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Wayne Haynes, Gordon Waddington and Roger Adams

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*Corresponding author: Wayne Haynes,
Faculty of Health, Research Institute
for Sport and Exercise, University of
Canberra, Canberra, Australia
Email: Wayne.Haynes@canberra.edu.au

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Stefan Elmer, University of Zurich,
Switzerland

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Physical activity, academic and developmental measures in older primary school-children: A principal components analysis

Wayne Haynes^{1*}, Gordon Waddington¹ and Roger Adams¹

Abstract: Relationships between physical activity variables, developmental measures, socio-economic status, academic test scores, perceptual-motor tests and gender were examined for 261 year-six primary school students (137 females) with mean age = 12.3 years, SD = 0.3. Characteristics of child development were examined to identify those aspects most weighted towards academic performance. An exploratory principal components analysis with varimax rotation was undertaken. Principal components analysis showed that 59% of the variance in the data-set could be explained by four sub-types. Scores for perception of verticality of a rod against a tilted frame and for frontal plane semi-tandem dynamic postural stability loaded with scores for reading, writing, numeracy and socio-economic status on the first sub-type called the “Academic-Cognitive” component accounted for 22.24% of total variance with an eigenvalue of



Wayne Haynes

ABOUT THE AUTHORS

The author is a practicing chiropractor and is currently fulfilling the requirements of a research doctoral studies program at the University of Canberra through the Research Institute for Sport and Exercise. His thesis work examines the association between frontal plane dynamic postural stability and perception of vertical with academic performance, physical activity and physical fitness in primary school children, with data that was collected in the Lifestyle of Our Kids (LOOK) research project.

PUBLIC INTEREST STATEMENT

Recently, Australian primary school-children’s academic performance has declined, together with levels of Physical Activity (PA) and general health. Reducing levels of school PA allowing increased academic class time has hindered efforts to improve physical health and has not resulted in significantly increased academic performance. Importantly, recent evidence suggests increased PA and Cardio-Respiratory Fitness (CRF) have a small but significant effect on childhood cognition and academic performance. Therefore it is important to examine the different components of PA to identify the elements having the greatest influence on academic performance. In this study we examine the relationships between Perception of Vertical (PV) and Frontal Plane dynamic Postural Stability (FPDPS) with academic performance in primary school children. Our studies found significant positive relationships exist between senior years NAPLAN scores and FPDPS and PV. The relationship is stronger than between NAPLAN and PA or CRF. Further, the PV relationship with NAPLAN scores matches that of socio-economic status. It is proposed the evolution of human cognition necessary for academic performance is linked to both FPDPS and PV with both complimentary and alternate pathways. The unique human ability for vertically aligned movements underlying PV and FPDPS is proposed to be associated with embodied cognition.

3.3. Other components with Eigenvalues > 1 were “Pubescent Development”, “Fitness, Strength and Body Mass” and “Physical Activity and Motor Coordination”. The grouping of perceptual-motor and postural coordination tests with academic scores suggests possibilities for activities having synergy with academic performance and suggests further investigation to ascertain the extent of the associations.

Subjects: Physical Education; Learning; Motor Skills; Perception; Visual Perception; Developmental Neuroscience; Health & Development; Development Theory; Childhood; Educational Psychology

Keywords: physical activity; academic success; child development; perception of vertical; postural stability; principal components analysis

1. Introduction

Parents, education institutions and the scientific community all have a vested interest in determining the developmental factors most associated with academic performance in pre-adolescent children. The attention given to child development and academic success is driven by a need to understand the underlying developmental influences that are most prominently linked to education and cognitive performance. The first step here is to analyse childhood developmental data in order to identify those factors most associated with academic success. The ultimate goal is to be able to evolve evidence based programs to improve academic performance. For the child, enhanced academic attainment is associated with greater future financial security (Duncan, Dockery, & Cassells, 2014) as well as positive health outcomes (Cutler & Lleras-Muney, 2006).

Data indicating specific developmental factors in education performance are already well established. Socio-Economic Status (SES) has long been noted as having significant association with academic performance. Children from families with higher incomes whose parents generally have higher education qualifications and who live in wealthy postcode areas perform significantly better academically than children growing up in with less educated parents residing in subsidised housing postcode areas (Sirin, 2005).

Recent research has also provided evidence suggesting that increased levels of moderate to high intensity physical activity leading to higher levels of cardio-respiratory fitness and lower per cent of body fat are related to enhanced brain function, including elevated executive function and academic success in primary school aged children (Castelli, Hillman, Buck, & Erwin, 2007; Chomitz et al., 2009; Donnelly et al., 2009; Grissom, 2005). Neurophysiologic studies using brain scanning techniques also support these findings (Chaddock-Heyman et al., 2015; Chu, Chen, Pontifex, Sun, & Chang, 2016). These results complement the substantial health and wellness effects arising from increased levels of physical activity, reduced per cent of body fat and enhanced levels of cardio-respiratory fitness in children (Bauman, 2004; Hills, King, & Armstrong, 2007; Poitras et al., 2016). Further, a review by Tomporowski, McCullick, Pendleton, and Pesce (2015) supports the proposition that a positive relationship exists between physical activity, cardio-respiratory fitness and academic success. However, researchers have questioned the extent to which levels of physical activity and cardio-respiratory fitness alone are associated with academic success and have suggested that other factors may be involved (Diamond & Ling, 2016). One such factor is the style of physical movement utilized during physical activity tasks, since different styles may have differing effects on brain development and academic performance. To examine the relationship between different styles of physical movement with academic performance and cognition, physical activity can be sub-classified into quantitative and qualitative elements or styles (Pesce, 2012; Tomporowski et al., 2015).

Further sub-categorising physical activity into qualitative and quantitative elements allows examination of specific elements of physical performance that may differentially contribute to academic success and cognition (Pesce, 2012; Tomporowski et al., 2015). Measures of quantitative elements of

physical activity include the shuttle run to assess cardio-respiratory capacity, measures of physical activity level using pedometers and strength tests (Chomitz et al., 2009; Tomporowski et al., 2015). Quantitative elements of physical activity relate solely to the duration and intensity of physical activities (Pesce, 2012). Research in this field proposes that the positive cognitive effects arise from moderate to high levels of sustained physical activity intensity conducted over a prolonged time-frame (Tomporowski et al., 2015). Multiple mechanisms are suggested to exist, generating enhanced academic success and cognitive performance in fitter, stronger and more active children. Those include; improved levels of sustained arousal and concentration (Hillman, Erickson, & Kramer, 2008), increased cerebral blood flow leading to angiogenesis, which in turn influences glucose and oxygen distribution (Markham & Greenough, 2004; Thomas, Dennis, Bandettini, & Johansen-Berg, 2012), stimulating the production of neurotransmitters—serotonin and norepinephrine—that support and facilitate information processing (Thomas et al., 2012) and increased proliferation of neurones in the hippocampus (Chaddock-Heyman et al., 2015; Voelcker-Rehage & Niemann, 2013).

Qualitative elements of physical activity often require less energy consumption compared to the quantitative elements (Pesce, 2012; Voelcker-Rehage & Niemann, 2013). Qualitative elements include more complex tasks requiring greater involvement of cognitive networks, perceptual mechanisms and executive control pathways; examples of which are gross motor skills (e.g. jumping, complex postural stability tasks), bimanual dexterity, fine motor control, quick repetitive movements, agility, ball skills and spatial awareness (Diamond, 2000, 2012; Diamond & Ling, 2016; Koutsandréou, Wegner, Niemann, & Budde, 2016; Lopes, Santos, Pereira, & Lopes, 2013; Pesce, 2012; Niederer et al., 2011; Voelcker-Rehage, Godde, & Staudinger, 2011; Voelcker-Rehage & Niemann, 2013).

It has been proposed that specific elements of qualitative physical activity may exploit similar pathways as well as alternate routes to engage neural networks involved in academic performance, in comparison to quantitative approaches (Haapala et al., 2014; Johann, Stenger, Kersten, & Karbach, 2016; Myer et al., 2015; Voelcker-Rehage et al., 2011). In particular, qualitative mechanisms are thought to stimulate the production of neurotrophins—leading to synaptogenesis, gliogenesis and dendritic growth (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Voelcker-Rehage & Niemann, 2013). Synaptogenesis occurs in conjunction with myelination (Black et al., 1990; Kleim, Lussnig, Schwarz, Comery, & Greenough, 1996; Kleim, Vij, Ballard, & Greenough, 1997). Kempermann et al. (2010) suggest that qualitative elements of physical activity, closely associated with environmental richness, lead to the integration of new neuronal connections into functional networks, increasing their likelihood of survival—a process argued as less likely to arise from quantitative methods of physical activity alone. Diamond (2012) further suggests that qualitative modes of physical activities, with emphasis upon cognitive tasking, may provide the best pathway toward a sustained enhancement of executive function and academic performance in children.

The spatial ability to accurately predict the direction of gravitational vertical is a qualitative element of movement performances, and has been shown to be moderately associated with physical activity, physical fitness and motor coordination (Brady, 1995; Liu & Chepyator-Thomson, 2008; Liu & Chepyator-Thomson, 2009), as well as with academic success in school children (Canavan, 1969; Kagan & Zahn, 1975; Kagan, Zahn, & Gealy, 1977). Perception of vertical is typically measured using the Rod and Frame Test, in which an individual in a darkened environment views a tilted illuminated frame enclosing a movable tilted illuminated rod (Bagust, Docherty, Haynes, Telford, & Isableu, 2013). Participants are instructed to align the rod to gravitational vertical, with the error score thus providing a measure of subjective visual vertical.

Findings from previous Rod and Frame Test research suggest two primary strategies in the formulation of gravitational vertical predictions in humans (Isableu et al., 2010; Witkin & Goodenough, 1980). Observing the tilted frame can cause large errors in some individuals who are then classified as Field Dependent (FD), a group who typically inflexibly exploit allocentric sensory inputs arising from their peripheral visual stream, simultaneously having difficulties incorporating vestibular and somatosensory cues that could aid accurate vertical predictions (Agathos et al., 2015; Isableu et al., 2010).

Individuals whose perception of vertical is based on egocentric frames of reference arising from the integration of vestibular and somatosensory inputs, producing greater accuracy in the prediction of vertical, are said to use a Field Independent (FI) strategy (Agathos et al., 2015; Isableu et al., 2010).

Previous research has proposed that the difference between FD and FI groups is primarily in the method by which information is cognitively processed. FD participants are seen to utilize a holistic tactic and FI individuals use a more analytical strategy (Agathos et al., 2015), FD participants have difficulty in integrating new information and processing ambiguous sensations whilst FI individuals are able to filter out task-irrelevant information more efficiently, having greater inhibition capability (Jia, Zhang, & Li, 2014).

A number of longitudinal studies assessing the perception of vertical developmental profile suggest that children at seven years are relatively FD and reliant upon visual inputs, but become more FI with age (Bagust et al., 2013; Witkin, Goodenough, & Karp, 1967). Data available therefore suggest that pre-adolescent children have an immature ability to accurately predict and exploit gravitational cues available from the integration and transformation of vestibular and somatosensory cues into a forward predictive internal representation.

It is plausible the associations between the Rod and Frame Test, academic performance, physical activity and physical fitness are modulated by the visual angle projected to the eye from the frame during the test. Associations between the Rod and Frame Test and academic performance in primary school children have previously been found only in perception of vertical obtained from tasks using small visual angles (Canavan, 1969; Kagan & Zahn, 1975; Kagan et al., 1977). No relationships have been observed between the Rod and Frame Tests using a large visual angles and academic performance (Buriel, 1978; Tinajero & Páramo, 1997; Wong, 1982). Further, the strong associations found with physical activity and fitness have been found only with perception of vertical tasks using large visual angles (Brady, 1995; Liu & Chepyator-Thomson, 2008; Liu & Chepyator-Thomson, 2009).

Large-scale field visual panoramas naturally create large visual angles and stimulate visual-vestibular interactions caused by head, body and eye movements in order to take in the full visual scene. Literature reviews propose that large visual angles stimulate perceptions associated with environmental interactions, such as physical movements and direction finding, and may be more closely associated with physical activity and fitness. Spatial perceptions arising from small object environments typically employ small visual angles with minimal eye, head or body movements are heavily reliant on foveal-based visual streams, and are related to spatial cognitive tasks (Quaiser-Pohl, Lehmann, & Eid, 2004; Wang, Cohen, & Carr, 2014). Small and large visual angle RFT's poorly correlate and appear to measure different elements of vertical perception (Streibel & Ebenholtz, 1982), and these conclusions are supported by findings from Wang et al. (2014) and Quaiser-Pohl et al. (2004). It is possible that large visual angles predominantly rely on sensory feedback to structure vertical perceptions, whilst small visual angles may utilize previous experiences of vertical alignment and orientation to internally construct a neural forward model of gravitational vertical which would rely on cognitive restructuring abilities.

The intent of the current study was to explore the shared associations arising from a large set of developmental variables including academic scores, SES, qualitative and quantitative physical activity styles and other age-related developmental variables. The study was intended to identify the components most weighted towards academic performance and other child development factors. Specifically, examining a large developmental data-set including both qualitative and quantitative elements of physical activity may provide evidence of significance of association with academic variables arising from specific modes of physical activity. If specific physical activity elements of child development are found to be associated with academic performance, then future research can be designed to examine possible causal relationships.

The current paper uses principal components analysis as an exploratory measure to examine the relationships emerging in a large set of developmental variables. The motivation for this work was to explore the shared associations emerging between academic variables and other developmental characteristics by reducing the large set of predictor variables into a smaller group of associated variables in pre-pubescent children. It was also considered important to identify the other common developmental characteristics forming associations during childhood development. The data was collected as part of the Lifestyle Of Our Kids (LOOK) longitudinal project set up to examine the effects of physical education in primary school children (Telford et al., 2009).

2. Methods

2.1. Participants

Twenty-nine schools in Canberra in the Australian Capital Territory took part in The Lifestyle of our Kids (LOOK) longitudinal study in 2005 (Telford et al., 2009). Data from 261 matched child participants were available for this cross-sectional study in 2009 (137 females) with mean age 12.3 years (S.D. 0.3). Schools were matched for their SES; with relative uniformity in the participating cohort. The study was approved by the Australian Capital Territory Health and Community Care Human Research Ethics Committee. Participation by the children was entirely voluntary and informed consent was received from parents or guardians.

2.2. Instruments

The variables examined using principal components analysis are summarised in Table 1. Academic results were collected from year five results in 2008, whilst all other data were collected from year six children in 2009.

2.3. Educational status

Children’s academic performance data was collected from the National Assessment Program-Literacy and Numeracy (NAPLAN, 2010) Australian national education test results for numeracy, reading and writing in 2008 from children in year five (<https://www.nap.edu.au/>). An independent statutory body, the “Australian Curriculum Assessment and Reporting Authority. National

Table 1. Summary of variables examined in the principal component analysis

Measure	Procedure
Read NAPLAN	National measure of reading ability
Writing NAPLAN	National measure of writing ability
Numeracy NAPLAN	National measure of numeracy
Parent education (SES)	Parental education level
Rod and frame test	Measures the ability to accurately predict the direction of vertical when confronted by a visual task distorting your spatial perception (qualitative measure)
Semi-tandem DPS	Balance for 30 s on a balance board rocking in the frontal plane only in a semi-tandem posture (qualitative measure)
Eye-hand coordination	Number of successful ball throw and catches (qualitative measure)
Jump height	Jump height recorded (qualitative measure)
PA	Pedometer estimate of PA levels. Every child wore a pedometer for approx. 7 days (quantitative measure)
CRF	20 metre shuttle run. Number of runs competed (quantitative measure)
core endurance	timed abdominal hold posture (quantitative measure)
Height	height in cm
Weight	weight in kg
Puberty score (tanner)	tanner self-estimate of pubescent maturity
Per cent fat (dexa)	regional body composition is measured using dual energy x-ray absorptiometry

Notes: Socio-Economic Status (SES), Physical Activity (PA), Cardio-Respiratory Fitness (CRF), Dynamic Postural Stability (DPS).

Assessment Program: Literacy and Numeracy (2010)", is responsible for the running of the Australian National Assessment Program, in association with agents from all states and territories as well as from non-government school jurisdictions. NAPLAN is conducted for all Australian students in Years 3, 5, 7 and 9. It tests essential skills needed for a child to move through school successfully. The assessments are conducted every year in May.

The NAPLAN writing task involves examination of persuasive and descriptive writing skills. The NAPLAN reading tests measure literacy ability and are focused on the reading of written English. In Year Five reading, categories include biographies, autobiographies and persuasive scripts. Unfamiliar vocabulary and sentence structure were also included in text. The NAPLAN numeracy task examines aptitude in numerical quantities; algebra, understanding patterns and measurement; spatial concepts and mathematical reasoning processes.

2.4. Socio-economic status

Parental education data, providing a measure of SES was collected as part of a questionnaire provided to the parents. The questionnaire enquired into the highest level of education attained by either of a children's parent, with a three level rating score. Rating one constituted parents who have attained to a level of Year Ten education. Rating two is represented by a parent or parents obtaining a Year Twelve or equivalent standard. Finally, rating three was awarded if a parent had achieved a tertiary education qualification. Parental education is acknowledged as an important and reliable measure of SES (Sirin, 2005).

2.5. Quantitative elements of physical activity

2.5.1. Cardio-respiratory fitness

Cardio-Respiratory fitness was measured by the number of completed trials in a 20 metre shuttle run, with participants running between 2 lines, 20 m apart, with a loud beep arising from a sound recorder providing pacing feedback, according to the methodology previously described (Tomkinson, Leger, Olds, & Cazorla, 2003).

2.5.2. Physical activity

Physical Activity was calculated by children wearing a pedometer for seven consecutive days. From the data obtained, a physical activity index was calculated, as described by Telford et al. (2009). Pedometer measurement provides data on the number of steps per day but does not provide information of physical activity intensity.

2.5.3. Core endurance

Core Endurance is a measure of the ability to support the abdominal core, assessed by hold time in a self-supported prone (plank) position on forearms and toes. The test was timed and a loss of form or child terminating the test was used as the end point.

2.6. Qualitative elements of physical activity

2.6.1. The computerised rod and frame test (CRAFT)

The Computerised Rod and Frame Test (CRAFT) employed to measure ability to accurately predict gravitational vertical is classified as a spatial perceptual-motor ability test (Bagust et al., 2013; Haynes, Bagust, & McGrath, 2008). In a darkened environment, participants view an illuminated tilted frame encasing a tilted illuminated rod. The child views the scene through a blackened viewing tube 530 mm long, with the child resting their chin onto the edge of the viewing tube to reduce head movements. With the size of the visual element combined with the distance of the visual scene, the resulting visual angle is 20°.

Figure 1. Semi-tandem frontal plane dynamic postural stability testing platform. A child in the semi-tandem stance on the unstable platform, balancing. The rocking movements in the frontal plane.



The child participant is asked to align the tilted rod to gravitational vertical. Tilting the frame may cause systematic errors in some subjects' ability to align the rod to vertical, whilst others are capable of aligning the rod accurately to vertical, appearing to be unaffected by the tilted frame. Measurement was attained by the average non-signed error setting (in degree) of the rod to gravitational vertical, from ten trials.

2.6.2. Frontal plane semi-tandem dynamic postural stability

Frontal Plane Semi-Tandem Dynamic Postural Stability testing involved an unstable platform, an attached draw wire sensor and signal conditioner connected to a computer recording the data at 5 hertz (Figure 1). The movements of the rocking platform were constrained to a single degree of freedom with rotation about the long axis of the unstable platform, creating a frontal plane postural stability challenge when the participant is positioned facing the long axis of the rocking platform. The child was required to stand and balance on the unstable platform in the configurations listed below for 30 s, described as semi-tandem frontal plane dynamic postural stability. Measurement of dynamic postural stability from movement of the draw wire sensor attached to the rim of the platform was transformed into the average rate of change of angular displacement of the unstable platform. The dynamic postural stability task examined was a combination of two step-out postures—semi-tandem left in which the left foot is in front of the right at hip width and semi-tandem right in which the right foot is in front of the left, again at hip width. The semi-tandem postures are proposed to enhance the challenge of dynamic postural stability in the frontal plane.

Reliability of semi-tandem frontal plane dynamic postural stability was measured within the testing event by file splitting each child's raw scores and determining the Intraclass Correlation Coefficient ICC (3, 1) from calculations between the first and second halves of the grouped data. Semi-tandem frontal plane dynamic postural stability with 545 cases had excellent reliability (ICC = 0.81, $p < 0.001$, 95% CI 0.78–0.84).

2.6.3. Eye-hand coordination

Eye-Hand Coordination was measured by a throw and wall-rebound catch test involving 40 attempts of increasing difficulty (Telford et al., 2013). Score was calculated from the number of successful throw and catch sequences performed.

2.6.4. Vertical jump height

Vertical Jump Height involved a single effort lower body power and coordination task and measured by a vertical jump calculated in cm. The child was instructed to jump as high as possible from a standing position.

2.7. Anthropometry

2.7.1. Height and weight

Every child's height was calculated by a portable stadiometer to the nearest 0.001 m and body mass by portable electronic scales to the nearest 0.05 kg.

2.7.2. Body composition

Body Composition was measured using dual energy X-ray absorptiometry (DXA, Hologic Discovery QDR Series, Hologic Inc., Bedford, MA, USA) (Winzenberg & Jones, 2011) and QDR Hologic Software Version 12.4:7 was used to generate body fat mass, then calculations of per cent of body fat were conducted.

Table 2. Descriptive statistics

Variables	Mean	Standard deviation
Read NAPLAN	517.5	75.8
Writing NAPLAN	500.4	68.3
Numeracy NAPLAN	505.2	70.8
Rod and frame test	2.9	1.7
Parent education (SES)	2.6	0.67
Semi-tandem DPS	0.3	0.22
Height	153.6	7.34
Weight	45.9	9.2
Puberty score (Tanner)	5.3	1.7
Percent fat (DEXA)	25.8	6.5
PA	95.9	12
CRF	6.2	1.9
Jump	33.6	5.99
Core	73.8	46
Ball catch and throw	34.1	6.7

Notes: Measurements fully repeated in 261 participants. Semi-tandem dynamic postural stability (DPS), physical activity (PA) and cardio-respiratory fitness (CRF).

Table 3. Component variance and eigenvalues

Sub type	Initial Eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cum %	Total	% of variance	Cum %	Total	% of variance	Cum %
1	3.34	22.24	22.24	3.34	22.242	22.24	2.49	16.6	16.6
2	2.45	16.33	38.58	2.45	16.334	38.58	2.22	14.81	31.41
3	1.96	13.04	51.62	1.96	13.041	51.62	2.2	14.66	46.07
4	1.14	7.57	59.18	1.14	7.566	59.18	1.97	13.11	59.18

2.7.3. Measure of pubescence

The self-report five-stage standard Tanner score as described by Tanner and Whitehouse (1976) was used to rate pubescent development.

3. Statistical analysis

An exploratory principal components analysis with varimax rotation was undertaken (Kinnear & Gray, 2006). A loading matrix was created exhibiting the amount of correlation between the individual measures included in the matrix and identified as component factors. The loadings of each measure on each factor range from -1 to $+1$ and then provide an estimate of the extent to which individual measures are weighted to an identified factor. Measures with a loading of ≥ 0.25 or ≤ -0.25 are considered important for data interpretation (Tabachnick & Fidell, 1996) providing a pattern of meaningful measures with the dominant characteristic naming the principal component. All variables were then converted into z scores and summed to produce a component score. Independent *t*-tests comparing male and females on the four factor scores were conducted.

4. Results

Table 2 contains the summary statistics from the principal components analysis, and Table 3 summarises the total variance and eigenvalues for the components exposed. The significant components produced using principal components analysis with varimax rotation are given in Tables 4 and 5 displays the independent *t*-test results from comparing males and females.

From the fifteen variables used, four principal components or sub-types with eigenvalues > 1 were identified after viewing the scree plots, and these together accounted for 59.18% of the total score variance. Principal component 1, labelled “Academic Cognitive” was characterised by high loadings on reading, writing, numeracy, SES, perception of vertical (CRAFT) and frontal plane semi-tandem dynamic postural stability, and accounted for 22.24% of total variance with an eigenvalue of 3.3. Principal component 2 was labelled “Pubescent Development” and was distinguished by Tanner score, height, weight, core endurance and jump height, contributing 16.33% to total variance of the model with an eigenvalue of 2.45. Principal component 3, “Fitness, Strength and Body Mass”, produced high loading on results for DEXA, Jump height, cardio-respiratory fitness and core endurance. This component accounted for 13.04% of the total variance with an eigenvalue of 1.96. Principal component 4 was designated “Physical Activity and Motor Coordination” and had high loadings on physical activity, ball catch and throw, cardio-respiratory fitness, core endurance and frontal plane dynamic postural stability, and accounted for 7.57% of the variance with an eigenvalue of 1.14.

Independent *t*-tests showed significant gender differences on the “Fitness, and Strength and Body Mass” principal component [$t(259) -4.082, p < 0.001$] and the physical activity and motor coordination principal component [$t(259) -5.129, p < 0.001$] with males performing significantly better than females (Table 5).

Table 4. Rotated component matrix

Loading matrix exhibiting the amount of correlation between the individual measures of child development producing 4 principal components

Characteristic	Principal component 1 = academic cognitive	Principal component 2 = pubescent development	Principal component 3 = fitness strength and body mass	Principal component 4 = PA and motor coordination
Read NAPLAN	0.84 [†]			-0.18
Writing NAPLAN	0.77 [†]			
Numeracy NAPLAN	0.84 [†]			
Rod and frame test	-0.44			-0.2
Parent education (SES)	0.44			
Semi-Tandem DPS	-0.25	0.22		-0.35
Height		0.87 [†]		
Weight		0.78 [†]	-0.53	
Puberty score (Tanner)		0.76 [†]	0.12	-0.15
Percent fat (DEXA)		0.18	-0.91 [†]	
PA				0.76 [†]
Cardio-respiratory Fitness			0.55	0.63
Jump height		0.25	0.74	0.24
Core endurance		-0.34	0.41	0.41
Ball catch and throw			0.16	0.73 [†]

Notes: Loading components below ≥ 0.1 or ≤ -0.1 suppressed.

Component loading above ≥ 0.25 or ≤ -0.25 in bold and considered meaningful to interpretation.

[†]Variables that contribute most strongly to each sub-type provide the naming of the principal component.

Table 5. Gender independent t-test using Z scores to for grand variables

Principal component variable	t	df	Sig (p)
Academic cognitive	-0.311	259	0.756
Pubescent development	1.812	259	0.071
Fitness and strength	-4.082	259	0.001
PA and motor coordination	-5.129	259	0.001

5. Discussion

A principal components analysis of national academic test results as well as physical activity and developmental measures was undertaken on measures accessed from a large group of primary school children, and produced four independent components or sub-types from fifteen independent variables. The four distinct components provide insight into the developmental profile of children in their senior years of primary school. The first principal component, “Academic Cognitive” explained 22.24% of the total variance of the model and was strongly loaded with all academic variables (reading, writing and numeracy). A novel result from this analysis was the significant loading on this component from measures of perception of vertical and frontal plane semi-tandem dynamic postural stability; both qualitative elements of physical activity. SES also significantly loaded with the “Academic Cognitive” principal component. The current finding is important when examined in context of the Myer et al., 2015 review that suggested brain development in pre-adolescents is associated with a high level of neuroplasticity, providing the opportunity for qualitative components of physical activity to influence a future lifetime of enhanced health and cognition.

Previous research has noted a close functional relationship between the ability to predict the alignment of gravitational vertical and whole body upright frontal plane postural stability, with perception of vertical providing a spatial frame of reference necessary for skilful postural alignment and orientation (Isableu et al., 2010; Witkin & Asch, 1948). Witkin suggested associations between basic spatial tasks (dynamic postural stability), spatial perceptions (perception of vertical) and higher-order spatial cognitive tasks (spatial dis-embedding challenges) (Witkin, 1950, 1959). It has been previously argued that participants accurately predicting the line of gravitational vertical when performing the Rod and Frame Test use a more complex frontal plane dynamic postural stability strategy than participants who are inaccurate in predicting vertical alignment (Isableu et al., 2010). Bray et al. (2004) also provides evidence that participants exhibit greater alignment to gravitational vertical when performing the Rod and Frame Test in a frontal plane dynamic postural stability stance, compared to a normal standing posture. Perception of vertical and frontal plane dynamic postural stability exploit common cortical zones during their performance (Fiori, Candidi, Acciarino, David, & Aglioti, 2015; Taubert et al., 2010) and are both associated with vestibular activation within these cortical zones, which are proposed to have cognitive relationships (Bigelow & Agrawal, 2015).

Perception of vertical as measured using a CRAFT is categorised as a small visual field spatial ability test (Quaiser-Pohl et al., 2004; Wang et al., 2014). Small-field spatial ability tasks have been found to more strongly associated with measures of human cognition and academic performance than large-field spatial ability tasks (Wang et al., 2014). The discriminating factor between small and large-field spatial ability tasks is the visual angle projected onto the fovea from the visual object or scene of interest.

In the present study, somatosensory and vestibular feedback required for the formation of an internal construct of a model of gravitational vertical may have been significantly limited due to the small visual angle and fixing the participant’s head in space methodology. This, in turn, increased the requirement for and involvement of cognitive strategies to internally construct a prediction of gravitational vertical. This proposed strategy may explain the strong association of the CRAFT with the Academic and Cognitive component. The loading of perception of vertical on the “Academic Cognitive” component is also implied in previous research showing a moderate association between

performance in a small-field Rod and Frame Test with academic results in reading and maths (Canavan, 1969; Kagan & Zahn, 1975; Kagan et al., 1977).

Therefore, FD participants already unable to effectively access, integrate, reweight and then reconstruct sensory inputs so as to more accurately predict the line of gravity have even greater difficulty due to the limitation of head movement and the small visual angle of the current testing procedure. Consequently, FD participants have greater reliance on sensory inputs from the visual scene for their frame of reference to predict gravitational vertical and subsequently produce large errors in this test, and are associated with poorer academic outcomes.

In previous studies using large visual angle Rod and Frame Test, moderate to strong associations have been found with physical fitness, physical activity and motor coordination (Brady, 1995; Liu & Chepyator-Thomson, 2008; Liu & Chepyator-Thomson, 2009). The current analysis found no association with the Fitness, Strength and Body Mass component and only a trend in association with the Physical Activity and Motor Co-ordination component (loading -0.2). It is plausible the current finding of strong academic associations with CRAFT but little relationship with physical activity, physical fitness or motor coordination is related to the small visual angle CRAFT and limiting head movement during testing. Supporting this view, studies providing evidence of an association between the Rod and Frame Test and physical activity, physical fitness and motor coordination have all used the same large visual angle with the head free to move in their methodology (Brady, 1995; Liu & Chepyator-Thomson, 2008; Liu & Chepyator-Thomson, 2009).

Previous research provides evidence of an association between postural stability competency and academic performance (Haapala et al., 2014; Lopes et al., 2013; Piek, Dawson, Smith, & Gasson, 2008). However, the loading of semi-tandem frontal plane dynamic postural stability onto the Academic Cognitive sub-type observed here is a novel finding. The result that semi-tandem frontal plane dynamic postural stability loads onto the “Academic Cognitive” component may arise due to a number of factors. The application of frontal plane dynamic postural stability exploits processing power and functional competencies of the lateral prefrontal cortex, posterior parietal cortex (together the fronto-parietal networks) and the cerebellum (Taubert et al., 2010)—areas strongly linked to human cognition (Diamond, 2000). In humans, beam walking (a frontal plane dynamic postural stability challenge) is likely to initiate increased supra-spinal postural control and is associated with pre-synaptic inhibition of spinal reflexes, (Llewellyn, Yang, & Prochazka, 1990). Conversely, significant pre-synaptic inhibition does not occur in normal walking on a treadmill, suggesting higher cognitive centres are active in frontal plane dynamic postural stability. Finally, the initial response to any upright postural perturbation arises in the frontal plane and originates at the level of the pelvis, thereby exploiting greater cortical engagement than sagittal plane stability responses (Bauby & Kuo, 2000).

It is proposed that the ability to accurately predict and align the body to gravitational vertical from internal body receptors may have evolved in pre-human arboreal primates and been an exaptive trait associated with the origins of elements of human cognition. Pre-human primates who may have lacked FI competency may have necessarily engaged a visually dominant frame of reference to predict vertical alignment in the arboreal environment, consequently have been more susceptible to falls and almost certain death. Supporting this view, recent research proposes that the ability to disembed complex visual geometric shapes to find a camouflaged hidden shape using the Embedded Figures Test, classifying an individual as FI, is strongly correlated with self-orientation and navigational abilities (Boccia, Vecchione, Piccardi, & Guariglia, 2017). Importantly, the Embedded Figures Test significantly correlates with measures of the Rod and Frame Test ($r = 0.5/0.7$) (Arbuthnot, 1972).

The evolutionary processes that underlie the unique human frontal plane dynamic postural stability may have arisen late in the evolutionary cycle in cognitively sophisticated pre-human primates exploiting arboreal lifestyles using upright non-stereotypical gaits along compliant branches (Thorpe, Holder, & Crompton, 2007). To achieve efficient upright non-stereotypical gait on compliant branches, moving so as not to fall, pre-human arboreal primates may have evolved domain-general

cortical zones used in sharing processing capacity for cognitive tasks, spatial reasoning and also applied to control frontal plane dynamic postural stability (Povinelli & Cant, 1995). Results from the present component analysis associating perception of vertical and semi-tandem frontal plane dynamic postural stability with academic performance appear to expose a previously unidentified foundational cognitive structure that is arguably linked to systems-based embodied cognition (Kozioł, Budding, & Chidekel, 2012).

Both semi-tandem frontal plane dynamic postural stability and perception of vertical appear to require a lengthy development time frame, reaching functional maturity sometime after puberty (Assaiante & Amblard, 1995; Bagust et al., 2013; Witkin et al., 1967). Witkin et al. (1967) provide evidence that children from 7 years slowly evolve a more accurate prediction of gravitational vertical, continuing into their early adulthood. Both skills require extensive involvement of cortical processing zones and with some shared networks (Fiori et al., 2015; Taubert et al., 2010).

The development of postural stability is also a non-linear process, transforming from feedback-based repertoires at 8 years to more complex and cognitively-demanding integrated feedback and feedforward processes in 10 to 12 year olds (Hay & Redon, 1999; Kirshenbaum, Riach, & Starkes, 2001). Assaiante and Amblard (1995) provide evidence of a close association between frontal plane dynamic postural stability and vertical orientation in pre-pubescent children. Children at 6 years walking along a narrow path use a visually dominated vertical alignment strategy. Alternatively, 8 year olds may use a more sophisticated articulation “unlock and unlink” strategy exploiting a more vestibular and proprioceptive-based orientation strategy.

The finding that no quantitative element of physical activity loaded with the “Academic Cognitive” factor challenges the long-held assumption of a close link between high levels of physical activity and fitness with human cognition (Castelli et al., 2007; Chomitz et al., 2009; Grissom, 2005). Further, the outcomes of the present study add support to propositions by Pesce (2012), Pesce et al. (2016) and Myer et al. (2015); of an association existing between qualitative elements of physical activity and academic performance. The findings are also in alignment with those reported by Diamond and Ling (2016) who suggest increased levels of physical activity and physical fitness alone may not be the primary ingredient in enhanced cognition found in previous studies. The data obtained in this study support the proposition that specific elements of qualitative physical activity—semi-tandem frontal plane dynamic postural stability and perception of vertical—are two factors associated with physical activity that play a role in academic performance in pre-adolescent children.

The component “Pubescent Development” accounted for the second largest amount of explained variance and was loaded with Tanner score, height and weight. The physical activity variables to also load in this sub-type were core endurance and jump height. Whilst jump height was positively associated with early growth and size (larger children having relatively higher jump height), core endurance was negatively linked (larger children found it more difficult to support their larger body mass in an abdominal hold task).

The third component to emerge was “Fitness, Strength and Body Mass” producing high loadings from per cent of body fat (DEXA), Jump height, cardio-respiratory fitness and core endurance. Children who are lean and fit also tend to have greater jump height and core endurance. Interestingly, this sub-type did not include the pedometer-based physical activity measure. The physical activity measure used in this study did not take into account intensity levels of physical activity performance, only daily step count. The suggestion from this finding supports the view that physical activity modes in pre-pubescent children tend to be of low-to-moderate intensity for extended time frames (Bailey et al., 1995) consequently having lower impact on cardio-respiratory fitness but a positive impact on motor skill acquisition. Supporting this hypothesis is the set of loading factors in component four. Component four, “Physical Activity and Motor Coordination”, had loading, in order of significance, for physical activity, ball catch and throw, cardio-respiratory fitness, core endurance and frontal plane dynamic postural stability. Evidence from the “Physical Activity and Motor

Coordination” component indicates that physical activity levels appear to have a substantial bearing on high motor coordination competency and significantly less so for physical fitness. This then suggests that the long duration of human pre-pubescence, engaging as it does sustained low to moderate level physical activity, is the optimal environment to promote motor coordination abilities. The present study also supports the view that sustained, low-to-moderate intensity level physical activity in pre-pubescent children promotes the acquisition of motor skill over fitness. It can also be suggested that the dual association between “Academic Cognitive” and “Physical Activity and Motor Coordination” arises in the loading of semi-tandem frontal plane dynamic postural stability with both. The suggestion here is that motor coordination activities arising from low intensity physical activity tasks may stimulate semi-tandem frontal plane dynamic postural stability competency and possibly result in enhanced cognitive outcomes. Whilst perception of vertical did not significantly load with “Physical Activity and Motor Coordination”, it did however suggest a trend towards association (loading factor 0.2). Similarly, perception of vertical may have a small relationship with semi-tandem frontal plane dynamic postural stability through motor coordination primarily associated with postural balance.

Interestingly, the reading variable produced a negative loading value of -0.18 with the “Physical Activity and Motor Coordination” component. The reading loading factor, being below -0.25 , fails to reach significance, but suggests a possible trend towards an association between poor reading skills and the “Physical Activity and Motor Coordination” component. The inference is that those very active children may simply not find the time to sit and read.

Finally, consistent with other studies, independent *t*-tests revealed boys to be fitter and stronger as well as more active and with better motor coordination than girls.

6. Conclusion

Specific elements of qualitative aspects of physical activity, namely perception of vertical and semi-tandem frontal plane dynamic postural stability, loaded significantly with the Academic Cognitive component in a large group of pre-adolescent children. No other physical variables loaded significantly (± 0.25) on this factor, or provided a loading component above 0.1. The current findings suggest that, on their own, quantitative elements of physical activity including physical activity, cardio-respiratory fitness and core endurance are insufficient to have an effect on academic outcomes in primary school children in their later years. However, the inclusion of frontal plane dynamic postural stability on the “Physical Activity and Motor Coordination” factor suggests that academic performance may be associated with fitness and physical activity through this common pathway. Two basic elements underlying and incidentally engaged in the performance of most physical activities are frontal plane dynamic postural stability and perception of vertical, and these also have the best synergy with academic scores in pre-adolescence. Further research into these novel elements of cognitive function and their inclusion into child activity programs are warranted. Results from the current study also suggest that future research using the CRAFT should include two separate methodologies. Firstly, a small visual angle CRAFT with head fixed and secondly, a large CRAFT with head free to move. The current CRAFT methodology thus presents as a way of exploring cognitive function in school children.

Whilst the present study is correlational and does not provide causal evidence, it provides support for specific style components of physical activity that are most likely to be stimulated by the dual engagement of semi-tandem frontal plane dynamic postural stability and perception of vertical. In pre-adolescence, activities in natural settings involving complex spatial environments are indicated. These environments and tasks may include; gardens where the child engages and maintains the complex environmental space whilst navigating narrow garden paths and single path orienteering in forested environmental settings, and in more traditional environments, activities such as yoga classes, soccer drills and gymnastics.

The data in the present study also suggest that physical activity levels in prepubescent children may be associated with acquisition of motor control competencies more than with the acquisition of physical fitness, which requires greater levels of physical activity intensity. Sports performance associated with motor skill acquisition may best be suited to activities engaging lower physical intensities in this age group. Finally, whilst eye-hand coordination, bimanual dexterity and core strength are important motor control attributes built during pre-pubescence, it appears also important to incorporate games and activities that involve both semi-tandem frontal plane dynamic postural stability tasks and activities stimulating spatial perception and orientation. These activities may contribute to cognitive enhancements, basic motor control acquisition and foundation in sports performance.

6.1. Limitations

Data in this research were gathered from children in Year Six, except for the academic results which were from the Australian national exam results in Year Five. Year Five data for RFT, frontal plane dynamic postural stability, ball skills and DEXA were not available, meaning that principal components analysis on the data in this year was not possible. However, physical activity and cardio-respiratory fitness scores from Year Five correlate with Year Six data ≥ 0.8 , providing support for the validity of the results.

6.2. Strengths

The project used a large sample of healthy Australian schoolchildren from the public education system, with none excluded, thereby providing an accurate description of Australian schoolchildren at the end of their primary school years.

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Competing Interests

The authors declare no competing interest.

Author details

Wayne Haynes¹
E-mail: Wayne.Haynes@canberra.edu.au
ORCID ID: <http://orcid.org/0000-0001-6603-6602>
Gordon Waddington¹
E-mail: Gordon.Waddington@canberra.edu.au
Roger Adams¹
E-mail: Roger.Adams@canberra.edu.au
¹ Faculty of Health, Research Institute for Sport and Exercise, University of Canberra, Canberra, Australia.

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