



Physical activity and motor skills in children: A differentiated approach

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ABSTRACT

Being physically active plays an essential role in a child's physical development. While there is ample evidence for a positive association between physical activity (PA) and motor skills in children, the question of how PA should be implemented to optimally foster motor skill proficiency is less clear. To address this gap, the current longitudinal study compared four groups of children with different patterns of leisure-time PA engagement—namely children engaging in either structured PA, unstructured PA, a combination of structured and unstructured PA, or no PA at all—with respect to their gross and fine motor skill development. Results of repeated measures mixed modeling procedures revealed that engaging in structured PA—either exclusively or in combination with unstructured PA—is beneficial for children's gross motor development, whereas engaging in unstructured PA lacks such effectiveness. As to fine motor skills, a beneficial tendency of structured PA was observed as well. Hence, PA seems to be beneficial for motor skill development particularly when implemented in a formal setting with guided opportunities for practice. In conclusion, regularly engaging in structured PA constitutes a promising way to promote motor skills and support motor development over the long term.

1. Introduction

Physical activity (PA) plays an essential role in children's and adolescents' lives, since it positively affects many aspects of physical and mental health (Biddle & Asare, 2011; Janssen & LeBlanc, 2010), fundamentally contributing to a positive social, emotional, and cognitive development (Ahn, Sera, Cummins, & Flouri, 2018; Donnelly et al., 2016; McNeill, Howard, Vella, Santos, & Cliff, 2018; Rasberry et al., 2011).

Furthermore, childhood PA promotes the development of motor skills (Iivonen & Sääkslahti, 2014; Zeng et al., 2017). Motor skill proficiency, in turn, is known to be an important factor accounting for future PA engagement and sports motivation (Ericsson, 2011), positive feelings toward physical education (Brown, Walkley, & Holland, 2005), and engagement in physically active play (Smyth & Anderson, 2000). Hence, motor skills play a fundamental role in the foundation of a life-long active lifestyle (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). Moreover, the mastery of motor skills, including gross and fine motor competence, has not only been shown to contribute to physical health and physical development, but also substantially contributes to cognitive and social development (Gashaj, Oberer, Mast, & Roebbers, 2019; Lubans et al., 2010), as it promotes self-esteem (Ericsson & Karlsson,

2011), higher-order cognitive skills (van der Fels et al., 2015), psychosocial adjustment, and school achievement (Bart, Hajami, & Bar-Haim, 2007).

From a theoretical perspective, there's genuine consensus that engaging in PA might be related to children's and adolescents' motor skills, since there is a longstanding belief that being physically active is essential to physical development in general (Seefeldt, 1986). More recently, Stodden and colleagues have outlined a developmentally dynamic model that assumes a reciprocal relationship between PA and motor development (Stodden et al., 2008; Robinson et al., 2015). According to this model, young children's PA plays an essential role in motor skill development, since it provides opportunities for experiences that will promote motor skill competence. That is, interindividual differences in motor skill proficiency are primarily considered the result of differences in movement experiences. From later childhood on, then, higher levels of motor skill proficiency are assumed to be a crucial factor that drives the individual's PA engagement. Hence, childhood is considered a critical time for the development of motor skills (Robinson et al., 2015).

The existing literature provides substantiated evidence for a positive relationship between PA and motor skill proficiency in young children (Figueroa & An, 2017). On the one hand, there is a substantial number of

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intervention studies supporting the assumption that PA has positive effects on motor skills (see Riethmuller, Jones, & Okely, 2009; Zeng et al., 2017 for a review). On the other hand, a growing body of research assessing habitual PA using accelerometers or pedometers (e.g., daily steps) indicates beneficial effects of everyday PA on motor skills (Iivonen & Sääkslahti, 2014 for an overview). Despite this growing body of research, several issues need further investigation. For instance, the question of how PA—or movement experiences, in Stodden's terms—should be implemented to optimally foster motor skill proficiency remains a pending issue. While the positive effect of PA on motor skills may vary with regard to its discipline, duration, as well as the setting in which it is performed, research about the characteristics of PA required to fundamentally improve motor skill proficiency is scarce (Iivonen & Sääkslahti, 2014). Hence, the present investigation addressed the question of whether different types of PA are equally apt in promoting children's motor skills.

Although many (of the published) interventions report successful promotion of motor skills in children, others report no substantial improvements (Bonvin et al., 2013), and further studies did not confirm significant long-term effects at follow-up assessment (Riethmuller et al., 2009). These findings raise the question of whether habitual leisure PA might be a promising longer-term alternative to specific intervention programs (Barnett et al., 2016; Bonvin et al., 2013). However, up to date, only little is known about the efficacy of leisure-time PA, that is, the PA children perform in their free time, after kindergarten or school, and independently of any intervention program. As this part of PA constitutes an integral part of children's everyday lives, further research seems promising.

At the same time, little is known about what types and in what contexts PA might provide optimal support to the development of motor skills. As stated by Iivonen and Sääkslahti (2014), research is needed to understand the characteristics of effective PA that can foster motor skills in children. One way to categorize (leisure-time) PA by relevant characteristics is by its level of organization and structuredness (Berry, Abernethy, & Côté, 2008; Mota & Esculcas, 2002). More specifically, PA can be classified into structured PA (i.e., formal exercise and deliberate sports practice performed under the guidance and direct instruction of an adult sports trainer) and unstructured PA (i.e., child-initiated non-formal sports activities and physically active play). While structured PA takes place regularly and aims to improve participants' sports-specific skills and athletic performance, unstructured PA primarily accentuates enjoyment and takes place in more playful settings (Coutinho, Mesquita, Davids, Fonseca, & Côté, 2016). Against this background, directed activities—in this case structured PA—have been assumed to be particularly helpful in supporting a positive development in general, as well as being more efficient for motor skill development than practice during unstructured PA (Dapp & Roebers, 2019; Gagen & Getchell, 2006; Iivonen & Sääkslahti, 2014; Robinson et al., 2015). Yet, more longitudinal research investigating and confirming the potential benefits of structured leisure PA for motor skill development is needed (Barnett et al., 2016; Holfelder & Schott, 2014).

Finally, while studies investigating the relationship between PA and gross motor skills, i.e., movements produced by large muscle groups, including locomotion and balance, have dominated the research field, the relationship between PA and fine motor skills has been less well investigated (Gaul & Issartel, 2016); perhaps because fine motor skills have primarily been associated with activities that are relevant in the typical school setting, where fine motor competences, such as writing legibly, are known to be particularly decisive (Cameron, Cottone, Murrah, & Grissmer, 2016). Nevertheless, fine motor skills have been claimed to be instrumental in many sports too, as they accomplish the small—but often decisive—adjustments in movements that are primarily produced by the large muscle groups (Payne & Isaacs, 2017). Given this interplay and the developmental interconnection of fine and gross motor skills, research addressing the effects of PA on motor skills by adopting a broader consideration of motor skills—including gross and

fine motor skills—is required.

2. The present study

The present longitudinal study investigated the relationship between leisure-time PA and motor skills in children, while looking more specifically at the association between the type, or setting, of PA (i.e., structured and unstructured PA) and the type of motor skill (i.e., gross and fine motor skills).

The study was conducted in Switzerland, providing several advantages regarding the investigation of PA effects. First, the number of physical education lessons at schools is constant across the country, providing all participants with the same amount of school-based physical education. Second, almost any structured PA takes place within so-called sports clubs, and these are organized by a nationwide organization. Thereby, structured PA, be it for kindergarten or primary-school children, is guided by qualified trainers, and—although the specific setting may vary between different sports—the basic guidelines of training should be analogous to each other. Finally, regarding unstructured PA, opportunities for self-initiated leisure PA can be assumed to be available for all participants, since locations for PA, such as sports fields, are numerous and easily reachable throughout the country (Lamprecht, Bürgi, & Stamm, 2020). Hence, the setting of the present study was well suited to address the issue of how different types of PA may affect children's motor skills.

In addressing this issue, the present work investigated the nexus of leisure-time PA and motor skill development in healthy, typically developing children. Since kindergarten years constitute a critical period in terms of motor skill development (Iivonen & Sääkslahti, 2014), this longitudinal study focused on kindergarten children's PA and its effect on motor skill proficiency 18 months later.

3. Method

3.1. Procedure

Data came from a longitudinal study investigating children's PA and motor development in kindergarten and in second grade. Assessments were completed over two-months periods in spring 2014 and fall 2015. The dataset comprised measures of structured and unstructured leisure-time PA assessed at baseline (T1), as well as gross and fine motor skills measured at T1 and follow-up (T2). While motor skills were assessed by trained experimenters during a regular physical education lesson in the morning at children's kindergartens and schools, PA was measured by a questionnaire completed by parents together with the child. All in all, the testing of each child took about 50 minutes.

The study had been approved by the Faculty of Humanities' Ethics Committee at the University of Bern, Switzerland, and was carried out in accordance with the Declaration of Helsinki. Parents gave written informed consent for their children to participate in the study, and children orally agreed to participate.

3.2. Participants

One hundred and sixty-four children from ten kindergarten classes from the German-speaking part of Switzerland participated in the study. The return rate of the PA-questionnaire at T1 was $N = 120$. Due to high doses and frequencies of training (i.e., three times a week or more for 90 minutes each), two children were assumed to be training in squads, and since their weekly training duration exceeded the outlier cut-off value of the third median absolute deviation (MAD; Hampel, 1974; Leys, Ley, Klein, Bernard, & Licata, 2013; i.e., 223.43 min/week), these two children were excluded from analyses. Another 18 children were lost due to data attrition. Three participants with incomplete information only for their age were retained for the analyses. Thus, the final sample consisted of $N = 100$ (49 girls). At T1, all children attended regular kindergarten

and had a mean age of 6.42 years ($SD = 0.32$). At T2, all children were in second grade with a mean age of 7.78 years ($SD = 0.33$).

3.3. Measures

Physical Activity. Leisure-time based PA was assessed by two sub-questionnaires of the Motorik Modul (MoMo; Bös et al., 2004), both having good reliability and validity (Bös, Worth, Opper, Oberger, & Woll, 2009). The first questionnaire assessed participants' engagement in *structured PA* (i.e., all kinds of organized sports performed within sports clubs), the second assessed *unstructured PA* (i.e., all kinds of non-formal sports-like leisure activities). For both questionnaires children had to note any sports and sports-like activities they were performing, as well as the respective weekly frequency and duration of each training session. Sports-like activities of any intensity were considered in the analyses.

For the analyses reported below, the independent variable PA was organized as follows. The mean duration (in minutes) of weekly performed structured and unstructured PA (hereafter referred to as *PA-duration*) was computed by multiplying the weekly frequency by the duration of trainings for all listed sports and then summing those values up. For the outlier analysis of the non-structured PA, the third MAD (i.e., 412.74 min/week) was computed similarly to the one reported for the structured PA (see above). However, exceeding values, which were observed in 10 participants, were adjusted to the third MAD, rather than being excluded from the analyses.

In addressing the issue of *type-dependent PA efficacy*, participants were categorized into four groups according to their pattern of leisure-time PA participation (hereafter referred to as *PA-group*). Namely, non-participants (neither structured nor unstructured PA), unstructured PA participants (only unstructured PA), structured PA participants (only structured PA), and combined PA participants (structured and unstructured PA). Additionally, a more specific classification was created by categorizing children according to their primary sports type (hereafter referred to as *sports-category*). The most assignable categories encompassed gaming and ball sports (e.g., soccer, hockey, tennis), martial arts (e.g., judo, capoeira), expressive sports (e.g., dance, artistic gymnastics), endurance sports (e.g., biking, swimming), and seasonal recreational sports (e.g., hiking, skiing).

Gross Motor Skills. Two speed tasks (*jumping sideways* and *moving sideways*) and one static balance task (i.e., *one-leg-stand* at T1 and *one-plank-stand* at T2, respectively) were used to assess gross motor skills. The speed tasks were taken from the Body Coordination Test for Children (KTK; Kiphard & Schilling, 2000), and the static balance from the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2009). All tests were carried out according to the test manual with two attempts each, whereof the best score was considered for the analyses. For jumping and moving sideways, the number of correctly performed jumps and action sequences, respectively, were used as dependent variables, whereas for the static balance, the sustained time was used. The gross motor index was computed by averaging the three z -standardized scores (Cronbach's $\alpha = 0.63$).

Fine Motor Skills. Two speed tasks and one precision task from the manual dexterity sub-scale from the M-ABC-2 (Petermann, 2009) were carried out according to the test manual. Along with the longitudinal study design, the subtests changed in accordance to children's age. Age-appropriate tests of the assessment battery were used at the respective waves (i.e., *threading beads*, *posting coins*, and *drawing trail 1* at T1 and *threading cord*, *pegboard*, and *drawing trail 2* at T2). Again, the best score of two attempts was considered for the analyses. For the threading and the pinning tasks, time to task completion was used as the dependent variable, while for drawing trail the number of mistakes was counted. A fine motor index was computed by averaging the three z -standardized and reversed scores (Cronbach's $\alpha = 0.63$).

3.4. Statistical analyses and modeling procedure

Since we were interested in the development of motor skills over time while comparing the effects of different types of PA, mixed modeling procedures were implemented. Gross and fine motor skills were analyzed separately. Results for gross motor skills are reported first, followed by the results for fine motor skills.

Modeling Procedure. SAS studio (version 9.4) and PROC MIXED were used to perform linear mixed effects repeated measure analyses of the relationship between PA-group membership (i.e., non-participants, structured PA participants, unstructured PA participants, and combined PA participants) and gross or fine motor skills, respectively, over time. The modeling procedure was identical for gross and fine motor skills. A set of fixed effects was considered, including PA-group, time (difference from T1 to T2), and—as to the main focus of interest—the interaction of PA-group with time, as well as gender, participants' age, PA-duration, and the specific sports-category as control variables. Autocorrelations and participants' intercepts were operationalized as random effects with the SAS REPEATED statement and allowed for separately grouped residual structuring along with the gender variable. P -values with 95%-CI, a set of model checks (i.e., Likelihood Ratio tests, residual checks, and influence assessments), and a Pseudo R^2 were obtained.

In order to compute the model, a top-down strategy (Zuur, Ieno, Walker, Saveliev, & Smith, 2009) was applied. Accordingly, the full model—with the maximal load of relevant parameters—was taken as the gateway to the mixed modeling procedure. Thereafter, information criteria were used to reduce the full model for fixed effects by ML estimation. Next, the random effects were fitted by making use of REML estimation. After all, the final model was estimated with REML. Due to unbalanced data, a Kenward-Roger degrees of freedom correction for the BLUP estimates was considered advisable.

Preliminary Analyses. Ordinary residuals (mean estimation), conditional residuals (Studentized and Pearson residuals), and scaled residuals—to check for the appropriateness of the covariance structure—were examined for normality via QQ-Plot inspection. Moreover, each residual was checked for variance homoscedasticity, zero mean, and no trends, by respective scatter plots and computations. All checks were in alignment with the mixed model assumption criteria.

4. Results

4.1. Descriptive statistics

Means and standard deviations of motor skill measures are reported in Table 1. As to the PA-groups, 24 children neither participated in structured nor unstructured PA, 28 children participated in unstructured PA exclusively, 22 children participated in structured PA exclusively, and 26 children participated in structured as well as unstructured PA. A non-significant χ^2 -test for independence revealed the gender-ratio to be similar across the four groups ($\chi^2 = 3.88$, $df = 3$, $p = .274$). Across the full sample (including non-participants), mean duration of PA participation accounted for 134.63 ($SD = 143.92$) minutes a week (see Table 1 for details). Again, there was no significant difference between boys and girls (Mann-Whitney-U-Test, $Z = 0.88$, $p = .378$).

4.2. Mixed modeling of gross motor skills

Model Diagnostics. Analyses were started with the parametrized full model and parameter selection was guided by ML estimation-based assessment of information criteria (see Table 2). Convergence was easily achieved after two iterations with respect to all model estimations. A full mixed model analysis was run with eight fixed effects (see Table 3a), namely PA-group, time (repeated measures), the interaction term PA-group*time, as well as gender, age, the interaction term age*gender, PA-duration, and the specific sports-category as control

Table 1
Descriptive statistics.

	Measurement Wave			
	T1 (Kindergarten)		T2 (2nd Grade)	
	M	SD	M	SD
Physical Activity				
Structured PA Duration ^a	45.21	54.41		
Unstructured PA Duration ^a	89.42	131.09		
Overall PA Duration ^a	134.63	143.92		
Gross Motor Skills				
Jumping Sideways ^b	19.04	5.48	22.97	5.18
Moving Sideways ^b	15.68	2.97	17.87	3.11
One Leg/Plank Stand (sec.) ^b	23.11	7.67	32.79	16.80
Fine Motor Skills				
Threading Beads/Cord ^c	38.57	8.55	25.92	4.59
Posting Coins/Pegboard ^c	18.92	1.94	30.52	4.65
Drawing Trail ^d	10.20	5.90	5.64	4.67

Note. Means (M) and standard deviations (SD) shown for motor skill measures and PA-duration (N = 100).

- ^a Minutes per week.
- ^b Achieved score (counts/seconds).
- ^c Seconds to task accomplishment.
- ^d Number of errors.

Table 2
Parameter estimates with goodness of fit statistics.

	Parameter Counts	Fit (Information Criteria)		
		-2 Residual Log Likelihood	AICC	BIC
Fixed Effects (ML)				
Null model ^a	0	858.4	862.4	868.9
Specified final model ^b	6	786.3	812.1	849.0
Random Effects (REML) ^c				
Type of covariance structure				
Variance Components	2	830.0	834.1	839.2
Compound Symmetry	4	794.1	802.3	812.4
Unstructured within sex	6	790.9	803.4	818.3
Final Model				
Final model after fit checks ^d	12	738.7	751.2	766.2

Note. Model diagnostics based on maximum likelihood estimation for gross motor skills.

- ^a No fixed parameters, no random part, no *df* correction.
- ^b Fixed parameters are PA-group, time, age, gender, PA-group*time, gender*age; no random part, no *df* correction.
- ^c With 6 fixed effects as from line above.
- ^d With fixed and random effects.

variables. According to Goodness of Fit statistics, we ended up with the best fit for the final model, including six fixed effects (Table 3b). Because PA-duration and sports-category remained statistically insignificant,

Table 3
Type 3 tests of fixed effects.

Effect	Table 3a. Full Model (GMS)				Table 3b. Final Model (GMS)				Table 3c. Final Model (FMS)			
	df _{Num}	df _{Den}	F	p	df _{Num}	df _{Den}	F	p	df _{Num}	df _{Den}	F	p
PA-Group	2	64.2	5.16	.008	3	86.7	3.93	.011	3	75.5	0.88	.454
Time	1	65.6	0.18	.673	1	83.8	0.11	.738	1	78.0	4.16	.045
PA-Group*Time	2	65.3	8.66	.001	3	83.6	5.91	.001	3	79.0	1.71	.171
Age	1	64.8	4.07	.048	1	89.2	6.17	.015	1	66.0	3.35	.072
Gender	1	65.2	3.90	.053	1	89.6	10.80	.002	1	67.3	6.06	.016
Age*Gender	1	65.3	3.76	.057	1	89.7	10.53	.002	1	67.5	5.60	.021
Sports-Category	1	54.6	0.35	.557								
PA-Duration	1	64.6	0.48	.490								

Note. Degrees of freedom (df), F-values, and significances reported for the full (initial) and final model of gross motor skills (GMS) and the final model of fine motor skills (FMS).

they were excluded from further analyses. In doing so, the model fit improved substantially with respect to model diagnostics.

The random effects model fitting resulted in an unstructured covariance structure (UN) for each gender, meaning that four variance and two covariance parameters were estimated as substantiated and statistically significant (Table 4). The appropriateness of UN was confirmed by a Likelihood Ratio test, $\chi^2(5) = 73.87, p < .001$. Alternatively to UN, the analysis did also fare well with a compound symmetry structure (CS), with only a marginally lowered log likelihood. However, UN was preferred over CS for two reasons. For one, the influence diagnostics clearly favored the unstructured variance-covariance structure. For another, there is theoretical evidence that motor development follows gender-respective as well as individual trajectories (Adolph, Cole, & Vereijken, 2015), indicating that non-homogeneous variability in the development of motor skills should be considered.

Influence diagnostics were accomplished by ten iterations to check for leverage on fixed and random effects parameters. Thereby, five data entries had to be dismissed due to large offsets in restricted likelihood, Cook's distance, and DFFITS values, in combination with suspiciously low covariance ratio statistics, resulting in N = 186 observations (97 participants) for the final analyses.

Main Findings. Since we were mainly interested in the effect of PA-group membership on gross motor development, multiple effect comparisons were run with regard to PA-group as well as the PA-group*time interaction term. Post-hoc results are based on Tukey-Kramer family-wise adjusted t-Test with 95%-CI (for details see Table 5).

As shown in Table 3b (see also Fig. 1), results revealed a significant effect of PA-group membership. Post-hoc analyses revealed no significant PA-group differences at T1. However, post-hoc comparisons for T2 indicated that the gross motor score of the structured PA-group, 95%-CI = [1.006, 4.156], as well as the gross motor score of the combined PA-group, 95%-CI = [0.218, 3.114], respectively, significantly differed from the gross motor score of the unstructured PA-group. That is, both structured PA participants and combined PA participants showed significantly better motor skills proficiency as compared to the unstructured PA participants. In contrast, there was no significant difference between the structured and the combined PA-group, 95%-CI =

Table 4
Covariance parameter estimates (GMS).

Covariance Parameter Estimates				
Cov Parm	Subject	Group	Estimate	p
UN(1,1)	id(PA-group)	girls	3.682	<.001
UN(2,1)	id(PA-group)	girls	2.952	<.001
UN(2,2)	id(PA-group)	girls	5.085	<.001
UN(1,1)	id(PA-group)	boys	5.514	<.001
UN(2,1)	id(PA-group)	boys	2.201	.002
UN(2,2)	id(PA-group)	boys	2.937	<.001

Note. Significance based on z-statistics.
GMS = Gross motor skills.

Table 5
Multiple effect comparisons between PA-groups and timepoints for gross and fine motor skills.

Compared Effects		Gross Motor Skills							Fine Motor Skills						
Group ^a	Group ^a	Estimate	SD	df	t	95%-CI	d	r	Estimate	SD	df	t	95%-CI	d	r
Longitudinal (T1 → T2)															
0	0	-0.015	0.397	82.8	-0.04	[-0.805, 0.775]	-0.009	.004	-0.703	0.322	75.6	-2.18	[-1.343,-0.062]	-0.501	.243
1	1	-0.701	0.368	82.7	-1.90	[-1.433, 0.031]	-0.418	.205	-0.312	0.295	77.3	-1.06	[-0.898, 0.274]	-0.241	.120
2	2	1.443	0.410	81.1	3.52	[0.628, 2.257]	0.782	.364	0.246	0.313	72.2	0.78	[-0.378, 0.869]	0.184	.091
3	3	-0.461	0.378	87.0	-1.22	[-1.211, 0.290]	-0.262	.130	-0.528	0.321	91.5	-1.65	[-1.167, 0.111]	-0.345	.170
Between PA-Groups T1															
0	1	-0.424	0.618	81.0	-0.69	[-2.044, 1.197]	-0.153	.076	0.164	0.488	84.4	0.34	[-1.118, 1.445]	0.074	.037
0	2	0.014	0.652	80.9	0.02	[-1.694, 1.722]	0.004	.002	0.079	0.508	81.9	0.15	[-1.254, 1.411]	0.033	.017
0	3	1.002	0.625	84.7	1.60	[-0.637, 2.641]	0.348	.171	0.559	0.498	87.4	1.12	[-0.748, 1.865]	0.240	.119
1	2	0.437	0.613	78.0	0.71	[-1.170, 2.044]	0.161	.080	-0.085	0.476	80.5	-0.18	[-1.334, 1.164]	-0.040	.020
1	3	1.425	0.600	85.3	2.37	[-0.148, 2.999]	0.513	.249	0.395	0.473	88.4	0.83	[-0.847, 1.637]	0.177	.088
2	3	0.988	0.633	85.3	1.56	[-0.670, 2.646]	0.338	.167	0.480	0.492	87.0	0.98	[-0.812, 1.772]	0.210	.104
Between PA-Groups T2															
0	1	-1.110	0.585	85.1	-1.90	[-2.644, 0.425]	-0.412	.202	0.554	0.438	60.0	1.27	[-0.595, 1.703]	0.328	.162
0	2	1.471	0.629	87.6	2.34	[-0.178, 3.121]	0.500	.243	1.027	0.460	59.7	2.23	[-0.181, 2.235]	0.577	.277
0	3	0.556	0.569	75.2	0.98	[-0.936, 2.049]	0.226	.112	0.733	0.472	70.1	1.55	[-0.505, 1.971]	0.370	.182
1	2	2.581	0.601	88.8	4.30	[1.006, 4.156]	0.913	.415	0.473	0.425	58.0	1.11	[-0.644, 1.590]	0.292	.144
1	3	1.666	0.552	79.6	3.02	[0.218, 3.114]	0.677	.321	0.179	0.447	70.6	0.40	[-0.995, 1.353]	0.095	.048
2	3	-0.915	0.597	83.6	-1.53	[-2.481, 0.651]	-0.335	.165	-0.294	0.467	69.1	-0.63	[-1.519, 0.932]	-0.152	.076

Note. Pairwise post-hoc group comparisons between PA-groups and timepoints, respectively. Estimate refers to differences of least squares means (z-scores). 95%-CI are based on Tukey-Kramer family-wise adjusted t-tests. T1 = Time 1; T2 = Time 2.

^a Group refers to the variable PA-group; 0 = no PA; 1 = unstructured PA; 2 = structured PA; 3 = combined PA.

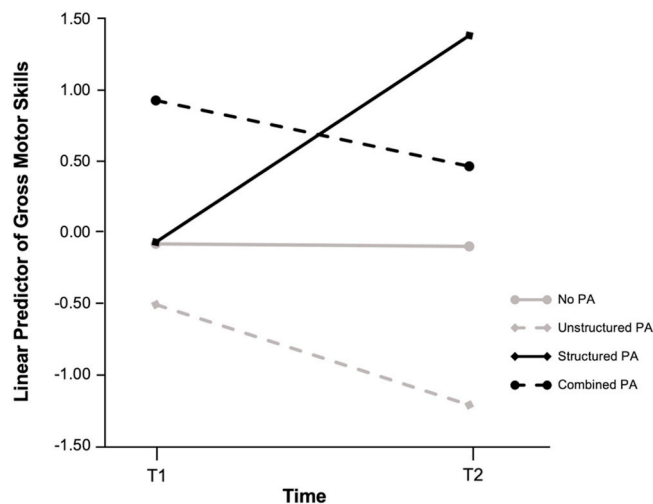


Fig. 1. Interaction plot for gross motor skills.
Note. Development of gross motor skills over time displayed for the four PA-groups (PA-group*time interaction; z-scores).

[-2.481, 0.651].
As to the effects of PA-group membership on the development of gross motor skills, the analysis was focused on the PA-group*time interaction term (Fig. 1). Contrast analyses were computed for each PA-group*time interaction term, but only the group of structured PA participants revealed a significant effect, 95%-CI = [0.628, 2.257].

Overall Effect Size. A Pseudo R^2 was calculated in order to obtain an effect size score for the full model. From the plethora of possible Pseudo R^2 estimates, we opted for the frequently encountered McFadden likelihood-ratio index, which resulted in a rather fair value of Pseudo $R^2_{McFadden} = 0.139$. For the mere fixed effects part, $R^2_{McFadden} = 0.084$ was achieved. It has to be stressed that Pseudo R^2 are a delicate and vigorously debated topic within the mixed model community (for a thorough overview, see Nakagawa & Schielzeth, 2013). Pseudo R^2 are not to be interpreted on the well-known scale from ordinary linear regression modeling. According to McFadden, a Pseudo R^2 of 0.200 and

above represents “excellence” (McFadden, 1977). Hence, one is cautioned to rely on a straightforward interpretation of such values. Still, our finding—although below the excellence margin—pointed to substantiated and robust effect findings.

Power Analysis. Since the definite covariance structure cannot be fixed beforehand in mixed modeling, no a priori power analysis could be obtained. In addition, and to the best of our knowledge, there is neither an approved procedure for post-hoc power analysis for mixed modeling procedures. Compensating for this issue, we relied on a procedure proposed by Stroup, Milliken, Claassen, and Wolfinger (2018) for a post-hoc power analysis for the effect of interest, namely the interaction effect of PA-group*time. Considering the initial model, the Stroup et al. (2018) procedure revealed a power of 94.7% (at alpha = .05) for the aforementioned interaction effect with the available number of observations. With the exception of age and time, all effects remained with a power > .80.

4.3. Mixed modeling of fine motor skills

Model Diagnostics. Regarding the modeling of the fine motor skills, the same strategy as with gross motor skills was adopted (see above) what proved to be efficient. Accordingly, analyses were started with the identically parametrized full model. ML estimation-based assessment of information criteria, along with the consideration of psychological knowledge of motor skill development, guided the fixed effects parameter selection, suggesting the omission of the insignificant sports-category ($p = .893$), resulting in a substantial improvement in the model fit. As to the PA-duration, the analysis turned out less straightforward, since the effect remained of borderline significance ($p = .045$), along with a change in BIC of 0.20 in favor of the more restricted model (i.e., without PA-duration). On the other hand, AICC disclosed a drop of 1.80, favoring the more comprehensive set of fixed effects. However, since it is well known that AICC is slightly biased toward favoring more complex models, as compared to BIC, the found difference is negligible (Harrison et al., 2018). Eventually, PA-duration was dismissed from the analysis because of critical residual and influence diagnostics. Hence, we ended up with the same set of fixed effects as used in the gross motor analysis (Table 3c). The information criteria for the final model yielded a difference of 53.1 and 16.0 for the -2Log Likelihood and AICC, respectively.

The modeling of the repeated measures variance-covariance structure (i.e., the random part of the mixed model), was implemented analogously to the gross motor skills analysis. We focused on UN and CS structuring of the variance-covariance parameters. As with the gross motor skills analysis, both approaches seemed to work out fine, with negligible information criteria differences of order 6.5 and 2.3 for -2Log Likelihood and AICC, respectively, both in favor of an UN covariance structure. As remarked above, theoretical reasons can be given as to why UN should be preferred over CS structuring. Eventually, each UN parameter turned out to be substantiated and statistically significant at $p < .002$. Overall significance for the UN structure was achieved by a Likelihood Ratio test, $\chi^2(5) = 53.45, p < .001$.

The fine-tuning of the mixed model was accomplished by comprehensive model diagnostics (as reported along with gross motor analysis) and urged to drop two participants and two additional observations. The final sample for the fine motor analysis consisted of $N = 186$ observations.

Main Findings. Evidence derived from the final mixed model is shown in Table 3c. In contrast to findings from the gross motor analysis, PA-group membership, as well as its interaction with time, were not significantly related to fine motor skills. Time itself remained significant, pointing to a developmental component in the change of fine motor skills. However, this did not signify a (general) increase in fine motor skills, but instead, as can be derived from Fig. 2, rather a tendency to a decrease in most PA-groups (for details see Table 5). The only increasing trend in fine motor skills was found for the group of structured PA participants. Though, post-hoc analysis revealed this increase to be non-significant at 95%-CI = [-0.378, 0.869]. In contrast, the decrease in the non-participants' group was statistically significant at 95%-CI = [-1.343, -0.062].

Overall Effect Size. For the fixed effects part, a $R^2_{McFadden} = 0.065$ was computed. The comparison of the finally specified model with the null model resulted in $R^2_{McFadden} = 0.132$. However, the interpretational problems with these measures have to be restated.

Power Analysis. A post-hoc power analysis according to the procedure described by Stroup et al. (2018) yielded a power of .83 and .81 ($\alpha = .05$) for the gender effect and the age*gender interaction term, respectively, for the full model with the available number of observations.

4.4. Supplementary analyses

As sample size did not allow the comparison of the impact of the

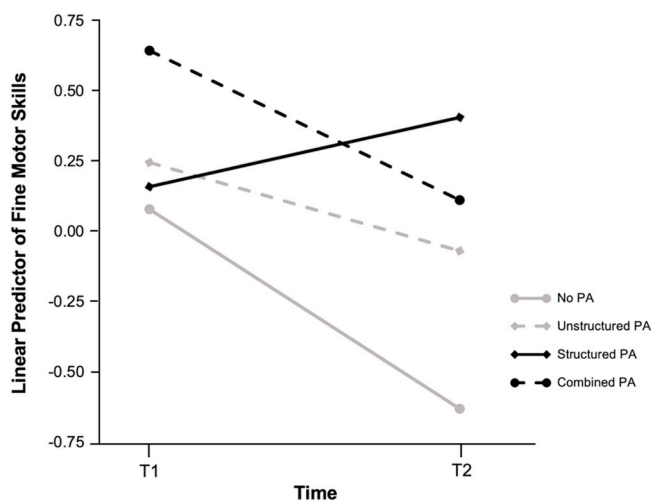


Fig. 2. Interaction plot for fine motor skills. Note. Development of fine motor skills over time displayed for the four PA-groups (PA-group*time interaction; z-scores).

different sports within the sports-category, exploratory findings, which might be of value for future research, are reported in the supplementary materials (Appendix A).

5. Discussion

Addressing the issue of how PA might be implemented to optimally foster children's motor skill development, the current study investigated the effects of *structured*—hence, organized, planned, and guided PA—and *unstructured*—that is, non-formal, playful, and spontaneously initiated PA. In comparing the pattern of children's PA participation with regard to the degree of PA structuredness, the present study provides new insights into the so-far widely open question whether different types of PA have the (same) potential to impact motor skill proficiency, as well as its development.

In line with previous research (Iivonen & Sääkslahti, 2014; Riethmüller et al., 2009; Zeng et al., 2017), the results revealed gross motor skills to be particularly affected by PA. However, in accordance with Robinson et al. (2015), the results clearly demonstrate that not all forms, or settings, of PA are equally effective in promoting motor skills. More specifically, we found that primarily the children engaging in structured PA benefit from PA when it comes to their motor development. That is, kindergarten children engaging either in structured PA exclusively or in a combination of structured and unstructured PA displayed significantly superior gross motor skills in second grade as compared to their peers engaging in unstructured PA exclusively. Moreover, the increase in gross motor skills over time was significant only for children engaging in structured PA. This finding becomes even more striking when considering the fact that the reported durations for unstructured PA were almost twice as high as the durations for structured PA. In fact, the factor of PA-duration could not explain a significant proportion of variance in children's gross motor skills. Hence, the PA's qualitative aspect of structuredness seems to be more decisive for gross motor skill development than the quantity of PA per se, and—insofar as the present results allow such conclusions—also more decisive than the specific sports-category.

In considering fine motor skills, a similar pattern emerged. While PA in kindergarten was neither strongly nor generally positively related to fine motor skills in second grade, the group of children engaging in structured PA was the only one showing a positive—however non-significant—trend in their fine motor skill development. As to that finding, one needs to note that fine motor skills were operationalized as manual dexterity, that is, movements that are probably less directly or less purposefully trained during leisure PA—especially with regard to sports performed by muscles of the lower body (e.g., running or playing soccer). Moreover, the fine motor tasks were more challenging at T2 assessment by consequence of the need for age-appropriate testing. Hence, children may have attained somewhat lower T2 scores relative to T1 test scores, as they were rather at the lower age boundary of the motor test battery used at T2. Against this consideration, the ascending trend for structured PA participants becomes noteworthy, and the lack of significance might be, at least partially, ascribed to the more challenging test format at T2. On the other hand, even if one interprets the decrease as a real decrease in fine motor skills, structured PA might still be conceived as a buffering factor against such a decline.

Taken together, the present findings suggest that engaging in structured leisure-time PA—either exclusively or in combination with some unstructured PA—is beneficial for children's motor development, whereas engaging in unstructured PA lacks such effectiveness. Hence, structured PA seems to feature essential characteristics when it comes to improving motor skills over the early school years. Based on the present study's findings, such key characteristics can be assumed to be due to the deliberate, instructional, and pedagogical designs underlying structured PA, where children are guided and formally instructed—also with the explicit purpose to increase sports performance, and thereby motor skills (Coutinho et al., 2016). The improvement of motor skills, in turn, will

enhance future PA engagement and sports motivation in the so-called “physically literate” person (Jurbala, 2015). Given the present findings, regularly engaging in structured PA constitutes a promising way to promote motor skills and motor development over the long term, at least with regard to gross motor skills. Since many children are active physically anyway, optimizing the setting of these activities according to the level of structuredness seems opportune.

5.1. Limitations and implications

While the current study’s longitudinal design can be valued, the lack of T2 PA-data is unfortunate. Since PA was only assessed at T1, neither could we control for the PA autoregressions nor could we consider eventual changes in PA-group membership. That is, although moderate stability of PA engagement can be assumed with respect to the present study’s age-group and time interval (for example, Nyberg, Ekelund, and Marcus (2009) reported a stability of $r = 0.59$ over a 18 months interval), some children might have changed according to their pattern of PA participation from T1 to T2. However, we could not investigate, for example, whether children who were stably in the structured PA-group—and hence had longer exposure to instruction and practice—had stronger motor-skill improvements as compared to children who probably disenrolled from structured PA organizations. Nonetheless, against this background, the positive effects of structured PA are no less notable, and probably, they might have turned out to be even stronger when information on long-term PA participation could have been taken into account. Addressing this issue, future research should assess both motor development and PA participation longitudinally and take potential shifts in group membership into account.

The sample size of the present study was not large enough to compare the specific sports-categories with regard to their efficacy on motor proficiency. Probably, different sports may affect different motor skills, and also be differently effective in promoting motor development in general. As far as we can anticipate a pattern of such effects, martial arts seem most promising (see supplementary analyses in Appendix 1). Yet, future research should further address the question concerning the “golden PA” to promote motor development with larger sample sizes.

Finally, in contrast to accelerometer-based PA measurement, questionnaire-based PA assessment has the limitation of being less objective, as it might be biased with respect to social desirability, memory retrieval issues, as well as judgment formation, which might be a challenge when estimating dose-response relationships between PA and various outcomes (Nigg et al., 2020). At the same time, questionnaires have the advantages to provide qualitative information on the type and context of PA, and are superior for larger population-based longitudinal studies (Iivonen & Sääkslahti, 2014; Nigg et al., 2020). Future studies might provide deeper insights into the relation between PA characteristics and motor skill development by combining objective and qualitative measures.

6. Conclusion

In conclusion, the present longitudinal study extends on prior research by specifying the prospective effect of PA on gross and fine motor skills: Impactful promotion of motor skill proficiency through PA seems to rely on the PA’s implementation, with structured settings being most beneficial for gross motor skills, and tendentially also for fine motor skills. Hence, regularly engaging in structured PA constitutes a promising way to promote the development of children’s motor skills over the long term and, since many children enjoy being active physically, optimizing the setting of these activities according to the level of structuredness seems opportune. In comparing children’s patterns of PA participation with regard to the PA’s degree of structuredness, the present study opens up a new research direction to address the search for the most effective characteristics of PA to promote motor development, as well as a positive and healthy development in general.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.psychsport.2021.101916>.

Conflicts of interest

The authors declare that there is no conflict of interest.

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