, and dribbling). PMC-OM and PMC-SM are mean scores (with a value range of 1–5) calculated from self-reported information on each of the 4 content-related SEMOK items. High scores indicate positive self-perceptions of MC. As part of the validation study,<sup>9</sup> (1) the construct and criteria validity of SEMOK were evaluated

**Table 1 Test Items of MOBAK-5-6 and SEMOK**

<b>MOBAK-5-6 test items<sup>30</sup></b>		<b>SEMOK test items<sup>9</sup></b>	
<b>Indicators of basic motor competence</b>	<b>Description</b>	<b>Scoring</b>	<b>Item wording (German original)<sup>a</sup></b>
<b>Object movement</b>			
Throwing	The child throws a juggling ball at a target 1.3 m in height from a scratch line at a distance of 3.5 m (6 attempts).	0 points = 0 to 2 successful attempts 1 point = 3 to 4 successful attempts 2 points = 5 to 6 successful attempts	I can hit a target with a ball. (Ich kann ein Ziel mit einem Ball treffen.)
Catching	The child throws a tennis ball at a wall from a scratch line at a distance of 4.0 m. The child catches the tennis ball directly in the air when it bounces back (6 attempts).	0 points = 0 to 2 successful attempts 1 point = 3 to 4 successful attempts 2 points = 5 to 6 successful attempts	I can catch a ball securely. (Ich kann einen Ball sicher fangen.)
Bouncing	In a marked corridor (8,0 × 1.1 m) with 4 obstacles 0.7 m in width, the child bounces a basketball (size 6) around the obstacles without losing the ball. The child has a maximum of 25 s for this (2 attempts).	0 points = 0 successful attempts 1 point = 1 successful attempt 2 points = 2 successful attempts	I can bounce a ball with my hands (eg, in basketball). (Ich kann einen Ball mit der Hand prellen [z. B. beim Basketball].)
Dribbling	In a marked corridor (8,0 × 1.1 m) with 4 obstacles 0.7 m in width, the child dribbles a futsal ball (size 4) through the corridor and around the obstacles without losing the ball. The child has a maximum of 25 s for this (2 attempts).	0 points = 0 successful attempts 1 point = 1 successful attempt 2 points = 2 successful attempts	I can dribble a ball with my feet (eg, in football). (Ich kann einen Ball mit dem Fuß dribbeln [z. B. beim Fußball].)
<b>Self-movement</b>			
Balancing	The child balances forward and backward across a long bench (placed on a springboard to create a seesaw) and crosses 2 wooden blocks (L 18 × H 6 × W 9 cm) taped to the bench without stepping on them (2 attempts).	0 points = 0 successful attempts 1 point = 1 successful attempt 2 points = 2 successful attempts	I can balance on a narrow beam. (Ich kann auf einem schmalen Balken balancieren.)
Rolling	The child performs a diving forward roll starting with a jump over a banana box (L 52 × H 23 × W 39 cm; 2 attempts).	0 points = 0 successful attempts 1 point = 1 successful attempt 2 points = 2 successful attempts	I can perform a forward roll from a jump. (Ich kann eine gesprungene Rolle vorwärts turnen.)
Jumping	The child skips rope on the spot for 20 s, changing rhythm after 10 s (2 attempts).	0 points = 0 successful attempts 1 point = 1 successful attempt 2 points = 2 successful attempts	I can change rhythm while jumping rope. (Ich kann beim Seilspringen den Rhythmus wechseln.)
Running	In a square (4,0 × 4,0 m), the child passes quickly through 3 hoops (diameter 80 cm) lying on the ground and changes the running style to fast side steps without crossing the legs. The direction and style of running are to be changed twice (2 attempts).	0 points = 0 successful attempts 1 point = 1 successful attempt 2 points = 2 successful attempts	I can change my rhythm when running. (Ich kann beim Laufen meinen Rhythmus wechseln.)

<sup>a</sup>SEMOK items were tested in the German version. Answering format: 1 = not at all, 2 = not well, 3 = only some parts well, 4 = fairly confidently, 5 = fully confidently.

successfully, (2) a tight link between MC and PMC was verified, and (3) the 2-factor model showed good overall FR (PMC-OM: FR = 0.75; PMC-SM: FR = 0.77).

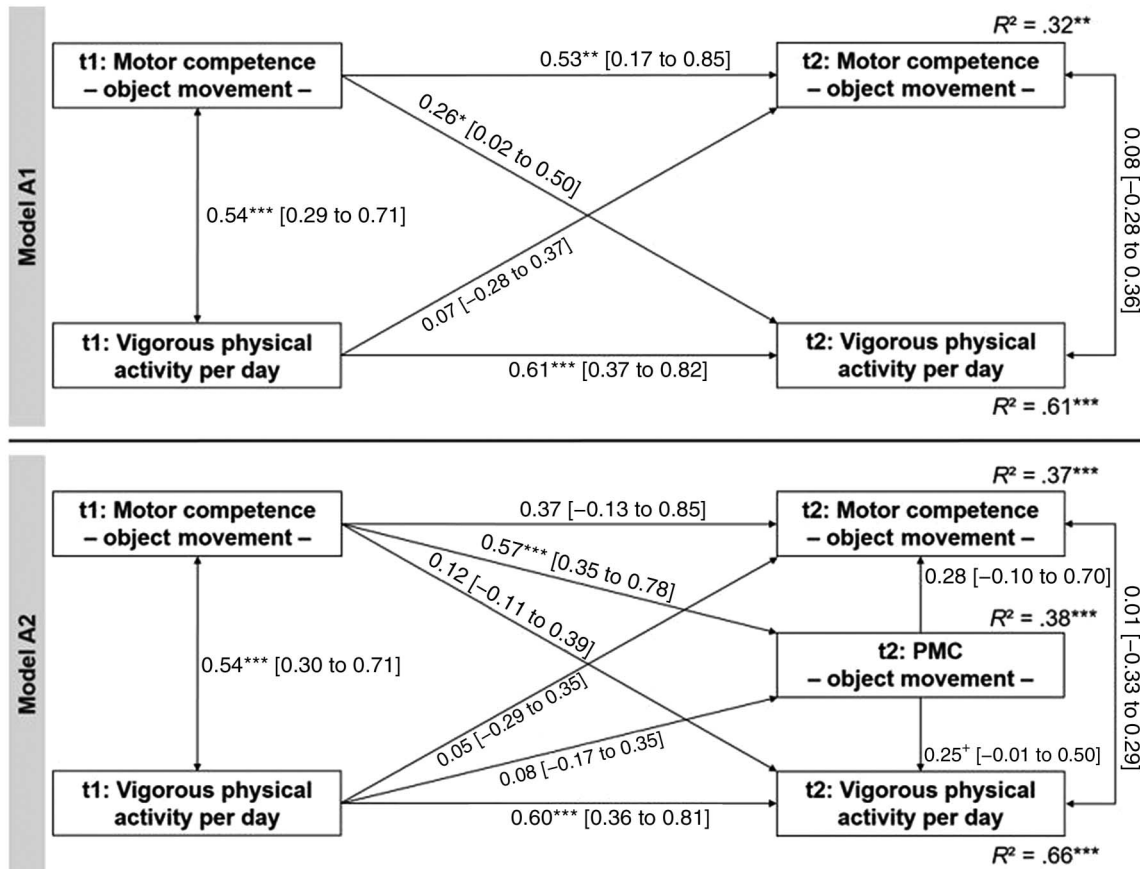
**Procedure**

This investigation was designed as a longitudinal field study with 2 points of measurement 10 months apart (t1: August 2016, t2: June 2017). Data were collected by research assistants. In a 3-hour training session, they were introduced to the test instruments and protocols. The teachers of the tested children were not involved in the data collection. At both times, VPA was measured first. After measuring VPA, MC was tested on the same day in sports halls during physical education lessons. Classes were divided into 5 to 8 small groups of 3 to 4 children. Each group was guided and assessed live by a research assistant. During the test sessions, all research assistants were supervised by a senior researcher who is a professional in sports and educational sciences. One test session lasted between 50 and 70 minutes. One week before MC was tested at t2, PMC was recorded within 4 to 6 minutes during a classroom survey. The testing order was chosen to (1) ensure the necessary temporal proximity of the tests and (2) prevent the participants' experiences and results of the MC assessment from influencing their current PMC and everyday PA.

The study was approved by the local school ministries and the University of Leipzig (Medical Faculty) ethics committee. All research procedures and methods in this study were in line with the Declaration of Helsinki. Assent and informed consent were provided by the children and their legal guardians, respectively.

**Data Analysis**

Data analyses were performed using Mplus (version 8.4; Muthén & Muthén, Los Angeles, CA).<sup>35</sup> The data were thoroughly tested for their suitability for the applied statistical methods. No serious violations of requirements (eg, homoscedasticity, linearity, normality of residuals) were identified. Four saturated pathway models in a cross-lagged panel design were analyzed. These models contained only manifest variables (Figures 1 and 2). Models A1 and A2 focused on the relationship between VPA and MC-OM. In models B1 and B2, VPA was associated with MC-SM. All models considered the VPA and MC data from t1 to t2. In addition, the self-perception of MC at t2 was included as a mediator variable in models A2 (PMC-OM) and B2 (PMC-SM). Parameters were estimated using the robust maximum likelihood estimation algorithm, and the models in which the variables had missing values were estimated using the full information maximum likelihood algorithm.<sup>36</sup> The data analysis included 15 students with partially incomplete data. There were 21 missing single values randomly appearing throughout all items (5.2%). The main reason was illness-related absence from physical education. Standardized  $R^2$  and  $\beta$  values, corresponding 95% confidence intervals (CIs; based on 5000 bias-corrected bootstraps), and  $P$  values were used to describe total, direct, and indirect effects. Indirect effects (based on mediation via PMC) were tested with a variant of the Sobel test implemented in Mplus. A 95% CI without including zero was primarily used to identify significant effects but also a  $P$  value  $\leq .05$ . Effect sizes were interpreted as *small* ( $R^2 > .02$ ,  $r > .10$ ,  $\beta > 0.05$ ),



**Figure 1** — Pathway models with a focus on the relationships between motor competence (object movement), vigorous physical activity, and PMC (perceived motor competence; object movement). Coefficients of determination ( $R^2$ ), standardized regression coefficients ( $\beta$ ), and 95% confidence intervals are presented. \* $P \leq .05$ , \*\* $P \leq .01$ , \*\*\* $P \leq .001$ , + $P \leq .10$ .

medium ( $R^2 > .15$ ,  $r > .30$ ,  $\beta > 0.25$ ), and large ( $R^2 > .35$ ,  $r > .50$ ,  $\beta > .45$ ).<sup>37,38</sup>

## Results

Descriptive statistics are reported in Table 2. Bivariate analyses of relationships among individual data at t1 and t2 suggested a high temporal stability of VPA ( $r = .76$ ,  $P < .001$ ), MC-OM ( $r = .57$ ,  $P < .001$ ), and MC-SM ( $r = .64$ ,  $P < .001$ ). In the multivariate and longitudinal analyses, the temporal stabilities of VPA and MC from t1 to t2 were reflected in significant pathways with large effect sizes (Figure 1: model A1; Figure 2: model B1). For example, the majority of children who spent more time on VPA or had a higher level of MC than other children at t1 also did so at t2.

### Reciprocal Relationships Between VPA and MC

There is a strong and positive association between MC-OM and VPA at t1 (Figure 1: model A1). However, a cross-sectional association between MC-SM and VPA is absent at both time points (Figure 2: model B1). With a view of the cross-pathways in models A1 and B1, VPA at t1 does not contribute to the explanation of MC-SM or MC-OM at t2. The variances in MC-OM and MC-SM at t2 are explained solely by the previous level of the same MC subdomain. For the reverse direction, only the cross-pathway from MC-OM at t1 to VPA at t2 was significant. The level of MC-SM at t1 does not seem to be relevant for later engagement in VPA (Figure 1: model A1; Figure 2: model B1).

### PMC as a Mediator

With the inclusion of PMC as a mediator in the reciprocal relationship analysis, the temporal stability of MC-SM and VPA between t1 and t2 remained widely unchanged. However, the inclusion of PMC-OM led to a weakening of the direct association between MC-OM at t1 and MC-OM at t2. In the 2 models with PMC as a mediator, the proportion of explained variance ( $R^2$ ) regarding MC-OM at t2 (+ 5%), MC-SM at t2 (+ 1%), and VPA at t2 (model A2: 5%, model B2: + 7%), was higher than before. In

addition, VPA at t1 was not related to either PMC-OM or PMC-SM at t2 (Figures 1 and 2), so that VPA at t1 also had no specific indirect effects on MC-SM at t2 ( $\beta = 0.00$ ;  $P = .920$ ; 95% CI,  $-0.06$  to  $0.09$ ) and MC-OM at t2 ( $\beta = 0.02$ ;  $P = .626$ ; 95% CI,  $-0.03$  to  $0.17$ ). Consequently, there are no significant total effects of VPA at t1 on MC-SM at t2 ( $\beta = 0.16$ ;  $P = .251$ ; 95% CI,  $-0.12$  to  $0.42$ ) and on MC-OM at t2 ( $\beta = 0.07$ ;  $P = .683$ ; 95% CI,  $-0.29$  to  $0.37$ ).

The results for model A2 showed a moderate total effect of MC-OM at t1 on VPA at t2 ( $\beta = 0.26$ ;  $P = .025$ ; 95% CI,  $0.02$  to  $0.49$ ), but no direct effect as found in model A1 (Figure 1). This relationship seems to be mediated via PMC-OM (indirect effect:  $\beta = 0.14$ ;  $P = .077$ ; 95% CI,  $0.01$  to  $0.31$ ). A strong, positive relationship was revealed between MC-OM at t1 and PMC-OM at t2, meaning that a higher level of MC may lead to a more positive self-perception of MC in the future. However, a significant increase in VPA due to a more positive PMC-OM could not be definitely determined, although the effect size was moderate ( $\beta = 0.25$ ;  $P = .060$ ; 95% CI,  $-0.01$  to  $0.50$ ). In model A2, there was also an insignificant relationship between PMC-OM and MC-OM at t2.

Model B2 (Figure 2) indicates neither a total effect ( $\beta = 0.02$ ;  $P = .823$ ; 95% CI,  $-0.19$  to  $0.24$ ) nor a direct effect of MC-SM at t1 on VPA at t2 but a small indirect effect via PMC-SM ( $\beta = 0.13$ ;  $P = .023$ ; 95% CI,  $0.04$  to  $0.26$ ). Similar to MC-OM in model A2, a higher level of MC-SM at t1 promotes more positive self-perception in the corresponding subdomain of MC at t2. Furthermore, a more positive PMC-SM contributes to significantly increased time per day in VPA at t2 (model B2).

Comparing models A2 and B2, it is remarkable that MC-OM at t1 explained 38%, and MC-SM at t1 26%, of the variance in the corresponding PMC. However, the proportion of explained variance in the 2 dependent variables (MC and VPA at t2) is of similar magnitude in both models.

## Discussion

The aim of this study was to investigate reciprocal relationships among VPA, MC, and PMC. Pathway models in a cross-lagged panel design were created to examine both directions of the reciprocal relationship between MC and VPA simultaneously, including PMC as a mediator. To our knowledge, this is the first longitudinal study to test assumptions of the theoretical concept of Stodden et al<sup>8</sup> in this way.

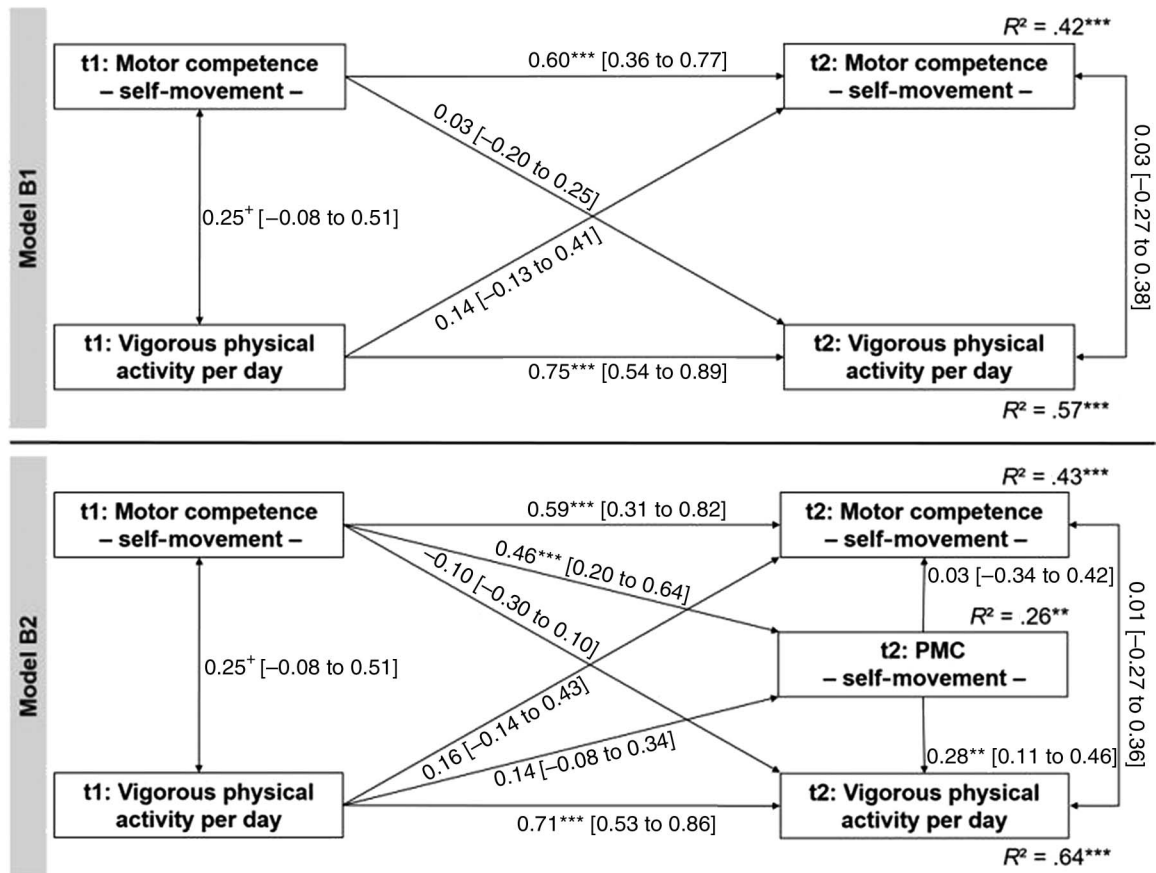
In accordance with the theoretical concept,<sup>8</sup> it was expected that children from middle childhood onward would be able to progressively assess their MC realistically. This assumption is supported by the revealed large and positive effect of MC at t1 on PMC at t2. This relationship was also found—albeit less strong—by cross-sectional studies.<sup>16,21,22</sup> The different effect sizes may be due to a more general assessment of PMC that was not aligned with the assessed MC in these studies.<sup>10</sup>

It was also hypothesized that from the moment children begin to perceive their MC more realistically, the MC-PA relationship will be increasingly mediated by PMC. The indirect effect of MC-SM at t1 on VPA at t2 revealed here indicates the importance of PMC as a mediator. This result is in accordance with the theory and suggests that higher levels of MC may provide greater opportunities to engage in various and more demanding physical activities. Previous studies also found indirect effects of similar size.<sup>16,21,22</sup> Contrary to these studies, no direct effect of MC on PA was detected as soon as PMC was considered to be a mediator. An obvious reason for this might be the aforementioned strength of the longitudinal association between MC and PMC. However, the

**Table 2 Results of Descriptive Analysis**

Variables	Number of items	Measurement time	N	M	SD
VPA (average minutes per day)	1	t1	47	51.35	26.72
		t2	45	52.74	20.38
MC-OM (sum score of 0–8)	4	t1	51	3.04	2.00
		t2	46	4.09	1.92
MC-SM (sum score of 0–8)	4	t1	51	3.51	1.72
		t2	44	4.52	1.82
PMC-OM (mean score of 1–5)	4	t2	51	3.87	0.75
PMC-SM (mean score of 1–5)	4	t2	51	3.96	0.71

Abbreviations: MC, motor competence; OM, object movement; PMC, perceived motor competence; SM, self-movement; VPA, vigorous physical activity.



**Figure 2** — Pathway models with a focus on the relationships between motor competence (self-movement), vigorous physical activity, and PMC (perceived motor competence; self-movement). Coefficients of determination ( $R^2$ ), standardized regression coefficients ( $\beta$ ), and 95% confidence intervals are presented. \* $P \leq .05$ , \*\* $P \leq .01$ , \*\*\* $P \leq .001$ , + $P \leq .10$ .

positive and direct relationship between PMC and VPA at t2 corresponds to the theoretical concept<sup>8</sup> and previous findings.<sup>11,16,23</sup>

Contrary to the assumption of a causal and reciprocal relationship between PA and MC, no direct or indirect effect of VPA at t1 on MC at t2 was found. This result also seems to contradict the results of other studies, which found indirect effects (via PMC) and, occasionally, direct effects of PA on MC.<sup>16,21,23</sup> This difference may be due to the fact that these studies used cross-sectional data, referred to slightly older participants, and tested PMC not in relation to MC using a task-specific and aligned scale. The last point should especially be emphasized because no evidence for the impact of PA on PMC<sup>39</sup> or PMC on MC<sup>40</sup> was found in studies using aligned instruments for MC and PMC. Barnett et al<sup>39</sup> explained the absence of a pathway from PA to PMC by pointing out that children may not perceive their MC as related to their engagement in (many) different types of PA (eg, swimming, cycling, climbing). To attain a more accurate understanding of the impact of PA on PMC, they suggested assessing self-perception in these types of PA, or specifically assessing MC as relevant to these different types of PA.

In summary, the assumed reciprocal relationship between MC and PA was not supported by this study's findings. MC seems to drive PA (at least indirectly) but not the reverse. Several studies have found different results for the associations among PA, MC, and PMC depending on the considered subdomains of MC.<sup>21,22,24,40</sup> The comparison of object movement and self-movement only revealed that the cross-sectional and longitudinal associations between

MC-OM and VPA tend to be slightly closer than between MC-SM and VPA when PMC is not considered to be a mediator. On the other hand, the comparison of subdomain-specific models A2 and B2 revealed similarities in the relationships between MC-VPA, MC-PMC, and PMC-VPA. However, the remarkable similarities between the 2 subdomains of MC support the maintenance of nonspecifically formulated assumptions in the theoretical concept.<sup>8</sup>

Besides the aforementioned strengths of this study, several limitations should be considered. First, the given sample allowed us to analyze saturated path models with the necessary test power to identify statistically significant medium to large effects. However, the sample size may not be sufficient to detect even small effects reliably. Therefore, the results should be interpreted with caution. Second, a more differentiated analysis of path models considering the potential impact of sex, body mass index, and socioeconomic status had to be omitted. Scientific reviews pointed out that these personal characteristics can have moderation effects on the relationships between MC, PMC, and PA.<sup>7,11,14,15</sup> Third, the analyzed data were partially incomplete. The missing values occurred mainly in the repeated collection of accelerometer data. A clearing of missing values using the full information maximum likelihood estimation algorithm was required. Although this may have caused data bias, there is some evidence that accelerometer data were considered to be missing at random.<sup>41</sup> Fourth, this study did not include HRF as a potential mediator besides PMC, which could provide more insights into the relationship between PA and MC.<sup>8</sup> Fifth, due to the selected study period of 10 months and the

age-homogeneous sample, only limited insights into the development of MC, PMC, VPA, and their relationships are given. Sixth, the consideration of MC and PMC is limited to object movement and self-movement. Other aspects of basic MC (eg, object locomotion, moving in water), which are also relevant for the promotion of motor development in school-based physical education, were not taken into account. It could be beneficial to use a more comprehensive measurement of MC and PMC to clarify the research questions examined here.<sup>42</sup> Last but not least, it should be noted that, with VPA, only a small part of children's PA was considered here. The results may not be generalizable to total PA or lower PA intensity levels. Previous studies have shown that the relationship between PA and MC are not independent of the PA intensity.<sup>18,19</sup>

## Conclusion

VPA did not predict MC. Conversely, MC-OM and MC-SM proved to be predictive of VPA after 10 months, but only when the relationship was mediated by the corresponding PMC. The comparison of object movement and self-movement revealed more similarities than differences in the examined relationships. The results correspond partially with the theoretical concept<sup>8</sup> and previous findings. This study suggests that MC and PMC should be considered as basic components in promoting children's VPA. Further longitudinal studies with larger samples, including different PA intensity levels and more moderator variables, are required to confirm, refute, or further deepen the presented results.

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