Motor skills in kindergarten: internal structure, cognitive correlates and relationships to background variables

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1. Introduction

Piaget's theory of cognitive development refers to a close relation between motor and cognitive abilities (Piaget & Inhelder, 1966). According to Piaget, the evolvement of motor skills (e.g. independent locomotion) enables the child to explore the environment and through assimilation and in particular accommodation leads to new and differentiated cognitive concepts. Thus, cognitive development is supported (Schwarzer, 2011). In turn, to successfully master complex motor tasks, a certain level of cognitive development (e.g. perception, attention, memory) is required (Singer, 1981). The assumed relation between motor and cognitive development in different age groups has also been empirically confirmed (Ahnert, Schneider & Bös, 2009; Rhemtulla & Tucker-Drob, 2011; Wassenberg et al., 2005). However, only little is known about specific relations among this concept. More precisely, information upon specific motor skills correlating with particular cognitive abilities, upon underlying information processes as well as upon background variables potentially contributing to the correlation is still being called for. To answer those open questions, the present study was conducted. Hence, based on a sample of kindergarten children, interrelations between motor coordination and executive functions and the impacts of home environment factors will be explored. A better understanding of these associations will contribute to well-grounded means to foster young children`s mental health since motor coordination and related physical activity one the one side (Biddle & Asare, 2012; Tomprowski, Lambourne & Okumura, 2011), and executive functions on the other side (Diamond, 2012; Moffitt et al. 2011), are known to have substantial impact on an individual`s mental and cognitive health.

To find out more about the associations between specific motor skills and specific cognitive abilities we chose a skill-based approach to classify motor skills. As a core aspect of this approach, individual differences in motor skills are quantified and the common classification in gross and fine motor skills is implied (e.g. Bjorklund & Hernández Blasi,

2012; Gentier et al. 2013; Raisbeck & Diekfuss, 2015). While gross motor skills are usually assessed with tasks involving whole body coordination (e.g. D'Hondt et al., 2014; Lopes, Santos, Pereira & Lopes, 2013), fine motor tasks refer to the control of arm movement and manual dexterity (e.g. Jansen, Quaiser-Pohl, Neuburger & Ruthsatz, 2015; Roebers et al., 2014). There is empirical evidence that both gross and fine motor skills, are related to school achievement. For one, there are studies confirming a strong correlation between general coordination abilities and school achievement (Planinsec, 2002; Rhemtulla & Tucker-Drob; 2011). For the other, studies report fine motor skills in early kindergarten being predictive for later school achievements (Grissmer, Grimm, Aiyer, Murrah & Steele, 2010; Son & Meisels, 2006). However, most of the studies did not include both, gross and fine motor skills, simultaneously. Thus, it remains unclear whether both aspects are of equal importance for and later school achievement when their impact is estimated together.

Further, to date not much is known about the mechanisms and information processes underlying the documented associations between motor skills and cognitive abilities or school achievement. To our knowledge, only one study so far addressed the issue and reports the correlation between school achievement and fine motor skills being mediated by executive functions (Roebers et al., 2014). Thereby, executive functions is an umbrella term for higher order cognitive processes. They are crucial for goal-orientated, flexible and self-regulated information processing, especially in new and challenging situations. Executive functions are commonly divided into three distinct but strongly related dimensions: (a) shifting/switching between multiple tasks, mental sets, rules or operations (b) Inhibition of pre-potent, dominant or automatic responses (c) updating in the sense of retaining and manipulating relevant information in working memory (Miyake et al., 2000). Using a latent-variable structural equation approach, the above-mentioned recent longitudinal study documented a significant association between fluid intelligence and fine motor skills. Furthermore, both served as predicting factors for later school achievement. However, when taking executive functions

into account, there was no remarkable change for the cross-sectional associations. But, later school achievement was now predicted mainly through executive functions (Roebers et al., 2014). These results suggest that executive functions and fine motor skills share information processes that partly serve as explanation for the motor-cognitive performance link.

In a longitudinal study of Cameron et al. (2012), positive correlations were also found for gross motor skills of 3-4 year old children and academic skills such as mathematics, reading and word comprehension assessed one year later in kindergarten. However, gross motor skills were no significant predictor for later kindergarten achievement in a regression model where background variables, executive functions and motor skills were included together. Similarly, in the longitudinal study of Grissmer et al. (2010) gross motor skills of 5-6 year old children were no significant predictor for later school achievement in fifth grade. In both studies gross motor skills were assessed with a screening instrument that contains six tasks adding up to an overall sum score. This sum score was used to predict later school achievement; unfortunately, both longitudinal studies did not look at specific relations between the different gross motor tasks and later achievement. In fact, only a handful of cross sectional studies focused on the specific relation between gross motor skills and executive functions in young children. In these cross-sectional studies some specific gross motor skills (e.g., jumping sideways) revealed significant relations with executive functions. This was in particular the case for inhibition and shifting (Roebers & Kauer, 2009). Thus, given the lack of consistent and convincing empirical evidence, it still remains unclear whether the association found for fine motor skills and executive functions is comparably apparent for gross motor skills and executive functions. This aspect will also be targeted in the present study.

Comparing results from studies on gross motor skills with the ones on fine motor skills is challenging. This is because executive functions as well as motor skills were assessed with different tasks respectively. A simultaneous approach, where both dimensions have been

assessed within the same study, has only rarely been implemented to date. This is unfortunate because based on such studies recommendations to support the development of motor skills and executive functions could be derived. Especially in young children who naturally engage more in gross motor coordination than in fine motor coordination, evidence on the relations with indicators of cognitive performance are being called for (Diamond & Lee, 2011).

Today, a neuropsychological approach usually serves as explanation for the link between motor skills and executive functions. More precisely, it is known that the same brain areas are activated during motor as well as executive function tasks (Diamond, 2000); namely, the cerebellum, the prefrontal cortex, basal ganglia and the striatum. This view is not only supported by studies using neuro-imaging approaches, but also by studies done with patients suffering from brain injuries that lead to cognitive as well as motor deficits (Diamond, 2000; Hayes, Davidson & Keele, 1998).

Even though this neuropsychological view seems plausible and has been empirically confirmed, a more general, socio-ecological view should be taken into account as well. Particularly, familial background variables should be considered. Executive functions as well as motor abilities are mainly driven by heredity (Friedman et al. 2008; Singer, 2009). Nevertheless, the interaction between the genetic dispositions and the child's environment, partly arranged by parents, should not be underestimated. This is because it will substantially affect the child's development in motor skills as well as in executive functions. In fact, studies have shown that socio-economic status and the child's physical activity level are related to executive functions (Best, 2010; Etnier & Chang, 2009; Noble, McCandliss, & Farah, 2007) and motor skills (Fisher et al., 2005; Piek, Dawson, Smith, & Gasson, 2008;Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). When additionally taking into account the familial movement socialization, the physical activity level of parents may serve as potential influence factor. This is because the child's physical activity level was found to positively correlate with the parents' one (Ahnert, 2005) and is assumed to partly explain the relation between motor

skills and executive functions. Just as well, differences in physical fitness among children may also partially explain the mentioned relation. More precisely, performances in motor tasks are known to be influenced by different basic motor abilities (Roth & Roth, 2009) who in turn are related to executive functions and school achievement. This is in particular the case for aerobic fitness and strength (Buck, Hillman & Castelli, 2008; Chomitz et al., 2009; Dwyer, Sallis, Blizzard, Lazarus & Dean, 2001; van der Niet, Hartmann, Smith & Visscher, 2014). Similarly, unstructured leisure time activities seem to be predictive for executive functioning (Barker et al., 2014) and thus a potential indirect influence factor for physical and mental health. However, to date, the number of studies that have systematically focused on the influence of such individual and environmental factors on the relation between motor skills and executive functions is rather small.

In the present paper, the association between gross motor skills, fine motor skills and executive functions will be examined simultaneously. Executive functions and motor skills will be assessed with commonly used tasks and their relation to each other will be described and compared. To check for possible correlations, a latent variable approach and structural equitation modelling techniques are used. With this approach, only shared variances of the chosen constructs are taken into account, thus enabling to estimate the links among the latent variables on the level of their theoretical constructs. Based on the current literature and on theoretical assumptions, we expect significant correlations between gross motor skills, fine motor skills and executive functions in kindergarten children. In addition to the commonly used neuropsychological explanation for the relation between motor skills and executive functions, the influence of some individual and background variables shall also be taken into account. However, the neuropsychological and the socio- ecological views shall not be tested against each other. Rather, aspects of motor skills for which a general socio-ecological view is sufficient shall be distinguished from those aspects calling for a specific neuropsychological view. Thus, an additional aim of the study is to provide a better understanding of those

associations. More precisely, the relation between gross motor skills, fine motor skills and executive functions with specific individual and background variables (also under control of age) shall be described.

2. Method

2.1 Sample

The sample consisted of 156 kindergarten children (51% girls). The mean age was 6 years and 5 months (SD = 4 months; range: 68 – 87 months). The children were recruited from 13 different kindergartens in Bern and its surrounding areas. The study was approved by the Ethics Committee of the Faculty of Philosophy and Human Sciences of the University of Bern, Switzerland (Approval No. 2013-12-733209) and the participation was confirmed by the parents' written permission. Furthermore, before every session, the children were given free choice for participation.

2.2 Procedure

The assessments were divided into two sessions, one for the motor tasks and one for the cognitive tasks. The two sessions were realized on two different days within one week, with the order of the tasks varying unsystematically. The motor tasks as well as the strength and endurance tasks were assessed in a circuit. The circuit lasted about 40 minutes, was held in the kindergarten's gym in groups of five. The six–minutes-run was done together and thus first up. Afterwards, five stations had to be completed individually, including motor tasks and the standing long jump. Each child started at a different station and then passed the circuit one station after the other. For the cognitive tasks, the children were tested individually during the morning hours for about 30 minutes in a quiet room of the kindergarten. The computer-based tasks were administered on a laptop using e-prime software (Psychology Software Tools, Pittsburgh, PA) and their order was counterbalanced. Skilled psychologists and psychology

master students were responsible for the testing. The physical activity levels of the child and its parents as well as their socio-economic status were assessed using a questionnaire. The parents were asked to fill out their own part of the questionnaire, as well as to help the children to fill out the part referring to the child's physical activity. The questionnaires were distributed in the first assessment session and the children were asked to bring them back within the next two weeks. The teachers assisted with reminding children and parents to complete and return the questionnaires. The return rate was 75%.

2.3 Material

2.3.1. Fine motor skills. Fine motor skills were assessed with the manual dexterity subscale of the Movement Assessment Battery for Children-2 (M-ABC-2, German Version; Petermann, 2009). This subscale includes two speed tasks (threading beads, posting coins) and one precision task (drawing trail). All tasks were conducted according to the test manual`s instructions. For the threading beads task, the dependent variable was defined as being the time needed for task completion with the dominant hand. For the posting coins task, the time needed to complete two trials, one with the dominant and one with the non-dominant hand, served as dependent variable. For the drawing trail task, the amount of errors was used as dependent variable. The internal consistency for fine motor tasks was $\alpha = .65$.

2.3.2. Gross motor tasks. To assess gross motor skills, three whole body coordination tasks were used; two speed tasks (jumping sideways, moving sideways) and one precision task (one-leg-stand). While the speed tasks originate from a test of body coordination ("Körperkoordinationstest für Kinder"; Kipphard & Schilling, 2007), the one-leg-stand is part of the above-mentioned M-ABC-2. Corresponding dependent variables were defined as follows: The amount of jumps/ sideway movements out of two trials each for the speed tasks, and time in seconds (max. 30 seconds) for the one-leg-stand. Thereby, two trials with the left

and two trials with the right leg were conducted, of which the better trial of each leg was used, building a sum score. The internal consistency for gross motor tasks was α = .63.

2.3.3. Executive Functions. While inhibition and shifting were assessed with an adapted version of the flanker task (Eriksen & Eriksen, 1974), the updating component was assessed with the backwards colour recall task (Schmid, Zoelch, & Roebers, 2008; Zoelch, Seitz & Schumann-Hengsteler, 2005). The internal consistency for executive functions tasks was α = .60.

For the inhibition task, a row of five red fish was presented to the children who were asked to feed the central target fish as fast as possible. This would be done by either pressing the left (when the mouth of the target fish was showing to the left) or the right response button (when the target fish's mouth was showing to the right), unaffected by the flanking outer fish. The task started off with a pure block, meaning all fish had the same orientation. The block consisted of four practice trials followed by 20 experimental trials, all with stimulus duration of 3000 ms and interstimuli intervals varying between 800 and 1400ms. A standard block followed, consisting of six practice trials and 48 experimental trials. While two thirds of the trials were congruent (flanking fish and target fish have same orientation), one third of the trials showed an incongruent pattern (target fish have opposite orientation). The stimulus duration in this block was set at 3500 ms, interstimuli intervals again varying between 800 and 1400 ms. The dependent variable was defined as being the accuracy (percentage of correct responses) for incongruent trials (Roebers & Kauer, 2009).

To assess shifting, two additional blocks (reversed and mixed) were added to the standard block. The reversed block served as a means to introduce a new rule. More precisely, besides the fish having changed colour to yellow, the children were now asked to feed the four outer fish (which all had the same orientation), again, unaffected by the orientation of the central fish. The central fish was either congruent (same orientation) or incongruent (opposite orientation). After six practice trials, 16 experimental trials followed (1/2 congruent, 1/2

incongruent). This block was only used as practice to introduce the new rule and therefore, data of this block was no used for the analyses reported below. The last block was the mixed block, meaning that red as well as yellow fish were presented, asking the children to switch between the rules flexibly. Eight practice trials were followed by 40 experimental trials (1/2 congruent, 1/2 incongruent, 20 with yellow and 20 with red fish). Congruent and incongruent trials were presented randomly. Stimulus duration for these two blocks was set at 7000 ms. The dependent variable for shifting was defined as the percentage of correct answers in the mixed block (Roebers & Kauer, 2009).

In the backward colour recall task, the children had to remember a sequence of differently coloured discs and recall them in reversed order. The task was embodied in a cover story about a dwarf and started with a sequence of two items. Whenever the child recalled at least three trials out of six correctly, the number of items was increased by one. Discs were presented for one second on the screen and interstimuli interval was set at 500 ms. The total amount of correct recalled trials served as dependent variable (Röthlisberger, Neuenschwander, Michel & Roebers, 2010).

2.3.4. Individual and background variables. To assess physical fitness, two tasks were used. While the standing long jump served as measure for strength, the six-minutes-run was used as a measure for aerobic endurance (Bös, 2001). For the standing long jump task, the child had to jump as far as possible using both feet. The better (wider) jump out of two was used as dependent variable. As for the six-minutes-run, the children needed to run as many rounds of 54 meters of length as possible. Here, the dependent variable was defined as being the distance ran in meters.

SES as well as physical activity of the children and their parents during leisure time was assessed by questionnaire. For the parents' level of physical activity, questions were taken from a German questionnaire of physical activity ("Bewegungs- und Sportaktivität Fragebogen"; Fuchs, 2012). Thereby, the dependent variable was a z-transformed sum score

of physical activity in leisure time and sports activity in leisure time (minutes per week) of the mother and the father. To measure physical activity level of the children, the Motorik-Modul (MoMo; Bös et al., 2004) was used. In order to assess physical activity in everyday life, in organized sports and in leisure time sports, three subscales were applied. We built z-scores of the three subscales and by adding them to a sum score, they served as dependent variable for the physical activity level of the child. The education of the parents, the income per month as well as the subjective satisfaction with their income were also assessed by questionnaire, z-transformed and added up in a sum score for SES (Alsaker, Nägele, Valkanover & Hauser, 2008; Schick et al., 2006). The return rate of the questionnaire was 76%. Due to some missing values the n of the background variables varies unsystematically between 110 and 119.

2.4 Statistical analysis

For the purpose of identical metrics, all dependent variables were z-transformed. Additionally, some measures needed to be reversed. As a result, higher values always corresponded with superior performance. Values that deviated more than ±3 standard deviations of the sample's mean were replaced with the value equivalent to the third standard deviation. Further, for variables that entered the confirmatory factor analyses, missing values (0.2 %) were imputed. As the MCAR test (Little, 1988) was not significant ($\chi^2(12) = 10.919$; $p = .536$), the values were missing completely at random. The expectation maximization method was used to replace the missing values. The confirmatory factor analyses were conducted with AMOS 22 (Arbuckle, 2013). Model fit was considered as good, if the Tucker-Lewis Index (TLI) and the Comperative Fit Index (CFI) were greater than .95. Further, the Root-Mean-Square (RMSEA) needed to be smaller or equal .06 and the normed χ^2 below 2 (Byrne, 2001; Hu & Bentler, 1998).

Two confirmatory factor analyses were conducted to check for the chosen tasks to truly capture empirically separable abilities; namely fine motor skills and gross motor skills.

At the same time, the correlation between motor skills and executive functions on the level of latent variables was examined. To test for possible associations with individual and background variables, bivariate as well as partial correlations (under control of age) were calculated.

3. Results

Table 1 shows the descriptive statistics of the motor tasks and the executive functions tasks. Thereby, a broad variation in the used tasks is clearly recognizable. From *Appendix A* you can learn that all gross motor and all fine motor tasks correlated positively with the executive functions tasks. Thereof, 32 out of a total of 35 correlations reached statistical significance. While Pearson correlations are presented above the principal diagonal, partial correlations controlling for chronological age are shown below. As becomes obvious through the illustration, the overall pattern of correlations is not substantially affected by chronological age. More precisely, there are only small changes and 31 out of 35 correlations remain statistically significant.

In a next step, a confirmatory factor analysis was used to look at the associations on the level of latent variables. For this purpose, the three whole body coordination tasks were used to build the latent variable gross motor skills and three manual dexterity tasks to build the latent variable fine motor skills. As shown in Figure 1A, factor loadings of all indicators on their construct were significant. The correlation of the two latent motor variables is very strong (r =.89; p <.001). In order to proof for such high correlation, a single factor model was tested additionally, mapping all indicators onto one single latent common motor factor variable (Figure 1B). For this model as well, all indicators loaded significantly on the latent variable. By comparing the theoretically assumed two factorial model with the single factor model, it occurs that the two factorial model fits the data slightly better [$\chi^2(8) = (p < .01)$; χ^2normed = 1.36; CFI = 99; RMSEA = .05; TLI = .97; AIC = 36,848]. Because the AIC of the

two factorial model was slightly lower and also theoretically derived, we refer to this model for further analysis. Another advantage in doing so is that associations with other constructs can be considered individually gross- and fine motor skills.

To illustrate the association between gross motor skills, fine motor skills and executive functions, another confirmatory factor analysis was conducted. For this purpose, a third latent variable was built (for executive functions). The corresponding loadings of the indicators illustrated in Figure 2 were statistically significant. Overall the model fit was good [$\chi 2(24) = 33{,}43$ ($p < .01$); χ^2normed = 1.393; CFI = 97; RMSEA = .05; TLI = .96; AIC = 75,43] Interestingly, the relation between gross motor skills and executive functions appeared to be slightly higher than the one between fine motor skills and executive functions.

Lastly, an explorative analysis of the relation between gross motor skills, fine motor skills, executive functions and the chosen individual and background variables was conducted. The descriptive statistics of those individual and background variables are shown in Appendix B. We built sum scores for gross motor skills, fine motor skills and executive functions out of the three corresponding tasks. Afterwards, Pearson correlations between the sum scores and the individual and background variables were calculated. Because chronological age also correlated with most of those variables, partial correlations controlling for age were calculated additionally. Pearson correlations and the partial correlations (separated by a slash) are shown in Table 2. When considering the individual variables aerobic endurance (six-minutes-run) and strength (standing long jump) in the upper part of the table, it is striking that those measures share significant amounts of variance with gross motor skills, fine motor skills and executive functions. In the lower part of the table, correlations with physical activity level of family members and the SES are shown. All age independent correlations with the considered background variables were negligible. However, concerning physical activity level, significant correlations were found. More precisely, the child's level of

physical activity level correlated with the one of its parents (father: $r = .37$; $p < .001$; mother: $r = .28$; $p < .01$) also under control of age (father: $r = .30$; $p < .01$; mother: $r = .29$; $p < .01$).

4. Discussion

The aim of the study was to look into the relations between gross motor skills, fine motor skills and executive functions on the level of latent variables. It was a matter of particular concern to analyse the relation between gross motor skills, fine motor skills and executive functions simultaneously. For a better understanding, the associations with individual (aerobic endurance and strength) and background variables (SES and physical activity) was also taken into account.

A confirmatory factor analysis was used to test whether the chosen motor tasks truly measure two empirically distinct, motor factors. Thereby, the theoretically based and commonly seen separation of the two factors gross motor skills and fine motor skills in kindergarten children showed a satisfactory model fit. Because both factors (gross and fine motor skills) represent partial aspects of the same higher order construct (common motor factor), no strict segregation of the two aspects was expected. Despite the correlation between the two factors being very high, the model fit was still slightly better and with regard to content more differentiated compared to a one factor solution.

Those results indicate that the chosen test share a substantial amount of common variance. This suggests that the different motor skills are interrelated. It is possible that subcomponents of general motor skills only differentiate more clearly later in the course of development. Thus, it may be the case that in early childhood all motor tasks (whole body coordination and manual dexterity tasks) contain a common, overall factor, despite obvious differences in task quality and task demands. Especially for the examined age range, environmental factors may promote the differentiation in gross and fine motor skills. More precisely, when entering primary school, the opportunity to practice fine motor skills clearly increases and is obviously supported by many school activities (McHale & Cermak, 1992).

Just as well, physical education in school or the participation in a sports team enables children to practice and further develop their gross motor skills (Fransen et al., 2012). Profound knowledge on the development of motor skills is very interesting in theory, but there is also a practical relevance to it (e.g., for physical education, for promoting healthy development, or the diagnosis and treatment of motor coordinative developmental disorders). Thus, to investigate the differences of developmental trajectories between gross and fine motor skills would be interesting for future research. Likewise, the influence of different environmental factors in the sense of exercise possibilities should be taken into consideration.

In line with previous studies, a significant correlation between fine motor skills and executive functions was found. However, contrary to current literature, the relation between gross motor skills and executive functions was slightly higher than the relation between fine motor skills and executive functions. This finding can possibly be explained with the chosen method of assessing executive functions. More precisely, in other recent studies, either teacher ratings (Grissmer et al., 2010) or the “Head-Toes-Knee-Shoulders” task (Cameron et al., 2012), a very general, behavioural measure for executive functions (Ponitz et al., 2008; Ponitz, McClelland, Matthews & Morrison, 2009), were used. What concerns the present study, the quantification of cognitive self-regulation with standardised and computerized tests seems to us like a methodological advantage. Consequently, the present results indicate that the correlation between gross motor skills and some aspects of self-regulation have been underestimated in previous studies.

The maturation of prefrontal cortex, cerebellum, basal ganglia and other connecting structures serves as a possible explanation for the relation between gross motor skills, fine motor skills and executive functions. Neuro-imaging studies showed that the same cortical areas are activated during motor coordinative as well as during executive functions tasks (Diamond, 2000). To master motor tasks (no matter its nature, whole body coordination or manual dexterity), central executive abilities are needed and used (Roebers & Kauer, 2009).

For example, to insert coins or move sideways, different sub-goals need to be remembered (to post as fast as possible; to hold the box with one hand – to stand with both feet on the board; to move the board with both hand) and the children have to plan ahead (to specify an order in which the coins will be posted – to plan the exact point when they move to the other board). Furthermore, the children also have to recall and use their strategies. Due to the presented findings, we conclude that to date the literature's focus has been on the relation between manual dexterity skills and executive functions. Thereby it was neglected that empirical evidence as well as the neuropsychological explanation also hold for gross motor skills. The focus on fine motor skills was probably due to its more obvious relevance for school readiness (e.g., Grissmer et al., 2010). However, as from our point of view, gross motor skills should also be taken into account. One important and practically relevant advantage of gross motor skills is that individual differences or abnormalities in the development may become obvious an earlier stage making prevention possible. Thus, recommendations for specific activities or empirically based intervention/prevention programs could be deducted that support further development.

Based on previous studies stating a relation between executive functions and fine motor skills as well as school achievement (Grissmer et al., 2010; Roebers et al., 2014), it stands to reason that the support of fine motor skills may enhance school readiness of young children. However, the hereby given evidence of a substantial relation between gross motor skills and executive functions (over and above fine motor skills) suggests that school readiness could also be enhanced in an indirect way through playful, gross motor exercises. This opportunity would provide a change to the usual scholastic work at the desk and above all would probably be more in the nature of young, lively and physically active children. More profound knowledge on the exact nature of the relationship could allow to integrate fine and gross motor in the daily routines in kindergarten, and thus serve as further contribution in enhancing school readiness of young children.

Another aim of the present study was to explore the relationship between executive functions, motor skills and specific individual and background variables. In this context, a positive correlation was found for physical fitness variables (aerobic endurance and strength) and executive functions, gross motor as well as fine motor skills. However, it seems that those relations are affected by chronological age. More precisely, while the correlation between fine motor skills and standing long jump remained significant after controlling for age, the correlation between fine motor skills and aerobic endurance did no longer reach significance. A possible explanation for this result is that the coordinative aspect of the standing long jump task is higher than for the six-minutes-run. Overall, general cognitive control processes provide an explanation for the mentioned associations between aerobic fitness, motor skills and executive functions (Roebers & Kauer, 2009). It is generally assumed that the relationship between aerobic fitness and executive functions is mediated by neuronal activation (Hillman, Castelli & Buck, 2005). This assumption is further supported by current findings concerning the relationship between fitness and executive functions in children (Buck et al., 2008; van der Niet et al., 2014). Literature as well as the findings of the present study suggest that all three domains (executive functions, motor skills and physical fitness) share proportions of the same higher order cognitive processes which in turn provides a possible explanation for the reported relations between the different domains. Thus, central executive abilities appear necessary not only in motor tasks, but in fitness tasks also. More precisely, in fitness tasks children have to maintain their goals (e.g., to run as fare as possible in 6 minutes). They have to plan how to do best (e.g., to run the same pace from the beginning until the end). Moreover, they have to implement their strategies even in case of distraction (e.g., not to be influenced of children who run faster). The delineation and identification of such higher order cognitive control processes (e.g., planning, monitoring, goal-orientation) should necessarily be taken into account in future research. Because different domains seem to be fundamentally affected

by such higher order cognitive control processes, differentiated knowledge concerning those processes is of theoretical as well as practical relevance.

In respect of background variables, one small but significant correlation between SES and executive functions was found. This result is in line with findings of previous studies (Noble et al., 2007; Röthlisberger et al., 2010). However, after controlling for age, the correlation between SES and executive functions did no longer reach significance. This suggests that the link was –at least to some extend – driven by albeit small age differences. Thus, no significant correlation was found for motor skills and SES, a result comparable to the findings of Röthlisberger et al. (2010) who reported no significant correlation between SES and fine motor skills. In general, the relation between motor skills and SES is reported as being small (Kemper, 1982; Kretschmer, 2001, Scheid, 1989), assumably because SES represents a too global indicator (Scheid, 2009). For this reason, we conclude that the SES has no significant influence on the relation between motor skills and executive functions for the tested age group.

The lack of correlation between motor skills, executive functions and the physical activity level of the family members was rather unexpected. However, it appears that physical activity behaviours of the parents influences the one of their child. This assumption is based on data of a classical study of Moore et al. (1991), showing that children with physically active parents were more active than those with less active parents. Altogether, we conclude that the influence of the physical activity level on gross and fine motor skills is rather small in kindergarten children. Even if former studies found significant correlations between physical activity and a common motor factor, the correlations were small and only of importance when the intensity of the physical activity was high (Fisher et al., 2005; Wortniak et al., 2006). Moreover, the relation between executive functions and physical activity was not significant in the present study leading to the conclusion that the relation between motor skills and executive functions is not fundamentally affected by physical activity level of young children.

Nevertheless, in certain circumstances, physical exercise is assumed to promote executive functions (Davis et al., 2007; Jäger, Schmidt, Conzelmann & Roebers, 2014; Tomporowski, Lambourne & Okumura, 2011). For this reason, the effect of physical activity, also in the context of socialization, should not be left underestimated. Thus, despite the fact that the correlations with the background variables were not significant (after controlling for age) most of them at least pointed into the expected direction. Hence, the influence of environmental factors should not be neglected, because as a whole they could have a cumulative influence on the relation between motor skills and executive functions.

Even though a wide range of aspects concerning child development have been accounted for in the presented study, there is one particular limitation to be noted. Even if not being a central concern, the multi-dimensional nature of executive functions was assessed with only one test for each dimension respectively. Consequently, no profound analyses and results within the construct of executive functions could be made. Likewise, we cannot rule out that a very low SES could have an influence on motor performance (as very low SES children might not have access to physical activities) and consequently on the motor cognitive performance link. This is because a low SES in Switzerland is probably not comparable to a very low SES in less developed countries. Nevertheless, to address the issue of access to physical activities, we built two SES groups, one group with high SES (N = 36; M = 2.45; SD = .55; Range = 1.34 - 3.03) and one with low SES (N = 36; M = -2.75; SD = 1.21; Range = -4.85 - -.92). The physical activity level of children with the highest SES did not differ from children with the lowest SES (t(69) = 1.04; p = .30; d = .25).Therefore, we can assume that there were no systematic differences in children`s access to play or to formal and informal sports participation. Of course, this does not rule out the possibility that children with a low SES in less developed counties have less access to play or sports participation than children with high SES. Consequently, a low SES could still have an indirect or direct influence on motor performance. Further research in this direction is desirable. Moreover, a broader picture

of the developmental environment of kindergarten children, including differentiated information about physical activity socialization, would allow for a more detailed evaluation of theoretically different models of motor and cognitive development.

In summary, the present study shows a specific correlation between executive functions and two areas of motor skills. This relation seems not fundamentally affected by either SES nor the level of physical activity. Additionally, certain significant correlations between fitness, motor skills and executive functions were found. A possible explanation for those associations lies in higher order cognitive skills, as for example goal- orientation, planning abilities and strategy use. The direct measurement of such constructs represents a great challenge for future research.

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6. Appendices

Appendix

Appendix A

Pearson correlations of the manifest variables.

		1	2	3	4	5	6	7	8	9
1	threading beads	1	**.56****	**.30****	**.35****	**.35***	**.45****	**.37****	**.26****	**.25****
2	posting coins	**.52****	1	**.30****	**.35****	**.40****	**.48****	**.33****	**.36****	**.31****
3	drawing trail	**.27****	**.28****	1	**.35****	**.30****	**.20***	.15	.15	**.19***
4	one-leg-stand	**.33****	**.33****	**.34****	1	**.33****	**.31****	**.26****	.08	**.24****
5	jumping sideways	**.31****	**.38****	**.29****	**.32****	1	**.45****	**.30****	**.40****	**.24****
6	moving sideways	**.41****	**.44****	**.18***	**.29****	**.43****	1	**.35****	**.36****	**.26****
7	inhibition	**.34****	**.30****	.13	**.25****	**.28****	**.32****	1	**.49****	**.31****
8	switching	**.25****	**.35****	.14	.07	**.39****	**.35****	**.48****	1	**.22****
9	updating	**.23****	**.29****	.17	**.23****	**.23****	**.24****	**.29****	**.21****	1

Note. Above the diagonal, Pearson correlations, below the diagonal, partial correlations controlled for age, ** $p < .01$, * $p < .05$.

Appendix B

Sample size (*N*), mean (*M*), standard deviation (*SD*), minimum (*Min*) and maximum (*Max*) of the individual and background variables.

	N	*M*	*SD*	*Min*	*Max*
individual variables					
6-minutes-rum	156	863.33	177.97	504.00	1578.00
standing long jump	156	107.85	16.57	66	153.00
background variables					
physical activity child	119	-.05	1.66	-4.1	4.09
physical activity mother	114	-.05	1.19	-1.36	5.76
physical activity father	111	-.03	1.34	-1.78	5.73
SES	110	.00	2.28	-4.85	3.03

Note. SES= socio-economic status; units: 6-minutes-run =meters; standing long jump = width cm; physical activity and SES = sum scores

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Table 1

Mean (*M*), standard deviation (*SD*), minimum (*Min*) and maximum (*Max*) of the raw scores of the gross motor skills, fine motor skills and executive function tasks.

	M	*SD*	*Min*	*Max*
gross motor skills				
one-leg- stand	46.99	14.73	12.00	60.00
jumping sideways	38.19	10.67	8.00	69.00
moving sideways	31.46	5.76	17.00	44.00
fine motor skills				
threading beads	38.36	8.06	26.49	90.00
posting coins	37.75	3.92	28.27	54.89
drawing trail	3.93	3.12	0.00	16.00
executive functions				
inhibition	.88	.17	.14	1.00
switching	.84	.13	.33	1.00
updating	9.13	4.24	0.00	18.00

Note. *N* = 156. Metrics: threading beads, posting coins, one-leg stand = seconds; drawing trail = errors; jumping sideway = amount of jumps; moving sideways = amount of correct sideway movements; inhibition, switching = percent of correct trials; updating = total amount of correct recalled trials.

Table 2

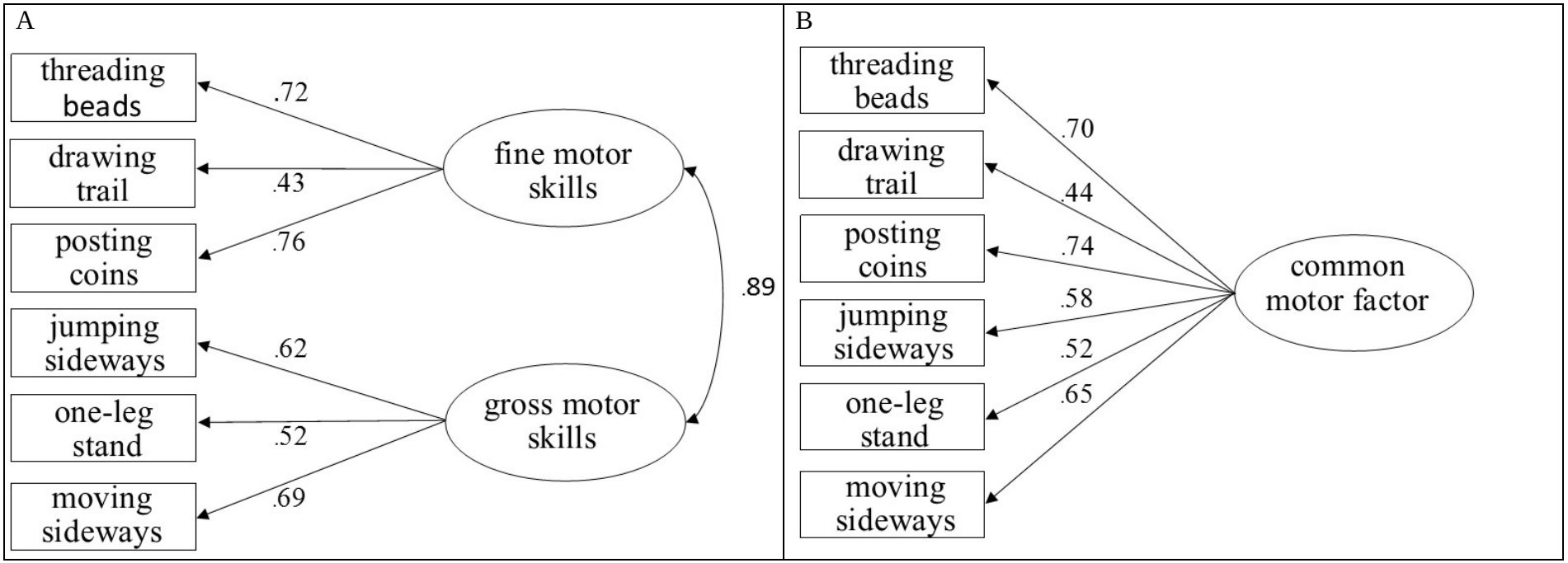
Pearson correlations of the manifest variables.

	gross motor skills	fine motor skills	executive functions
individual variables			
six minutes run	**.31***/ .35*****	**.18*/** .10	**.27***/ .**17
standing long jump	**.46***/ .44*****	**.23**/ .20***	**.17*/ .21***
background variables			
physical activity child	.11/ .12	-.07/ -.10	.10/ .16
physical activity mother	.09/ .10	-.04/ -.05	.04/ .11
physical activity father	.12/ .12	.02/ -.02	-.05/ .04
SES	.17/ .14	.08/ -.02	**.23*/**.19

Note. Pearson correlations, after the slash controlled for age; *** p < .001; ** p < .01; * p < .05.

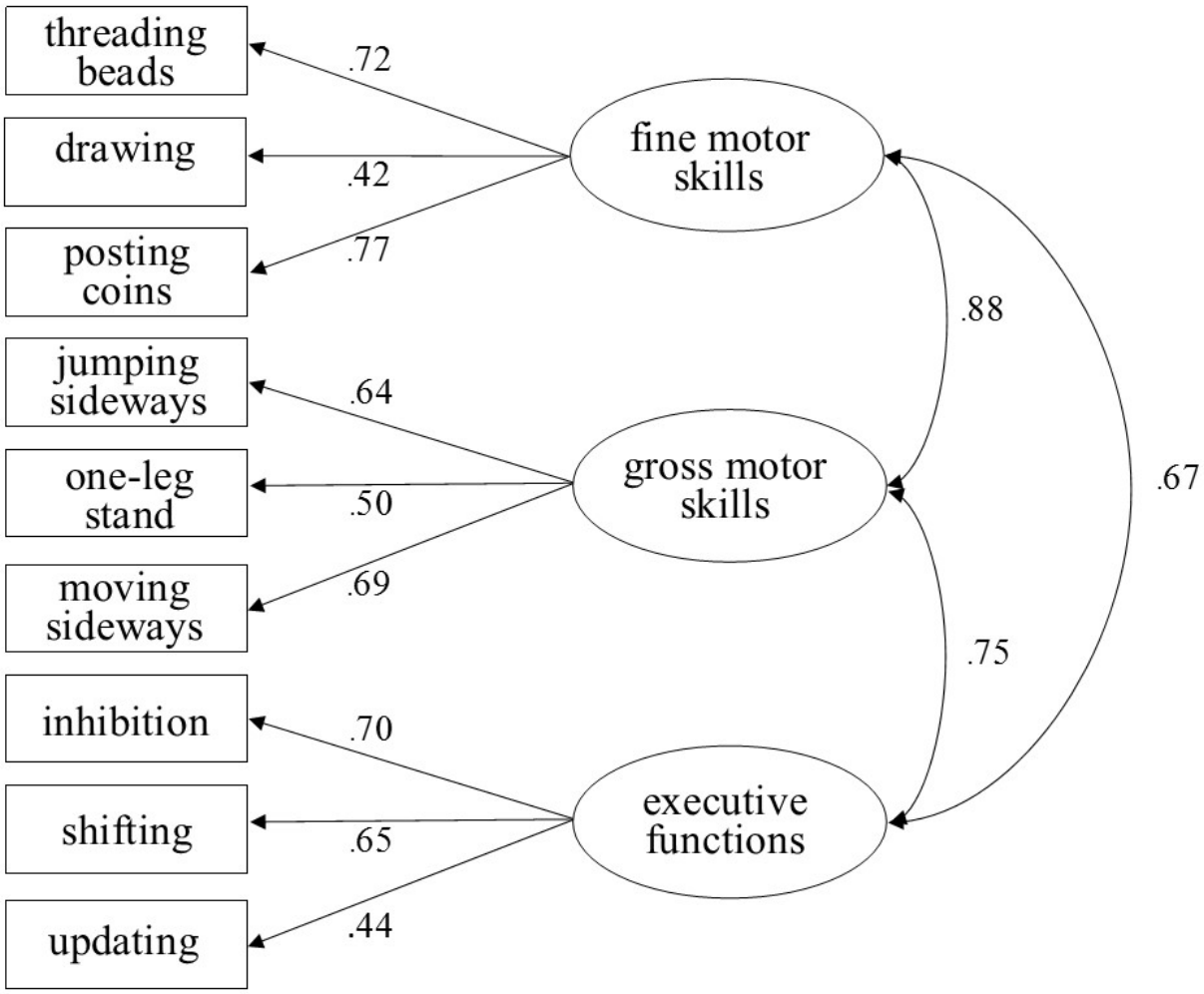
Figure 1

Single and two factorial model of motor coordination



Note. Two factorial model (Figure 1A) and single factorial model (Figure 1B).

Figure 2



Note. Intercorrelations between gross motor skills, fine motor skills and executive functions.