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# Identifying patterns of motor performance, executive functioning, and verbal ability in preschool children: A latent profile analysis

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ABSTRACT

*Background:* A relationship between motor performance and cognitive functioning is increasingly being recognized. Yet, little is known about the precise nature of the relationship between both domains, especially in early childhood.
*Aims:* To identify distinct constellations of motor performance, executive functioning (EF), and verbal ability in preschool aged children; and to explore how individual and contextual variables are related to profile membership.
*Methods and procedures:* The sample consisted of 119 3- to 4-year old children (62 boys; 52%). The home based assessments consisted of a standardized motor test (Movement Assessment Battery for Children – 2), five performance-based EF tasks measuring inhibition and working memory, and the Receptive Vocabulary subtest from the Wechsler Preschool and Primary Scale of Intelligence Third Edition. Parents filled out the Behavior Rating Inventory of Executive Function – Preschool version. Latent profile analysis (LPA) was used to delineate profiles of motor performance, EF, and verbal ability. Chi-square statistics and multinomial logistic regression analysis were used to examine whether profile membership was predicted by age, gender, risk of motor coordination difficulties, ADHD symptomatology, language problems, and socioeconomic status (SES).
*Outcomes and results:* LPA yielded three profiles with qualitatively distinct response patterns of motor performance, EF, and verbal ability. Quantitatively, the profiles showed most pronounced differences with regard to parent ratings and performance-based tests of EF, as well as verbal ability. Risk of motor coordination difficulties and ADHD symptomatology were associated with profile membership, whereas age, gender, language problems, and SES were not.
*Conclusions and implications:* Our results indicate that there are distinct subpopulations of children who show differential relations with regard to motor performance, EF, and verbal ability. The fact that we found both quantitative as well as qualitative differences between the three patterns of profiles underscores the need for a person-centered approach with a focus on patterns of individual characteristics.

## What this paper adds?

Although there is some evidence that motor performance and cognitive functioning are related in children, the precise nature of the relationship between the two domains, especially in early childhood, is still an open question. To fill this gap, this study examines

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the relationships between motor performance, executive functioning, and verbal ability in 3- to 4-year old children. A further significance of this study lies in applying a person-centered approach to examining these relationships. This approach enables creating profiles on a continuum of skills which is especially important when examining young children whose development is characterized by intra- and interindividual variability. Our results highlight qualitatively different skill profiles in preschool aged children, offering useful insight for early screening and intervention.

## 1. Introduction

Throughout development, children become increasingly more able to control their motor actions (Hamilton, Southgate, & Hill, 2016). This developing motor control represents planning, organizing, monitoring, and controlling complex motor coordination which seem to have an intuitive connection with executive functioning (EF). Although the exact definition is widely discussed, most researchers would agree on the notion that EF refers to a set of higher-order cognitive processes, such as inhibition, working memory, and cognitive flexibility, which are instrumental in supporting action control and thought (e.g., Carlson, Faja, & Beck, 2016). The conceptual overlap has been highlighted previously: by definition, purposive movement involves action control, and action control is an essential part of EF (Koziol, Budding, & Chidekel, 2012). Another key developmental skill to consider when exploring the relationship between motor performance and EF is verbal ability. Verbalizing thoughts supports action control, i.e., expression of actions, reflection of performed actions, and planning of future actions (Kray, Eenshuistra, Kerstner, Weidema, & Hommel, 2006).

The idea that there is a relationship between motor performance and higher-order cognitive functions, such as EF and language, stems also in part from theoretical perspectives. For example, in the embodied cognition perspective, cognition – and EF and language as subdomains of cognition – are considered to occur in the context of the individual's bodily interaction with the physical and social environment (Barsalou, 1999; Gibbs, 2005; Smith & Gasser, 2005). Being able to act upon their environment allows children to gain knowledge about their surroundings, which leads to changes in various perception-action systems (Von Hofsten, 2009). These changes bring about advances in cognition that in turn will affect how children examine and manipulate their environment (Campos et al., 2000; Von Hofsten, 2007). This is not to say that the physical body is the only system involved in cognition or that one can assume a global association between motor performance and cognition, but that *specific* motor actions could play a role in this process (Oudgenoeg-Paz, Volman, & Leseman, 2016).

In addition, several authors have argued that thought, reasoning, and other forms of complex cognitive processes, such as EF, depend on interiorization of actions (Ardila, 2012). Verbal ability may be viewed as an essential means in the interiorization of actions. For instance, a central point in Vygotsky's theory (1962) is that verbal ability represents a major instrument of internal representation of the world and thinking. Similarly, Clark (2008) describes language as cognitive scaffolding, extending the embodied mind and making it possible to generalize across situations and experiences. Verbal ability thus helps children to regulate their own actions and thoughts.

The conceptual and theoretical link between the aforementioned developmental domains is supported by neuroimaging research (Diamond, 2000; Pangelinan et al., 2011; Pulvermüller, 2005). Brain areas associated with EF, such as the dorsolateral prefrontal cortex, and brain areas necessary for the planning and execution of movements, such as the cerebellum and basal ganglia, are co-activated during the execution of specific motor and EF tasks (Diamond, 2000). For example, a study examining brain activity in 8- to 12-year old children during a motor task showed activation of a broad network of regions, including the dorsolateral prefrontal cortex, inferior parietal lobule, and the cerebellum (Zwicker, Missiuna, Harris, & Boyd, 2011). Furthermore, areas of the brain implicated in language functions (e.g., Broca's area) are also activated during EF tasks (Gerton et al., 2004) and motor tasks (i.e., action planning, action observation, action understanding, and imitation; Nishitani, Schürmann, Amunts, & Hari, 2005). In addition, the activation of motor areas has been observed during language tasks (e.g., Casado et al., 2018; Pulvermüller, 2005; Willems & Hagoort, 2007).

Yet behavioural studies looking at direct connections between developmental domains have not yielded clear results. Studies examining the relationship between motor performance and EF have revealed only modest associations between both domains, including studies that do not find these associations (Hamilton et al., 2016; Van der Fels et al., 2015). In addition, although studies reported that children with motor coordination difficulties, including children with a diagnosis of Developmental Coordination Disorder (DCD), have clear EF difficulties (Leonard & Hill, 2015; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013), research has also shown that the commonly assumed link between motor coordination difficulties and executive dysfunction is not always present (Molitor, Michel, & Schneider, 2015).

Similarly, while in recent years increasing empirical evidence is reported for a link between motor performance and language in typically developing children during the first 3 years of life (e.g., He, Walle, & Campos, 2015; Libertus & Violi, 2016; Walle & Campos, 2014), the relationship seems to weaken or disappear as a function of age (Libertus & Hauf, 2017; Oudgenoeg-Paz et al., 2016). In addition, developmental disorders such as Specific Language Impairment (SLI) have been related to motor coordination difficulties and DCD to language impairments (see Hill, 2001 and Leonard & Hill, 2014 for reviews). Although the general finding in children with developmental disorders is one of relatively high rates of co-occurrence between motor coordination difficulties and language impairments, not all children with motor coordination difficulties have language impairments and vice versa.

With regard to the relationship between verbal ability and EF, a number of studies have shown that typically developing children's verbal ability is related with EF performance, and that children with SLI score poorly on EF tasks (e.g., Fuhs & Day, 2011; Gooch, Thompson, Nash, Snowling, & Hulme, 2016; Kaushanskaya, Park, Gangopadhyay, Davidson, & Weismer, 2017; see Müller, Jacques, Brocki & Zelazo, 2009 for a review). However, with regard to the EF of children with SLI, conflicting results are also present with some researchers finding evidence of dysfunction in children with SLI and others reporting equivalent performance between children with SLI and typically developing children (Kapa & Plante, 2015).

Overall, studies are inconclusive about the exact extent of the relationships between developmental domains, which might be due to developmental differences within children, individual differences across children, and to different measures used to assess children's motor performance, EF, and verbal ability (Leonard & Hill, 2015; Libertus & Hauf, 2017). Furthermore, despite empirical associations between motor performance, EF, and verbal ability in different bivariate combinations, no study has yet explored how these three domains interact. This research is the first to examine these three areas of child development concurrently in early childhood in order to shed light on the constellations of motor performance, EF, and verbal ability in young children.

Mainly variable-oriented and correlational methods have been used when examining the relationship between the aforementioned developmental domains, which have been based on the assumption of linearity of relationships. Such an approach potentially oversimplifies the complex interplay between developmental domains in young children. The possibility that subgroups of individuals may show profiles with different interrelations between motor performance, EF, and/or verbal ability has rarely been taken into account. A person-centered approach, such as latent profile analysis (LPA), can describe the patterning of multiple variables within individuals to capture essential features of functioning that may be lost when simple linear associations are analysed (Bergman & Magnusson, 1997; Collins & Lanza, 2010). Using a person-centered approach for examining the relationship between motor performance, EF, and verbal ability may be vital at all stages of child development, but even more so during the preschool-age period because this developmental period is characterized by both a rapid growth as well as considerable intra- and interindividual variability in motor performance, EF, and verbal ability (Howard, Okely, & Ellis, 2015; Piek, Hands, & Licari, 2012).

An important issue to consider when examining EF in preschool children is the structure of EF. For primary school children, adolescents, and adults there is conclusive evidence concerning three distinguishable, yet interrelated, constructs of EF; that is: working memory, inhibition, and cognitive flexibility (Huizinga, Dolan, & van der Molen, 2006; Miyake, Emerson, & Friedman, 2000). Yet, in preschool aged children the evidence regarding the structure of EF is less conclusive. Factor analysis studies with 3-year olds consistently show a unitary EF factor model (Wiebe, Espy, & Charak, 2008; Willoughby, Wirth, & Blair, 2012). Both one- and two-factor models have been found within samples of 4- and 5-year old preschoolers, with the majority of two-factor models revealing an inhibition and working memory component (e.g., Lee, Bull, & Ho, 2013; Monette, Bigras, & Lafrenière, 2015). It is important to note however, that in many of these two-factor models working memory and inhibition were significantly correlated (with correlations > .80; Monette et al., 2015). Additionally, it is argued that cognitive flexibility is only emerging from the primary school age and thus not yet distinguishable in preschool aged children (e.g., Garon, Bryson, & Smith, 2008). In sum, empirical evidence seems to support an initial unitary structure of EF, and as a function of age a differentiation of components occurs.

Related to the structure of EF, is the operationalization and measurement of EF, specifically performance-based measures versus parent ratings of EF (Leonard & Hill, 2015; Toplak, West, & Stanovich, 2013). There is mounting evidence that performance-based measures and parent ratings of EF do not assess the same construct (Toplak et al., 2013). While performance-based EF measures typically assess specific, individual executive functions under highly structured and standardized conditions, rating scales of EF were developed to tap into complex, real-world manifestations of executive functions (Toplak et al., 2013). It has been suggested that the type of EF measurement may affect the relationship found between motor performance and EF (Houwen, van der Veer, Visser, & Cantell, 2017; Ten Eycke & Dewey, 2016). Addressing this issue is particularly relevant in early childhood, where assessment of EF by performance-based measures is a challenge, as validated tests are relatively few, norms are uncertain, and variables as limited attention span, motivation, and confidence in the testing situation might influence the results (Nilsen, Huyder, McAuley, & Liebermann, 2016).

Therefore, the first aim of the current study was to identify distinct constellations of motor skills, EF, and verbal ability in preschool aged children. For EF both multiple performance-based measures and a parent rating measure were used. Based on the reviewed evidence and our young sample, we expected a one-factor model for EF including inhibition and working memory tasks. As performance-based EF measures and parent ratings of EF have been found to provide complementary but distinctive information, we assumed a model with a unitary EF variable based on performance-based tasks and a unitary EF variable involving the parent rating. We have chosen to focus on receptive vocabulary as a measure of verbal ability, as receptive vocabulary develops rapidly in early childhood and builds the foundation for language acquisition and literacy (Powell & Diamond, 2012). Furthermore, it has been suggested that receptive vocabulary tests provide the purest measure of language ability (Milligan, Astington, & Dack, 2007). Given the exploratory and innovative nature of our study, it was impossible to have a comprehensive view on the number of possible profiles. We did, however expect to delineate profiles that not only differ in quantity, but exhibit qualitatively distinct patterns of motor, EF, and verbal ability skills. The second aim was to explore how individual and contextual variables were related to profile membership.

## 2. Method

### 2.1. Participants

The current study used data drawn from a larger longitudinal study examining the motor skills, executive functions, and language abilities from 3 years to school entry. Dutch-speaking children aged 3;0 to 5;11 years were eligible for inclusion. A parent-reported socio-demographic questionnaire was used to ascertain the absence of physical disabilities, neurological disorders (e.g., intellectual disability or autism spectrum disorder), and sensory impairments. Participants were recruited from day care centres, playgroups, preschools, and primary schools as well as via social media, public advertisements and snowball sampling.

The final sample consisted of 119 children, including 68 3-year-olds (M = 41.0 months, SD = 3.5, range = 35–47; 48.5% boys) and 51 4-year-olds (M = 53.6 months, SD = 3.6, range = 48–59; 56.9% boys). There were no children with a formal diagnosis of DCD, but 20.6% scored at or below the 16th percentile on the Movement Assessment Battery for Children-2, Dutch Version (MABC-2; Henderson, Sugden, Barnett, & Smits-Engelsman, 2010), putting them at risk for motor coordination difficulties. There were no children with a formal diagnosis of ADHD; 8% scored in the clinical range on the Hyperactivity-Inattention subscale of the Strengths and Difficulties Questionnaire3–4 (SDQ3–4; Goodman, 1997). There were no children with a formal diagnosis of SLI, but 10.1% had been referred to a speech and language therapist for language problems as indicated by parents in the socio-demographic questionnaire. Socioeconomic status (SES), based on maternal educational level, was unequally distributed across low SES (5.2%), intermediate SES (18.6%), and high SES (76.2%).

### 2.2. Instruments

#### 2.2.1. Motor performance

Motor performance was assessed with age band 1 from the MABC-2 (Henderson et al., 2010). This test consists of three sections: Manual Dexterity (three items), Aiming and Catching (two items), and Balance (three items). The raw scores of each item can be recoded into an item standard score, which uses correction for age, and summed into a total standard score (range 1–19, mean score = 10, SD = 3) and percentile score.

The psychometric properties of the MABC-2 suggest that it is a valid and reliable measure to be used in young children (Ellinoudis et al., 2011).

#### 2.2.2. Performance-based EF measures

Both verbal and non-verbal EF tasks were used

*2.2.2.1. Inhibition.* The *Day/Night task* (Gerstadt, Hong, & Diamond, 1994) is a verbal inhibition task, where a child is presented with two different cards. When the child is shown a white card with a yellow sun, the child is instructed to say ‘night’. When the child is shown a black card with a yellow moon and stars, the child is instructed to say ‘day’. After a few practice trials, the child performed 16 test trials. One point was awarded for each correct response (0–16). Studies have shown good internal consistency as an items set in preschoolers with α coefficients of 0.93 and 0.89 (Chasiotis, Kiessling, Hofer, & Campos, 2006; Rhoades, Greenberg, & Domitrovich, 2009) and good test-retest reliability over a 2-week period ($r$ = 0.84; Thorell & Wahlstedt, 2006). The Day/Night task has been found to be related to other measures of EF, as well as to preschool academic achievement (McClelland et al., 2014).

*The Hand-Tapping task* (Diamond & Taylor, 1996) is a fine motor inhibition task, where a child is asked to do the opposite of what the experimenter is doing. The child is asked to tap twice with a pencil when the tester taps once and vice versa. After a practice phase brief training, 16 test trials were presented. A correct response was coded as 1. The total score was based on the number of correct responses (0–16). The internal consistency of the Hand-Tapping task as an item set in preschoolers and kindergartners has been reported by several studies, with α coefficients between 0.75 and 0.88 (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Blair & Razza, 2007; Rhoades et al., 2009). Test-retest reliability has been shown to be good over a 2-week period ($r$ = 0.80; Meador, Turner, Lipsey, & Farran, 2013). Inter-rater reliability between a live coder (the tester) and a reliability coder using a videotape has shown to be high (ICC > .80; Smith-Donald, Raver, Hayes, & Richardson, 2007). Performance on the Hand-Tapping task is related to teacher reports of effortful control, as well as emerging math and literacy abilities in kindergarten (Blair & Razza, 2007).

*The Head-Toes-Knees-Shoulders* (HTKS; Ponitz, McClelland, Matthews, & Morrison, 2009) is a gross motor inhibition task. First, the child was asked to do the opposite of what the tester was doing (e.g., touch head when experimenter touches the toes). There were four practice trials and 10 test trials. Children received 2 points for a correct response, 1 point for a self-corrected response, and 0 points for an incorrect response. Second, children were asked to touch their shoulders when the tester touched his/her knees, and vice versa. After four practice trials, the tester gave 10 trials of head, toes, knees, and shoulders commands. The two sets of test trials were summed to give a total score (0–40). The construct validity of the HTKS task has been supported by moderate-to-strong correlations with other EF tasks (McClelland et al., 2014) and moderate correlations with ratings of EF (Ponitz et al., 2009). Internal consistency is high with an α coefficient of 0.93 (Lonigan, Allan, Goodrich, Farrington, & Phillips, 2017). McClelland et al. (2014) showed high inter-rater reliability (92.3%) and acceptable test-retest reliability over a period of 3–7 months ($r$ = 0.60 in pre-kindergartners and $r$ = 0.74 in kindergartners).

*2.2.2.2. Working memory.* Because our sample consisted of young children, we have chosen to use forward span tasks instead of backward span tasks, which could be regarded more short-term memory tasks than working memory tasks. Backward span tasks, which are supposed to measure working memory, proved to be too difficult for young children (Bull, Espy, & Wiebe, 2008; Kegel & Bus, 2012). Before children become able to manipulate information in their minds they must accomplish the skill of holding information in their mind over a delay (Garon et al., 2008), therefore short-term memory tasks can be used as a measure of rudimentary working memory.

The *Forward Digit Recall Task* (Gathercole & Pickering, 2000) was used as a verbal working memory measure. In this task the child was asked to repeat digits in the same order as the test administrator. During a practice phase with two practice trials it was confirmed that the child understood the task. The task started with three trials of two digits long. At least one correct response of the three trials led to the following three trials being one digit longer. The maximum possible sequence was seven digits long. Testing was discontinued when the child responded all three trials of the same length incorrectly. The total score was based on the number of correct responses (0–18). The forward version of the Digit Recall has shown acceptable to good test-retest reliability in preschoolers

($r = 0.68$ in the study of Gathercole (1995); $r = 0.84$ in the study of Alloway, Gathercole, & Pickering (2006); ICC = 0.66 in the study of Müller, Kerns, & Konkin (2012)).

The *Forward Corsi Block Task* was used to measure visual-spatial working memory (Pickering, Gathercole, & Peaker, 1998). A child was shown six identical blocks positioned in front of the child on the table. The tester tapped the blocks in sequence and the child was asked to reproduce the exact sequence shown. During a practice phase with two practice trials it was assessed whether or not the child understood the task. The actual task consisted of five series, each of three trials starting with two blocks and one block was added each series resulting in a maximum of six blocks in a row. The test was finished when a child performed incorrectly in all three trials of a series. The total score was based on the number of correct responses (0–15). Studies have shown good test-retest reliability ($r = 0.83$ and $r = 0.90$; Alloway et al., 2006; Alloway, Rajendran, & Archibald, 2009).

### 2.2.3. Rating scale of EF

Parents completed the Dutch translation of the Behaviour Rating Inventory of Executive Function–Preschool version (BRIEF–P; Gioia, Espy, & Isquith, 2005), a 63-item standardized rating scale that assesses different aspects of EF in children 2;0–5;11 years. Corresponding to the performance-based EF subdomain measures, only the subscales Inhibition (16 items; e.g., "Acts out of control") and Working Memory (17 items; e.g., "Has trouble remembering, even after a short amount of time") were used in the present study. The primary caregivers were asked to rate how often their child exhibited various behaviours related to EF in the past 6 months on a 3-point scale (1 = never, 2 = sometimes, 3 = often). Raw score totals for each scale are converted to age- and sex-specific T-scores (M = 50, SD = 10) in which higher scores indicate greater executive dysfunction. T-scores of 65 and above are considered clinically significant.

The Dutch version of the BRIEF–P (Van der Heijden, Suurland, De Sonneville, & Swaab, 2013) showed sufficient to high internal consistency, test–retest reliability, interrater reliability, and construct validity.

### 2.2.4. Verbal ability

Children completed the Receptive Vocabulary subtest of the Dutch version of the Wechsler Preschool and Primary Scale of Intelligence Third Edition (WPPSI-III-NL; Wechsler, 2009, 2010). Four pictures are shown to the child and the child is asked to point to the picture matching the word the tester said. The total score is the sum score of correct responses, which are converted into age-standardized scores. Sufficient-to-good reliability for the WPPSI-III-NL and evidence for good content, construct, and criterion validity of the instrument has been reported (Wechsler, 2009, 2010).

## 2.3. Procedures

The study protocol was approved by the Ethics Review Committee of the Department of Pedagogical and Educational Sciences, Faculty of Behavioural and Social Sciences, University of Groningen. Written consent was obtained from all parents after they were given written information.

The participants were assessed in two home sessions as part of a larger study, each lasting up to 90–120 min. While the parents filled out questionnaires, children completed a battery of tasks measuring motor skills, EF, language, and general cognitive ability. The assessments were videotaped for scoring purposes. Children were allowed rest breaks and received stickers for completing each task. After the home visits were completed, children were given a small gift and a diploma, and parents received a short report of the results by mail. To ensure confidentiality, data were entered and stored using a personalized study identifier.

## 2.4. Data analysis

Our analytical approach consisted of three phases, of which the first two were conducted using M*plus* Version 8.0, and the latter using SPSS Version 24. First, in accordance with our expectations regarding the structure of EF, a one-factor CFA model was tested. This model entailed a latent variable *EF_tests*, with the performance-based tests as manifest indicators; and a latent variable *EF_parent rating*, including the BRIEF-P working memory and inhibition subscales as indicators. The raw scores on the performance-based EF tasks were transformed into *z*-scores to reduce individual variable scale effects. The scores were z-standardized per age group (i.e., 3- and 4-year olds) and therefore represented age-adjusted performance. To evaluate model fit we inspected the following model fit measures: Chi-square ($\chi^2$), Root Mean Square Error of Approximation (RMSEA), Tucker-Lewis Fit Index (TFI), Comparative Fit index (CFI), and Standardized Root Mean Square Residual (SRMR) (Kline, 2005). Good model fit is indicated by low values of $\chi^2$ (with a corresponding non-significant *p*-value), RMSEA and SRMR $< 0.08$, and TFI/CFI $> 0.9$.

Secondly, we used LPA to delineate profiles of motor performance, EF, and verbal ability. Given the paucity in previous empirical evidence, we took on an exploratory approach by testing a range of 1–6 LPA solutions. To decide on the most appropriate number of profiles we first evaluated several information criteria concerning model fit: the Akaike's Information Criterion (AIC), the Bayesian Information Criterion (BIC), and the Sample-Size-Adjusted BIC (SSA-BIC; Ram & Grimm, 2009). The lower these values, the better the balance between the model accurately representing the data and being parsimonious (Collins & Lanza, 2010). Subsequently, we considered relative model fit, by evaluating the Bootstrap Likelihood Ratio Test (BLRT). LPA solutions with *k* profiles are compared to solutions with *k-1* profiles and a significant *p*-value supports selection of the model with *k* profiles (Nylund, Asparouhov, & Muthén, 2007). Finally, we evaluated classification accuracy (endorsed by entropy values > .80), profile prevalence (no profiles with < 5% of cases) and substantive interpretability of the LPA solutions (Collins & Lanza, 2010). To avoid local maxima we increased the number of start values to 500 and checked for replicability of the best log likelihood (Geiser, 2012; Vermunt & Magidson, 2002).

**Table 1**
Descriptives means, standard deviations and range.

| | M | SD | Range |
|---|---|---|---|
| Age [months] | 46.39 | 7.17 | 35–59 |
| *Motor performance* | | | |
| MABC-2-NL Manual dexterity | 10.25 | 2.96 | 4–19 |
| MABC-2-NL Aiming and Catching | 10.27 | 2.95 | 2–19 |
| MABC-2-NL Balance | 9.12 | 3.09 | 3–18 |
| MABC-2-NL Total score | 10.00 | 3.17 | 1–19 |
| *Executive functioning* | | | |
| BRIEF-P Inhibition | 50.16 | 9.48 | 34–73 |
| BRIEF-P Working memory | 50.78 | 10.14 | 36–83 |
| Corsi Block[a] | 0.00 | 0.99 | −2.32 to 3.62 |
| Day/Night[a] | −0.01 | 0.99 | −2.85 to 1.15 |
| Digit Recall[a] | −0.00 | 0.99 | −2.09 to 3.03 |
| Hand-Tapping[a] | −0.00 | 0.96 | −3.29 to 1.58 |
| Head-Toes-Knees-Shoulders[a] | −0.012 | 0.99 | −2.64 to 1.57 |
| *Verbal ability* | | | |
| WPPSI-III-NL Receptive Vocabulary | 10.41 | 2.60 | 3–18 |

*Note:* MABC-2-NL = Movement Assessment Battery for Children-2 Dutch version; BRIEF-P = Behaviour Rating Inventory of Executive Function-Preschool; WPPSI-III-NL = Wechsler Preschool and Primary Scale of Intelligence Third Edition Dutch version.
[a] Standardized *z*-scores.

In the last analysis phase, by means of multinomial logistic regression, we examined whether profile membership was predicted by age, gender, risk of motor coordination difficulties, ADHD symptomatology, language problems, and SES. Concerning risk of motor coordination difficulties and language problems, we created two new variables. For risk of motor coordination difficulties, scores at or below the 16th percentile on the MABC-2 total score were coded as 'at risk', scores above the 16th percentile were labelled as 'typically developing'. Language problems were coded either zero ('no problems', i.e., not treated by a speech and language therapist as reported by parents) or one ('language problems', i.e., treated for language problems by a speech and language therapists as reported by parents). Furthermore, we applied the model building strategy recommended by Hosmer, Lemeshow and Sturdivant (2013); that is (1) univariate chi-square tests between all predictor-outome pairs, (2) adding significant predictors (as indicated by a significant chi-square test in the former step) in a preliminary multinomial logistic regression model, (3) adding non-significant predictors one-by-one, and (4) interpret final model and test for assumptions. Because of multiple testing, we applied the Šidak-Bonferoni correction (Abdi, 2007) resulting in an alpha level of 0.009 for significance.

## 3. Results

### 3.1. Preliminary analyses

Descriptive statistics including means, standard deviations, and ranges are presented in Table 1.

Concerning missing data we deleted cases with more than 50% missing on all variables ($n$ = 17; 12.5%) from the original dataset ($n$ = 136), resulting in the final sample ($n$ = 119) used for further analyses. The remaining missing data (12.2%) were missing completely at random (MCAR; Little's MCAR test: $\chi^2$ (474) = 503.64, $p$ = .167). Although data was missing on all variables, a substantive part of missingness was due to incomplete observations on EF performance-based tests.

Assessment of assumptions regarding LPA revealed two univariate outliers, which we adjusted to a (score corresponding to a) $z$-score of ± 3.29. No multivariate outliers were found, as indicated by Cook's distances all < 1. Furthermore, the assumption of univariate normality was not met for most of the variables. To account for missing data on the indicator variables and for deviations from normality, we used the robust maximum likelihood estimator (MLR) in M*plus* (Enders, 2001). Finally, the assumptions of (no) multicollinearity and local independence were met.

Additional checking of assumptions relevant for logistic regression, revealed the absence of multicollinearity, indicated by tolerance value > 0.1 and VIF value < 10 (tolerance 0.9 and VIF 1.0). The data did however show sparseness of information (i.e., more than 20% of expected cell counts ≤5) on all predictor-outcome combinations, except for risk of motor coordination difficulties. Therefore, with the chi-square tests we used Fisher's exact test in case of sparseness. For the logistic regressions, we pooled the 'low' and 'intermediate' categories of the SES variable into one 'low to intermediate' category. Similar, for ADHD symptomatology, we combined the 'borderline and abnormal' category. Since sparseness remained for analyses involving the SES variable we applied the Hosmer and Lemewshow goodness-of-fit statistic for all analyses with sparseness of information present (Hosmer, Lemeshow, & Klar, 1988). As this statistic is not (yet) available for multinomial logistic regression, we employed the individual logistic regression approach, as suggested by Begg and Gray (1984).

### 3.2. Confirmatory factor analyses

The one-factor CFA model resulted in a Heywood case (as indicated by an inadmissible parameter value, that is a negative residual

**Table 2**
Model fit indices regarding one-factor model CFA of performance-based EF tests.

| | Model 1a | Model 1b |
|---|---|---|
| $\chi^2$ (*p*) | 20.391 (.001*) | 5.814 (.21) |
| RMSEA | 0.15 | 0.06 |
| TFI/CFI | 0.57/0.14 | 0.95/0.87 |
| SRMR | 0.07 | 0.04 |

*Note:* RMSEA = Root Mean Square Error of Approximation; TFI = Tucker-Lewis Fit Index; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residual. Model 1a = one-factor model with *EF_Tests*as a general latent variable; in model 1b the covariance between the Hand-Tapping task and the Head-Toes-Knees-Shoulders task is added.
* $p < .01$.

variance for the BRIEF-P working memory scale). Heywood cases typically indicate misspecification of models from a substantive perspective (Geiser, 2012). Therefore, our next step was to test a one-factor model with performance-based EF measures only, which initially showed poor model fit (see Table 2). Inspection of modification indices revealed that allowing the Hand-Tapping and HTKS task scores to correlate might improve model fit. From a theoretical perspective this adjustment is also corroborated, since these tasks measure a quite similar skill, that is motor response inhibition. Furthermore, these scores were significantly correlated, $r_s = 0.36$, $p < .01$. Accordingly, we added this covariance to our measurement model, after which the one-factor model showed acceptable to good model fit. Subsequently, all further analyses were conducted with *EF_tests* as a latent variable.

### 3.3. Latent profile analyses

In order to delineate profiles of motor performance, EF, and verbal ability in preschool aged children, we tested six LPA solutions, ranging from 1 to 6 profiles. A summary of model fit indices is presented in Table 3. The six-profile solution resulted in a non-positive definite first-order derivate product matrix. Closer inspection of model results revealed that one of the profiles only consisted of one case, resulting in a non-identified model within this profile. This is most likely a sign of trying to extract too many classes. Thus, only the 1–5 profile solutions are discussed hereafter.

Together, the different model fit criteria indicated that a three-profile solution best fitted our data, whilst simultaneously showing parsimony. That is, the BIC, BLRT, and entropy all support a three-profile solution. Although the AIC and SSA_BIC decreased until the five-profile solution, they showed the steepest decrement for the two- and three-profile solution, thus supporting the latter. Additionally, the three-profile solution showed a theoretically meaningful, and interpretable constellation of motor performance, EF, and verbal ability. Absolute mean scores of motor performance, EF, and verbal ability scores per profile of the final solution are presented in Table 4.

As can be inferred from Fig. 1, children who were likely to be classified into *profile 1* (prevalence of 43.3%) showed average[1] motor performance and slightly below average verbal ability skills. Furthermore, these children exhibited few inhibition and working memory problems as reported by their parents, and exhibited above average EF skills assessed with performance-based tasks. *Profile 2* (prevalence of 6.7%) is characterized by a constellation of average to below average motor performance, a high prevalence of inhibition and working memory problems as reported by parents, and below average performance-based EF skills and verbal ability skills. Finally, similar to *profile 1,* children in *profile 3* (prevalence of 50%) displayed average motor performance, yet showed a distinct pattern concerning EF and verbal ability skills. That is, parents reported somewhat elevated inhibition and working memory problems, whereas mean performance-based EF skills were average and verbal ability skills slightly above average.

### 3.4. Additional analyses

The distribution of individual and environmental variables over the identified profiles is presented in Table 5.

Concerning the first step of the additional analyses, we only found a significant association between ADHD symptomatology and most likely profile membership, $\chi^2$ (2) = 13.43, $p = .001$. Thus, in the subsequent analysis step, we ran a multinomial logistic regression with ADHD symptomatology as the sole predictor variable. This preliminary model showed a good fit to the observed data, $\chi^2$ (2) = 12.13, $p = .002$. Subsequently, when adding the other predictors (i.e., gender, SES, age, risk of motor coordination difficulties, and language problems), risk of motor coordination difficulties turned out to make a significant contribution to the prediction of most likely profile membership, in the presence of ADHD symptomatology as predictor. Therefore we chose the model with ADHD symptomatology and risk of motor coordination difficulties as our final model. As presented in Table 6 this model significantly fitted the data, with a moderate effect size. Compared to children whose parents did not report aberrant levels of ADHD symptomatology, children scoring borderline or abnormal on ADHD symptomatology were less likely to be in profile 1 or 3, than in profile 2. Similarly, children scoring at or below the 16th percentile on the MABC-2 were less likely (compared to their peers showing no risk for motor

[1] With ‘average’ we refer to the overall sample mean. Z-standardized scores between −0.1 and 0.1 are subsequently considered as ‘average’; standardized scores above 0.1 as ‘above average’, and scores below −0.1 as ‘below average’.

**Table 3**
Absolute and relative model fit indices, entropy, and smallest profile size per LPA solution.

| *k* | AIC | BIC | SSA-BIC | BLRT (*p*) | Entropy | Prevalence smallest profile (%) |
|---|---|---|---|---|---|---|
| 1 | 5335.27 | 5413.31 | 5324.80 | NA | NA | NA |
| 2 | 5263.38 | 5363.73 | 5249.92 | 87.89 (< 0.001*) | 0.80 | 47.5 |
| 3 | 5232.12 | 5354.77 | 5215.66 | 47.27 (< 0.001*) | 0.91 | 6.7 |
| 4 | 5223.45 | 5368.40 | 5204.00 | 24.67 (.08) | 0.90 | 6.7 |
| 5 | 5213.51 | 5380.76 | 5191.07 | 25.94 (.05) | 0.91 | 6.7 |

*Note:* *k* = amount of profiles extracted; AIC = Akaike's Information Criterion; BIC = Bayesian Information Criterion; SSA-BIC = Sample-Size Adjusted BIC; BLRT = Bootstrap Likelihood Ratio Test.
*Significant *p*-value, indicating that this solution fits the data significantly better as compared to the *k*-1 solution.

**Table 4**
Indicator means per profile based on most likely class membership for three-profile solution.

| Indicator | Profile 1 (52/43.3%) | Profile 2 (8/6.7%) | Profile 3 (60/50%) |
|---|---|---|---|
| MABC-2-NL Manual dexterity. | 10.37 | 9.17 | 10.30 |
| MABC-2-NL Aiming and catching | 10.18 | 9.98 | 10.24 |
| MABC-2-NL Balance | 9.38 | 8.69 | 8.93 |
| BRIEF-P Inhibition | 42.31 | 64.39 | 55.01 |
| BRIEF-P Working memory | 41.27 | 70.69 | 56.32 |
| EF_tests[a] | 0.288 | −1.30 | 0.0004 |
| WPPSI-III-NL Receptive vocabulary | 10.11 | 7.47 | 11.11 |

*Note:* MABC-2-NL = Movement Assessment Battery for Children-2 Dutch version; BRIEF-P = Behaviour Rating Inventory of Executive Function-Preschool; EF_tests = latent variable representing performance-based EF skills (Corsi Block task, Day/Night task, Digit recall, Hand-Tapping, Head-Toes-Knees-Shoulders); WPPSI-III-NL = Wechsler Preschool and Primary Scale of Intelligence Third Edition Dutch version.
[a] EF_tests mean score is the mean factor score − composed of z-standardized performance-based EF scores- per profile based on the most likely class membership.

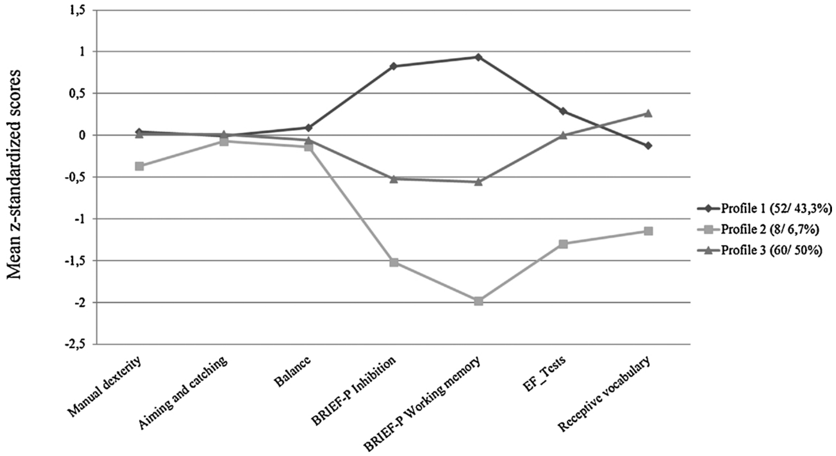


**Fig. 1.** Pattern of mean z-standardized scores of preschool children's motor performance, EF, and verbal ability scores in each of the three profiles. *Note.* EF_tests = latent variable representing performance-based EF skills. The BRIEF-P scores have been reversed to be consistent with the other measures (where lower z-standardized scores reflect poorer functioning).

coordination difficulties) to be classified into profile 1 or 3, than into profile 2. Finally, a comparison between profile 1 and 3 revealed that children scoring borderline or abnormal on ADHD symptomatology, or scoring at or below the 16th percentile on the MABC-2 were more likely to be in profile 3 as compared to profile 1. In other words, children at risk of ADHD or motor coordination difficulties were more likely to be classified into profile 2 and 3 compared to profile 1, whereas other child (gender, age, and language problems) or contextual (SES) factors did not seem to be associated with profile membership.

## 4. Discussion

### *4.1. Main findings*

The aim of this study was to determine if there are distinct profiles of preschool aged children who show similar patterns of

**Table 5**
Distribution of child and contextual characteristics over profiles of motor performance, EF, and verbal ability.

| Characteristic | Profile 1 | Profile 2 | Profile 3 |
|---|---|---|---|
| Age | | | |
| 3 years old | 29 (24.4%) | 3 (2.5%) | 36 (30.3%) |
| 4 years old | 22 (18.5%) | 5 (4.2%) | 24 (20.2%) |
| Gender | | | |
| Female | 26 (21.8%) | 4 (3.4%) | 27 (22.7%) |
| Male | 25 (21.0%) | 4 (3.4%) | 33 (27.7%) |
| SES | | | |
| Low and Intermediate | 7 (7.2%) | 2 (2.1%) | 14 (14.4%) |
| High | 33 (34%) | 4 (4.1%) | 37 (38.1%) |
| ADHD symptomatology | | | |
| Borderline and Abnormal | 2 (1.8%) | 4 (3.5%) | 10 (8.8%) |
| Normal | 48 (42.5%) | 4 (3.5%) | 45 (39.8%) |
| Language problems | | | |
| Yes | 5 (4.2%) | 3 (1.7%) | 4 (3.4%) |
| No | 46 (38.7%) | 6 (5.0%) | 56 (47.1%) |
| Risk of motor problems | | | |
| Yes | 7 (6.5%) | 3 (2.8%) | 22 (20.6%) |
| No | 38 (35.5%) | 5 (4.7%) | 85 (79.4%) |

**Table 6**
Multinomial logistic regression results for the final model predicting likely profile membership from ADHD symptomatology and risk of motor coordination difficulties.

| | *B* (*SE*) | 95% CI for Odds Ratio | | |
|---|---|---|---|---|
| | | Lower | Exp(*B*) or Odds Ratio | Upper |
| Profile 3 vs. 2 | | | | |
| Intercept | 2.69 (0.18)** | | | |
| ADHD[a] | −1.83 (0.23)** | 0.01 | 0.16 | 0.25 |
| Risk of motor problems[b] | −0.97 (0.23)** | 0.24 | 0.38 | 0.60 |
| Profile 1 vs. 2 | | | | |
| Intercept | 2.88 (0.18)** | | | |
| ADHD[a] | −4.04 (0.34)** | 0.01 | 0.02 | 0.03 |
| Risk of motor problems[b] | −1.63 (0.25)** | 0.12 | 0.20 | 0.32 |
| Profile 3 vs. 1 | | | | |
| Intercept | −0.19 (0.07)* | | | |
| ADHD[a] | 2.21 (0.29)** | 5.18 | 9.11 | 16.04 |
| Risk of motor problems[b] | 0.66 (0.14)** | 1.46 | 1.93 | 2.55 |

*Note:* Model $\chi 2(4) = 16.69$, $p = .002$; Nagelkerke $R^2 = 0.18$.

[a] ADHD symptomatology as measured by SDQ Hyperactivity-Inattention subscale; with 'borderline and abnormal' coded as 1 and 'normal' coded as 2; reference category is 'normal'.

[b] Risk of motor coordination difficulties as measured by the MABC-2 Total percentile score; with 'at or below the 16th percentile (i.e., at risk)' coded as 1 and 'above the 16th percentile (i.e., typically developing)' coded as 2; reference category is 'above the 16th percentile'.

** $p < 0.001$.

performance across motor performance, EF, and verbal ability. Using a person-centered approach, three profiles with qualitatively distinct response patterns of motor skills, executive functions, and verbal ability were discriminated. Quantitatively, the profiles showed most pronounced differences with regard to parent ratings and performance-based tests of EF, as well as verbal ability. In addition, ADHD symptomatology and risk of motor coordination difficulties were associated with likely profile membership.

Remarkably, the three profiles in our study did not seem to differ much with regard to motor performance (broken down into manual dexterity, aiming and catching, and balance tasks), except for manual dexterity. Children in profile 2 (6.7%) scored about 0.5 SD lower for manual dexterity than the children in the other two profiles. In addition, these children were characterized by a constellation of a high prevalence of parent-rated inhibition and working memory problems, below average performance-based EF and below average verbal ability. Profile 2 may suggest an 'at-risk' group, which can already be identified at this early age. The constellation of profile 2 corresponds to a body of literature showing that children who lack adequate fine motor skills are likely to have problems in cognitive functioning (e.g., Cameron et al., 2012; Van der Fels et al., 2015). Interestingly, Molitor et al. (2015) have shown that 5- to 6-year old children with motor coordination difficulties showed marked deficits in EF, but that a subsample of children with motor coordination difficulties had no EF problems. These children outperformed the rest of the motor impairment group in manual dexterity. It has been suggested that fine motor skills are more strongly related to cognitive skills than gross motor skills, because fine motor skills generally have a higher cognitive demand (Van der Fels et al., 2015).

It is plausible that relationships between motor performance and EF are dependent on the child's developmental period. Libertus and Hauf (2017) have suggested that there is a shift in the relationship between developmental domains as a function of age. Specifically, motor skills seem highly related to other developmental domains during the first 3 years of life, but this relation seems to weaken or disappear as children grow older (Oudgenoeg-Paz et al., 2016). An alternative explanation is that the development of young children is characterized by rapid growth but is also considered non-linear (Ben-Sasson & Gill, 2014). Discontinuity can be a predictor of developmental problems but can also arise as age-typical development due to system reorganization. Improving performance in one area can be accompanied by decreases in performance in other areas because the child has to divert energy toward the emerging skill at the expense of other areas (Ben-Sasson & Gill, 2014). Thus, it is possible that there is not a clear relationship between motor performance and EF in young children due to the discontinuity in their development and the biological coping mechanism of diverting their energy to one specific emerging skill while ignoring the others for that moment.

Another possible explanation for the lack of clear relationships between motor performance and EF grounds in the embodied cognition perspective. The embodied cognition perspective advocates that the relationships between motor performance and EF are specific and not general but grounded in the unique experiences a child has in his/her environment. Research that recognizes the complexity and fast changing nature of motor skills in young children implies that it is challenging to measure a full range of motor skills solely with a motor test (Kaiser, Albaret, & Cantell, 2015). In addition, for example children's caregivers provide another perspective to the child's motor performance in its daily environment. Therefore, the skills that were assessed in the present study – manual dexterity, aiming and catching, and balance – do not reflect a full range of functional daily skills of preschool aged children and therefore it might be understandable that no relationships were found.

The present conceptualization of EF is that of a complex, multicomponent construct involved in supporting action control and thought (Carlson et al., 2016), including but not limited to motor- or verbally related processes (Cameron et al., 2012). Our findings showed that these multiple components cannot readily be captured in simple patterns and associations. Rather, our detailed account of the different configurations of EF and verbal ability skills reveal considerable variability ranging from below to above average skills, even within one profile.

In a first attempt to validate our profiles, we found that profile membership was predicted by the ADHD symptomatology, i.e., the degree of hyperactive-inattentive problems reported by parent, and whether a child was at risk of motor coordination difficulties or not. Concerning the latter, a remarkable finding was that the at-risk children were distributed over all profiles, so apparently not all children with motor coordination difficulties exhibit a more problematic pattern of different developmental abilities (as found in *profile* 2). Considering that being at-risk for motor coordination difficulties was a significant predictor in the presence of ADHD symptomatology suggests that hyperactive-attention problems pose an extra risk factor for having a more problematic pattern of different developmental disabilities. Studies have indeed shown associations between ADHD symptomatology and EF (Houwen et al., 2017; Vernon-Feagans, Willoughby, Garrett-Peters, & The Family Life Project Key Investigators, 2016) and ADHD symptomatology and language difficulties (Yew & O'Kearney, 2017).

### *4.2. Strengths and limitations*

The most important strength of our study was using a person-centered approach when examining relationships between developmental domains. Previous published work has used correlation-based approaches and the results are mixed in regard to the relations among these domains (Van der Fels et al., 2015). Our results indicate that there are distinct subpopulations of children who show differential relationships, possibly explaining the inconsistent findings in the literature. The fact that we found both quantitative as well as qualitative differences between the three patterns of profiles underscores the need for a person-centered approach with a focus on patterns of individual characteristics (Lanza & Cooper, 2016). Some interesting combinations of child characteristics in specific groups of children would not have been detected if we had used a variable-centered approach.

Although the current study has numerous strengths, there are some limitations. Our sample was homogeneous and the generalizability is limited to a low-risk, predominantly White sample. Furthermore, we used a battery of performance-based EF tasks, consisting of five measures. The use of other performance-based EF measures might have yielded different EF factors, and might thus have captured other EF profiles present in this group of young pre-schoolers. An additional limitation is that the measures used did not assess 'pure' EFs; most EF tasks measured more than one EF. Tapping pure EFs is conceptually not feasible, because almost every task requires the individual to keep rules in mind and thus also addresses working memory. By conducting a factor analysis, we deducted the common variance between the variables from the measures used, resulting in a latent EF variable.

Because of the young age of our sample, we did not include children with a diagnosis for a developmental disorder, such as DCD or ADHD. In our sample, the children classified into profile 2 seem to convey an at-risk group, or at least they are falling behind. It has been suggested that stronger associations between developmental domains are to be expected in children with atypical development reflecting abnormal dependences between neurocognitive processes (Dyck, Piek, Hay, Smith, & Hallmayer, 2006).

In studies with young children, participant fatigue can sometimes affect the validity of assessments. For some children, fatigue may have influenced performance on the various measures. By skillfully engaging children and scheduling breaks in our assessment procedures, however, we minimized effects of child fatigue on our data.

### *4.3. Future directions and implications*

Whilst we found conceptually meaningful profiles, we were not yet able to fully validate them, given our cross-sectional design. It is recommended to replicate and validate these profiles, by exploring their predictive and/or discriminant validity on an array of distal outcomes (Lanza & Cooper, 2016). It might be a viable option to examine the clinical value of profiles; that is, the extent to which they can predict the likelihood of future developmental disorders. In addition, future profile validation studies should thus compare mean score patterns over a variety of relevant criterion measures.

Inherent to all endeavours aimed at studying development is the concept of intra-individual variability. It is important that future studies examine the structural and individual stability of the profiles we revealed. Longitudinal studies could explore whether quantitatively and/or qualitatively similar profiles emerge at successive time-points, and whether children remain in or shift between certain profiles during development. Concerning the former, longitudinal explorations of structural stability of profiles could take into account that the structure of EF might differ between 3- and 4-year olds. That is, whereas a unitary EF model fitted our data well, allowing the dimensionality of EF to differ between ages might unveil quantitatively and/or qualitatively distinctive profiles.

Our focus on an array of motor skills and executive function measures enabled us to take into account certain methodological issues such as task impurity and measurement error, and reveal detailed profile patterns. The EF performance-based tests and parent ratings did indeed seem to convey complementary information regarding children's skill profile. Thus, future studies should include both these types of measures. However, we were not yet able to include an array of social-emotional and behavioural measures although they have been related to future academic and EF skill development (Bierman, Torres, Domitrovich, Welsh, & Gest, 2009). Notably, our findings did reveal an association between likely profile membership and ADHD symptomatology which can be seen as a proxy measure for social-emotional behaviour. Thus, adding such measures as indicators of possible profiles could uncover even more detailed and meaningful profiles. Additionally, it is important to note that other variables may influence classification of children to the profiles. Children are in constant interaction with their environment, and develop by experience and practice. Since every child develops in a unique environment, these unique exposures might affect their development. This ecological view is shared with the Dynamic Systems Theory (Thelen & Smith, 1994). Thus, investigating interactions between environmental factors and profile classification seems a promising avenue for future studies.

## 5. Conclusion

This is the first study examining the relationships between motor performance, EF, and verbal ability in preschool aged children using a person-centered approach. It shows that there are distinct subpopulations of preschool aged children who show differential relations in the three domains with regard to motor performance, EF, and verbal ability. If the three profiles are validated in the future, then they provide important implications for early screening and interventions.

and

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