A Network Perspective on the Relationship Between Moderate to Vigorous Physical Activity and Fundamental Motor Skills in Early Childhood

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ABSTRACT

Background: The relationship between moderate to vigorous physical activity (MVPA) and fundamental motor skill (FMS) is inconsistent in early childhood, due to its complex and non-linear characteristics. This study aimed to analyze the non-linear relationships between MVPA, FMS, body mass index (BMI), sex and age in preschoolers. **Methods:** This cross-sectional study with preschoolers (n = 201; 4.0 ± 0.8 years-old; 99 boys), provided objective physical activity (PA) data, FMS assessments, and BMI. The associations between MVPA, FMS, BMI, sex, and age were explored using the network analysis (Rstudio and qgraph). **Results:** Boys were more motor competent than girls in all FMS skills, while girls were more active than boys during the weekend. Older children were less active than their younger peers during these days. MVPA is weak and differently related to each FMS, and the leap skill emerged with the highest betweenness and strength values in the network. **Conclusion:** For the assessed preschoolers, when considering BMI, age, and sex, the relationships between MVPA and FMS are inconsistent, and leap emerged as the main variable. During early childhood, these variables are connected as part of a complex system in which each skill has a dynamic role within the emerging pattern.

Key-words: fundamental motor skill, network analysis, physical activity, early childhood

Introduction

Accruing adequate time spent engaging in physical activity (PA) in early childhood is related to several health benefits[1,2], including the development of fundamental motor skills (FMS)[3]. Mastery in FMS plays an important role for a positive trajectory of health outcomes, such as body mass index (BMI) and PA[4], which is reinforced by theoretical models about PA across lifespan, suggesting that PA and FMS are reciprocal and dynamically related throughout life[5,6]. As children get older, the relationship between these variables tends to strengthen due to the complexity of the skills involved in sports, the better development of perceptions of competence, and the continuous improvement of physical fitness[5].

A prior systematic review study suggests sex as determinant in the relationship between PA and FMS in early childhood, as boys are more active than girls[7]. Further, there is evidence suggesting that boys have higher scores in object control skills than girls, whilst girls better perform locomotor skills[8]. Indeed, each FMS (run, gallop, hop, leap, jump and slide, strike, bounce, catch, kick, throw and underhand roll) has a single importance in this relationship[9]. Besides age and sex, data also suggest that in early childhood, BMI shows an inverse association with FMS[10] and is a moderating factor in the relationship between FMS and PA[11]. Moreover, countries worldwide have recognized low adherence to PA in young children as an emerging problem, especially due to the low time spent in moderate-to-vigorous physical activity MVPA[7]. Thus, the close relationship between PA and FMS may also be determined by MVPA levels[3], that vary substantially during week and weekend days[12]. All these interacted factors create a temporally variable relationship between MVPA and FMS to a greater extent in early childhood, than in middle or late childhood, and subsequently more difficult to unpick for this stage of childhood.

Although with a relevant contribution to the area, the isolated linear relationships tests between PA and FMS are important limitations, as it disregards the synergic, dynamic and non-linear interactions between these variables and demographic factors. How all these constructs interact and cooperate to generate children´s healthy patterns are still unknown. In preliminary studies, we have shown the non-linear interrelations between movement behaviours and FMS in preschoolers[13]. However, the role of each skill was not considered. Concerning FMS emerge within a complex and dynamic system, consisting of a task, performed by a learner, in a particular environment[14], the relationship between MVPA and FMS involves complex pathways, a diversity of factors with different scales, and different dimensions. Thus, it is reasonable to suggest that interactions within MVPA, motor skills, and demographic variables have not yet been elucidated, and that the theoretical perspective of complexity may provide important information to better understand the pathways underlying these relationships.

According to this perspective, the relationships between MVPA, FMS, age, sex, and BMI consist of a non-linear system where all the mechanisms interact to form an emerging pattern, that allows the identification of the most important variables to maintain a desirable theoretical pattern of the system[15]. Without this important understanding, the ability of key stakeholders, such as teachers, coaches, and public health practitioners, to positively influence children's health through FMS, may be compromised or missed entirely. Therefore, the aim of this study was to analyze the non-linear relationships between MVPA, FMS, BMI, sex, and age in preschoolers using a network perspective.

Methods

Study Description

This cross-sectional study uses baseline data from the "Movement´s Cool" project, which aims to analyze the associations between movement behaviours and health outcomes in low-income preschool children from João Pessoa / Brazil. All the Helsinki Declarations' ethical aspects were followed. The evaluation methods and procedures were approved by the Research Ethics Committee of Health Science Center of Federal University of Paraiba (protocol n. 2.727.698), and by the Education Board of João Pessoa city.

Population and sample

In João Pessoa, the preschool public education zone is divided into nine poles, where eighty-six early childhood education and care services (ECEC) are located. These preschools are institutions for full-time education for children from 0 to 5 years old, with similar physical structures, which aim to develop six main areas: coexist, play, participate, explore, express, and know yourself[16].

From those, fifty institutions have 3-to-5 years old registered children, and ten of them, located in vulnerable zones, were previously selected. A representative number of ECEC by poles was calculated and six were conveniently selected, considering the preschool´s structure to conduct the study´s protocol. In these six preschools, 573 preschoolers of varying ages were registered, which corresponds to the study´s population. All the six preschools were located in deprived areas of the city, and the families are from low socio-economic status (SES): 62.5% of the mothers or fathers were unemployed and over 45.4% of the mothers and 54.1 % of the fathers had finished the 9th grade or less. The Human Development Index (HDI) of the ECEC´s areas range from 0.4 to 0.5[17].

A total of 310 healthy preschool children, aged 3- to- 5 years old, with no chronic disease, were invited to participate in the study. From those, 27 parents did not give consent for their children to participate, 30 children refused to do the protocol, 16 did not attend the preschool on assessments' days, and 36 did not validate the accelerometer criteria for data analysis (a minimum use of 2 week days and 1 weekend day, and 8 daily hours of data register). Thus, the final sample was composed of 201 children (50.5% female).

Study design

Children enrolled in ECEC attend preschool from Monday to Friday, from 7am to 5 pm. These preschools are spaces for full-time education for children from 0 to 5 years old, with similar physical structures. In general, preschools have an outdoor playground, five classrooms, baby changing room, indoor yard, laundry, and kitchen. Physical Education teacher's presence as a member of the staff is not mandatory.

Measurements were performed during a three-month period between March and May 2018. All the schools and parents were informed about the project´s protocols and procedures in meetings with the project coordinator (one meeting in each school) and agreed to participate. The socio-demographic data (children´s age, birth date, parent´s address and educational level) were provided by their parents or guardians.

Variables and protocols

<u>Fundamental motor skills</u>

Fundamental movement skills were measured using the Test of Gross Motor Development - Second Edition (TGMD-2). The TGMD-2 is valid and reliable for use in Brazilian children[18]. This test evaluates gross motor performance in children aged 3 to 10 years[17], and consists of two factors: six locomotor skills (run, gallop, hop, leap, jump and slide) and six object control skills (strike, bounce, catch, kick, throw and underhand roll).

The TGMD-2 was administered according to the guidelines recommended by Ulrich[19]. Before the testing of each skill, participants were given a visual demonstration of the skill by the researcher using the correct technique, but were not told what components of the skill were being assessed. Participants were then called individually to perform the skill twice. General encouragement but no verbal feedback on performance was given during or after the tests. The tests were carried out at preschool by previously trained physical education teachers, and the time taken to assess each child was approximately 40 minutes. All skills were video-recorded and later assessed by one trained assessor who did not administer the tests.

After viewing each trial, the trained assessor analyzed each skill component. A "1" indicated that the component was present in the performance of the skill for that trial or a "0" indicated the component was not present. The video analysis was performed by two expert evaluators, obtaining high intra and interrater reliability (ICC: 0.93-0.98). The locomotion and object control scores are based on the presence (one) or absence (zero) of each of the performance criteria. For each subtest the sum of the raw scores varies from (0-48 points).

<u>Physical activity</u>

PA was objectively assessed using accelerometers (Actigraph, model WGT3-X, Florida), which has been shown to be a valid instrument for measuring PA in preschoolers[20]. The preschool teachers of the CREI's received verbal and written instructions for the correct use of the accelerometer, including placement, and the correct positioning. The teachers were instructed to register an activity diary of wear and non-wear time. The device initialization, data reduction and analysis were performed using the ActiLife software (Version 6.13.3).

The participants were instructed to wear the accelerometer on the right hip for 7 consecutive days (Wednesday morning to Tuesday afternoon). Children were allowed to remove the device during water-based activities and while sleeping (at night). During preschool time, accelerometers were removed by teachers around 11am for children´s bath and fastened properly after it.

Accelerometers were setup to measure acceleration at a 30 Hz sampling rate and analyzed as ActiGraph counts considering vector magnitude and using a 15-s epoch length[21]. Periods of ≥20 min of consecutive zero counts were defined as non-wear time and removed from the analysis, and the first day of accelerometer data was omitted from analysis to avoid subject reactivity[22]. For analysis purposes MVPA was considered in two situations: week days (Monday to Friday) and weekend (Saturday and Sunday).

Hourly average values in counts per minute (CPM), were used to describe the children´s daily PA pattern. Time spent in the commonly defined intensity domains light, moderate and vigorous was estimated using the cut-points proposed by Butte et al.[23] with light intensity defined as 240 to 2.119 counts, moderate intensity defined as 2.120 to 4.449 counts and vigorous intensity as ≥4.450 counts. For analysis purposes, MVPA was dichotomized (<60 min / day ≥) according to the recommendations of the World Health Organization (WHO)[24].

Anthropometric measurements

Height (cm) and weight (kg) were determined using a *Holtain* stadiometer, and by digitized weighing scales (Seca 708), while the participant was lightly dressed and barefoot, following a standardized procedure[25]. Body mass index (BMI) was calculated by dividing body weight with the squared height in meters (kg/m^2). The BMI classification was made from the Z score according to guidance from the WHO: low weight (BMI score z <-1); normal weight (BMI z score from -1 to +1); overweight (BMI z score from +1 to +2) and obese (BMI z score> +2)[24]. For analysis, the categories were dichotomized into healthy weight (normal weight) and overweight (overweight and obesity)[24].

Data analysis

To characterize the sample, measures of central tendency and dispersion were used, the differences between the sex were tested by Student T test and effect sizes were calculated using Cohen's d.

For analysis of associations, a Machine Learning technique called Network Analysis was used, which aims to establish interactions between variables from a graphical representation. Before performing the network analysis, the distribution of the data was verified using the Kolmogorov Smirnov test.

In network analysis, even a weak effect (i.e. r = 0.10) is important within the system, as it may change the entire configuration of the network[26-28]. Therefore, the intensity and importance of the relationships are predominantly dependent on the theoretical role of each variable in the network, then in the p value (inference), as usually seen in linear procedures. In this sense, commonly used inferential statistics tools are not applicable to network data, as it can often give false positive responses[29].

To conduct network Analysis, the "Fruchterman-Reingold" algorithm was applied, such that data were presented in the relative space in which variables with stronger associations remain together, and the less strongly associated variables were repelled from each other[30]. We used the pairwise Markov random field model to improve the accuracy of the partial correlation network, which was estimated from L1 regularized neighborhood regression. The least absolute contraction and selection operator was used to obtain regularization and reduce model sparsity[31]. The Extended Bayesian Information Criterion (EBIC) parameter was adjusted to 0.5 to create a network with greater parsimony and specificity[32].

To quantify the importance of each node in the network, the betweenness and strength centrality indices were calculated. The betweenness index is estimated from the number of times a node is part of the shortest path among all other pairs of nodes connected to the network, The strength centrality is the sum of all the weights of the paths that connect a node to the others. Each of these indices were normalized (mean = 0, and standard deviation (SD) = 1), so that an index value of > 1 indicates that it is > 1 SD from the mean. Positive relationships are expressed by the green color, and negative relationships by the red color in the network. The thickness of the graph indicates the weight of the ratio[33]. The package qgraph from the RStudio Version 1.1.463 software was used

Results

Most of the assessed preschool children had a healthy BMI (80.1%). Approximately 37% were compliant with MVPA recommendations during the week, and 52.7% during the weekend days. These data were similar for boys and girls. Boys showed higher scores for run ($p = 0.022$), leap ($p = 0.011$), strike ($p = 0.032$), kick ($p < 0.001$), and throw ($p = 0.008$) skills, and for locomotion, object control, and total motor score (Table 1).

*******Table 1*******

Being female was associated with MVPA during weekend days ($b = 0.433$), and older children were less active on weekends ($b = -0.231$). In addition, MVPA on weekdays showed a weak and negative association with kick (-0.117) and catch skills (-0.203), and a positive with association with strike (0.140) (Table 2).

*******Table 2*******

The network configuration is presented in Figure 1. The blue color expresses positive relationships between the variables, and negative relationships are expressed by the red color. The thickness of the graph indicates the weight of the ratio.

*************Figure 1*************

The centrality indicators show the roles of each variable in the network. It was highlighted that sex, leap, and MVPA during week days had the highest Betweenness values (close to 2), which indicates that future interventions in these variables may generate a theoretically desirable pattern in the entire network. The leap, hop, strike and kick skills showed the highest Strength values (>1 - Figure 2).

*******Figure 2*******

Discussion

The present study applied machine learning techniques through a network analysis to characterize the associations between MVPA, FMS and BMI in preschoolers. Such information extends understanding of how each motor skill may contribute to positive health trajectories during early childhood. Prior studies have investigated the association between PA and FMS in preschool children[4,21,34]. However, this is the first study to offer a unique insight into the relation between these variables, considering BMI, sex, and age as part of a systemic network. In accordance with the aims of our investigation, we found that MVPA during week and weekend days are weak and differentially related to motor skills. Boys were more motor competent than girls for all the assessed skills. However, girls were more active than boys during weekend days, and older children were less active on these days.

Different associations between MVPA and FMS during the week and the weekend days were also described in a previous study[35]. The children assessed in the current study spent 10 hours per day at preschools where there is no space and/or structure to play ball games, and, therefore, the participation in these activities are predominantly restricted to weekend days. The negative correlation observed between MVPA during weekend days and kick or catch may be related to the lack of experience and environmental opportunities, combined with biological aspects. Children in this age group need greater stability skill to perform more complex movements. Therefore, those with a better performance in these skills may be involved in light physical activities, which would then allow them to perform with greater movement quality. Indeed, this hypothesis is supported by Foweather et al.[35] who observed children with higher scores in object control skills are involved in a greater amount of light physical activities.

Indeed, the relationship between PA and FMS in young children should be interpreted with caution, as the results of this association are more inconsistent than in older children[3,36]. In the present study, no strong and consistent association was observed between MVPA and the several FMS assessed. It is important to emphasize, and without giving a hierarchical logic, that in addition to the PA characteristics (i.e. type and quality), several other factors, such as maturational stage[36], environmental context[9], children´s executive function[37] and families educational level[38], could also influence any relationship between PA and FMS in this age group.

In general, the results of the current study suggest that children were more active during weekend days than during the week days. When taking age into account, the older children were more active during the week[39] observed by a reduction in PA levels with advancing age, from the age of five. However, even over the early childhood stage, PA levels differ according to the day of the week where PA is assessed. In the evaluated sample, 36.9% of the children comply with international MVPA recommendations during the week days and 52.7% on the weekend days, respectively. Considering that no participant was involved in structured PA, we may argue that the cultural and geographical environment they reside in may determine their PA levels and its consequences in specific skill´s development in detriment of others[6].

Our findings also demonstrate that boys presented higher scores than girls in all FMS. A systematic review study conducted by Iivonen and Sääkslahti[8] reported that boys are more proficient than girls in object control skills whilst girls are more proficient in locomotor skills. Nonetheless, Barnett[36] stated there is no evidence to support this differentiation between sexes. It is also important to highlight that both studies identified a “friendly” environment for skill development as a key determinant for FMS development, even more than sex. Considering that boys are culturally encouraged to engage in PA and sports to a greater extent than girls and, therefore, have more opportunities[36], they are also more likely to engage in games that require specific skills[36]. Previous studies have shown that Physical Education classes emphasize boys´ preferences, such as football[40], so boys tend to be more involved in these classes, and also in free-play activities in preschool context[41]. Moreover, although in our study girls were more physically active than boys in the weekend days, the type and quality of the activities they are involved in, which may potentially contribute to FMS development, were not assessed.

The network created in the present study showed sex as the highest betweenness in the network. As stated before, the controversial relationship between sex with PA and FMS has been evidenced in prior studies with preschool children[8,36]. Moreover, in terms of the individual FMS, leap has emerged as the most important variable in the network. Considering the leap is a skill with a greater degree of complexity, as it requires strength, speed, balance and synchronized movements of legs and arms during an inflight phase, we may hypothesize that children present greater variability in its performance, which increases the power of this skill to differentiate their performance levels in relation to overall motor skills. While we recognize the other skills are important in sports and daily PA, the network analysis suggests that each FMS has a different discriminating role in the entire system. This perspective is theoretically congruent with recent research from Barnett et al.,[36] for example, suggesting motor assessment batteries should consider which motor skills are actually related to sports and physical activity according to context / culture and time for execution. Such an observation is rarely considered, as prior studies tend to rely on scores for total FMS, or subset scores for locomotor and object control skills pooled together. Moreover, preschool years are a key timepoint in which FMS can be developed[3]. Capturing this information when these skills are beginning to develop, and understanding its dynamic and non-linear relationship with MVPA, can provide valuable insight into the development of FMS in children, and yield insights into what are the most determining individual skills to target via interventions, so that adequate motor patterns are developed. Consequently, the current study adds hitherto unseen granularity in understanding how MVPA and FMS are related during early childhood

It is also important to highlight that BMI did not emerge as an important variable in the proposed network. This does not mean that BMI should not be considered as important, but that in our sample, generally composed by normal-weight children, it is not determinant of FMS and/or PA. Using a network approach alongside a longitudinal design may however be a useful future research direction as with increasing age body dimensions increase and may be determinant MVPA[42] and FMS[43]. Although MVPA has presented a weak association with almost all the FMS (approximately $r = 0.1$), it is important to consider that in a complex system, all agents connect and interact to generate an emerging pattern[15,44], and simple changes in the initial conditions can produce exponential effects in the final pattern[45].

The results of the present study need to be interpreted with caution, once the type and quality of PA performed, for example, activities inside or outside physical education classes, were not analyzed, and should be considered in future research. Nontheless, some strengths also need to be highlighted, namely: a) the network perspective used to explore the interdependent associations between MVPA, FMS, age, sex, and BMI is fundamental to investigate the interrelationships between variables in a developmental perspective[46]; b) the insights into the non-linearity between MVPA and each of the skills assessed, which plausibly indicates the need to consider the quality, and not only the intensity of the activity children are performing.

Theoretically, these relationships can be conceptualized as phenomena emerging from a system of dynamic, reciprocal and non-linear interactions, also known as complex systems[46]. Nonetheless, our study has limitations that should be highlighted. As there are no prior published studies that the authors are aware of, which have used a network analysis to associate MVPA with FMS or has worked specifically with a preschool population, direct comparisons with other studies are difficult to make. However, this clearly highlights the need for further examinations of these variables as a dynamic system, that considers the interactions between individual, environment and task, as previously theoretically proposed by Newell[14].

Conclusion

When considering BMI, age, and sex, the relationship between MVPA and FMS is part of a complex system, in which each skill has a dynamic role within the emerging pattern. Inconsistent weak associations were seen between MVPA and motor skills, though for the assessed preschoolers, MVPA on weekends, and the leap skill have shown the highest centrality values, and should be considered in interventive strategy towards promoting healthy patterns. When analyzing FMS, future studies should consider the role of each individual skill, in the specific context of assessment. Finally, parents and preschool teachers should focus both on quantity and quality of PA, and on a diversity of movements that demands the different FMS.

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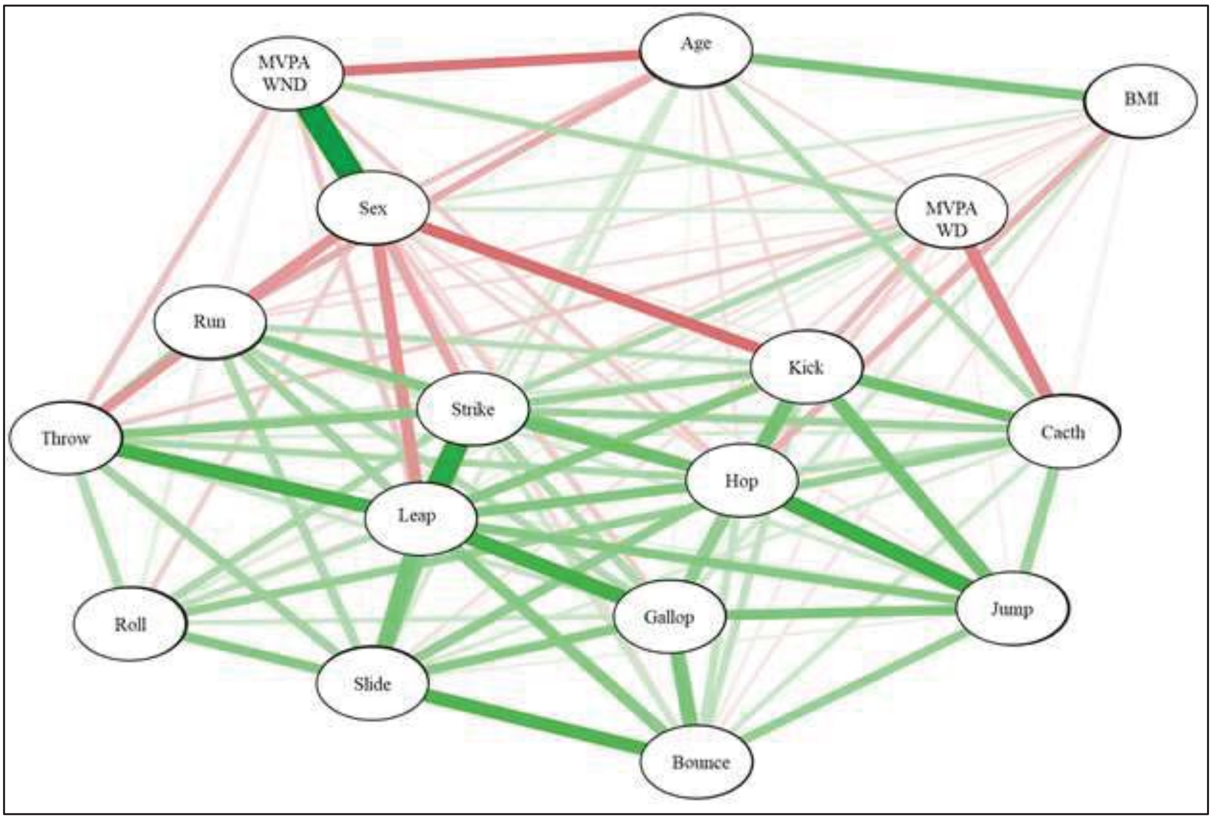
Tables and figures

Table 1. Sample´s characteristics stratified by sex.

Variables	Boys (n = 99)		Girls (n = 102)			
	Mean	**SD**	**Mean**	**SD**	**p**	**d**
Age	4.00	0.80	4.08	0.70	0.488	-0.098
BMI	16.16	1.82	16.04	2.03	0.684	0.057
MVPA week	52.31	23.54	54.56	21.79	0.485	-0.099
MVPA weekend	59.66	24.69	65.25	21.08	0.086	-0.243
Motors Skills						
Run	6.48	1.34	6.04	1.33	**0.022**	0.235
Gallop	2.46	2.59	2.04	2.22	0.223	0.172
Hop	2.82	2.08	2.47	2.22	0.241	0.166
Leap	3.89	1.89	3.18	2.06	**0.011**	0.360
Horizontal jump	2.24	1.73	2.03	1.31	0.349	0.133
Slide	1.50	2.00	1.52	2.21	0.961	-0.007
Strike	4.30	2.35	3.61	2.13	**0.032**	0.305
Bounce	0.44	1.14	0.28	0.87	0.265	0.158
Catch	2.56	1.56	2.44	1.69	0.589	0.076
Kick	6.49	1.55	5.67	1.69	**<0.001**	0.503
Overhand Throw	0.88	1.57	0.40	0.94	**0.008**	0.376
Underhand Roll	1.90	1.58	1.64	1.75	0.268	0.157
Locomotion score	19.42	6.94	17.31	6.26	**0.025**	0.319
Object control score	20.90	6.87	17.68	6.53	**<0.001**	0.481
Total motor score	40.33	11.80	35.00	10.68	**<0.001**	0.474

Student T test; *p = 0.05. MVPA= Moderate to Vigorous Physical Activity; BM = Body Mass Index; d = Cohen’s d



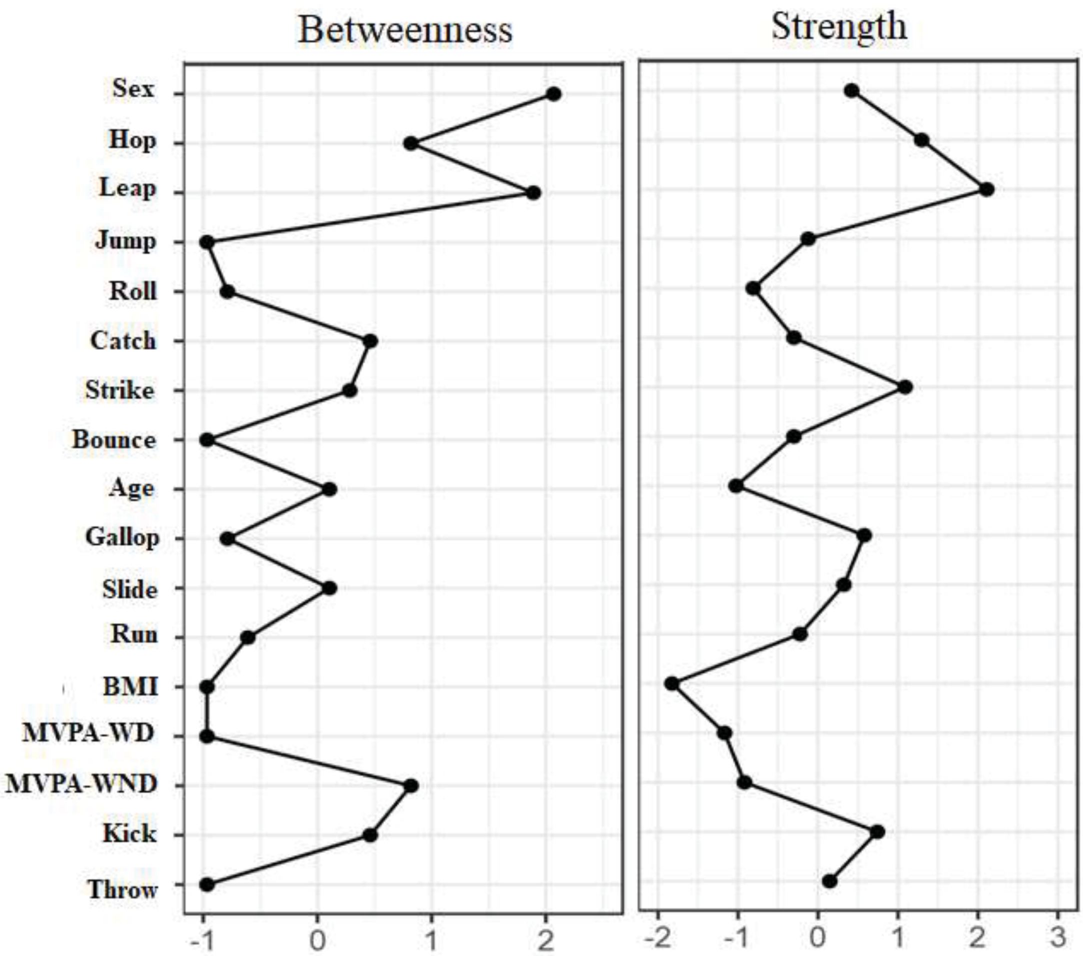
*MVPA WD: Moderate to Vigorous Physical Activity in the week; MVPA WND: Moderate to Vigorous Physical Activity in the weekend; BMI: Body Mass Index

Figure 1. Relationships between age, sex, FMS, moderate to vigorous physical activity during week and the weekend days and BMI.

Table 2. Correlation matrix of variables age, sex, motors skills, moderate to vigorous physical activity of the week and the weekend and BMI of preschool children. João Pessoa-PB. Year 2018.

	Throw	Kick	MVPA WND	MVPA WD	BMI	Run	Slide	Gallop	Age	Bounce	Striker	Catch	Roll	Jump	Leap	Hop	Sex
Throw	-																
Kick	0.079	-															
MVPA WND	-0.104	0.013	-														
MVPA WD	-0.095	-0.117	0.146	-													
BMI	-0.024	-0.046	-0.008	-0.014	-												
Run	0.167	0.130	-0.019	-0.058	-0.061	-											
Slide	0.160	0.021	-0.017	-0.054	0.010	0.138	-										
Gallop	0.101	0.176	-0.054	0.009	0.085	0.137	0.208	-									
Age	0.026	-0.057	-0.231	-0.059	0.228	-0.141	0.071	0.026	-								
Bounce	0.006	0.108	-0.043	-0.036	-0.043	0.040	0.302	0.226	0.001	-							
Striker	0.204	0.178	-0.048	0.140	-0.059	0.092	0.210	0.141	0.060	0.090	-						
Catch	0.068	0.251	-0.006	-0.203	-0.024	-0.029	0.074	-0.007	0.137	0.089	0.172	-					
Roll	0.135	-0.055	-0.020	0.056	-0.045	0.051	0.211	0.093	0.015	0.105	0.145	0.182	-				
Jump	0.051	0.238	-0.006	-0.026	0.020	0.085	0.046	0.223	0.007	0.181	0.030	0.167	0.066	-			
Leap	0.319	0.206	-0.098	0.042	-0.011	0.159	0.233	0.322	0.073	0.204	0.367	0.070	0.122	0.209	-		
Hop	0.150	0.240	-0.089	-0.076	-0.130	0.207	0.191	0.186	-0.050	0.105	0.249	0.125	-0.011	0.330	0.221	-	
Sex	-0.176	-0.245	0.433	0.081	0.078	-0.165	-0.006	-0.086	-0.103	-0.063	-0.146	-0.038	-0.079	-0.045	-0.182	-0.074	-

*Color blue: positive associations; Color red: negative associations; MVPA WD: Moderate to Vigorous Physical Activity in the week; MVPA WND: Moderate to Vigorous Physical Activity in the weekend; BMI: Body Mass Index



*MVPA-WD: Moderate to Vigorous Physical Activity in the week; MVPA-WND: Moderate to Vigorous Physical Activity in the weekend; BMI: Body Mass Index

Figure 2. Centrality indicators of the network analysis between age, sex, FMS, moderate to vigorous physical activity during week and the weekend days and BMI.