2013

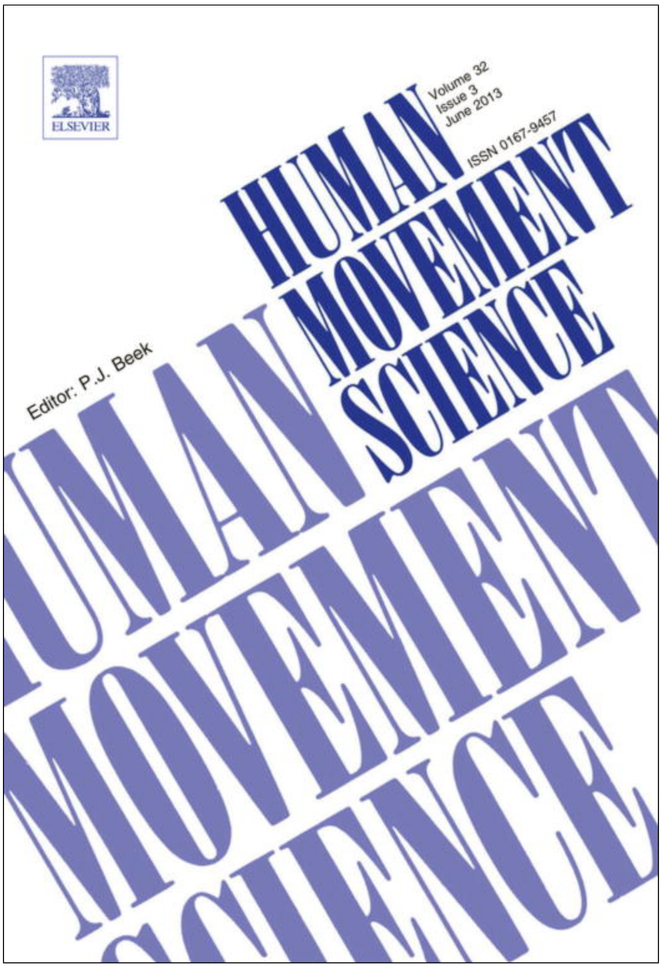
The psychometric properties of the McCarron Assessment of Neuromuscular Development as a longitudinal measure with Australian youth

Beth P. Hands
University of Notre Dame Australia, beth.hands@nd.edu.au

Dawne Larkin
University of Western Australia, dawne.larkin@uwa.edu.au

Elizabeth Rose
University of Notre Dame Australia, erose@aanet.com.au

This article was originally published as:
Hands, B. P., Larkin, D., & Rose, E. (2013). The psychometric properties of the McCarron Assessment of Neuromuscular Development as a longitudinal measure with Australian youth. *Human Movement Science, 32* (3), 485-497.
http://doi.org/10.1016/j.humov.2013.02.007

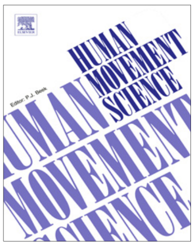

Volume 32
Issue 3
June 2013
ISSN 0167-9457
HUMAN MOVEMENT SCIENCE
Editor: P.J. Beek
ELSEVIER

Human Movement Science 32 (2013) 485–497

Contents lists available at SciVerse ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov



The psychometric properties of the McCarron Assessment of Neuromuscular Development as a longitudinal measure with Australian youth

Beth Hands [a],*, Dawne Larkin [b], Elizabeth Rose [c]

[a] *Institute for Health Research, University of Notre Dame Australia, PO Box 1225, Fremantle, Western Australia 6959, Australia*
[b] *School of Sport Science, Exercise and Health, University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia 6009, Australia*
[c] *School of Health Sciences, University of Notre Dame Australia, PO Box 1225, Fremantle, Western Australia 6959, Australia*

ARTICLE INFO

Article history:
Available online 28 May 2013

PsycINFO classification:
2221

Keywords:
Raine study
Motor development
Motor assessment
Factor analysis
Gender difference
Cultural difference

ABSTRACT

The importance of considering age and sex differences in the assessment of motor performance has been largely overlooked. This study examines the psychometric properties of the US developed McCarron Assessment of Neuromuscular Development (MAND) using data from a longitudinal sample of 986 Australian youth at 10, 14 and 17 years. A key finding was the sex and age interaction of the Neuromuscular Developmental Index (NDI) ($F = 121.46$, $p < .001$). Males had a significantly lower mean NDI score at 10 years and the females had a lower score at 17 years. The factor structure differed from the US samples (McCarron, 1997) at each age and between males and females. The sex specific analyses showed that the underlying structure was more complex for younger females. Although the MAND remains a useful test of motor performance for Australian children, further consideration is warranted regarding sex differences, the relevance of the US based normative tables and factor structures.

1. Introduction

The measurement of motor competence in children and adolescents is challenging. The development of motor skill is a lifelong process and competence may fluctuate in response to numerous

---

* Corresponding author. Address: Institute for Health Research, The University of Notre Dame Australia, 19 Mouat Street, PO Box 1225, Fremantle, Western Australia 6959, Australia. Tel.: +61 8 9433 0206; fax: +61 8 9433 0210.
E-mail address: beth.hands@nd.edu.au (B. Hands).

0167-9457/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.humov.2013.02.007

influences such as sex, cultural environment, physical maturity, movement interventions, or type and level of physical activity (Adolph, Karasik, & Tamis-LeMonda, 2010; Visser, Geuze, & Kalverboer, 1998). Longitudinal motor performance measures are essential to better understand how developmental changes occur. Only with this baseline information can we understand changes that have come about as a result of intervention or movement deprivation. Further, we need to establish whether motor performance tests accommodate differences between males and females, are culturally neutral or able to accommodate cultural differences.

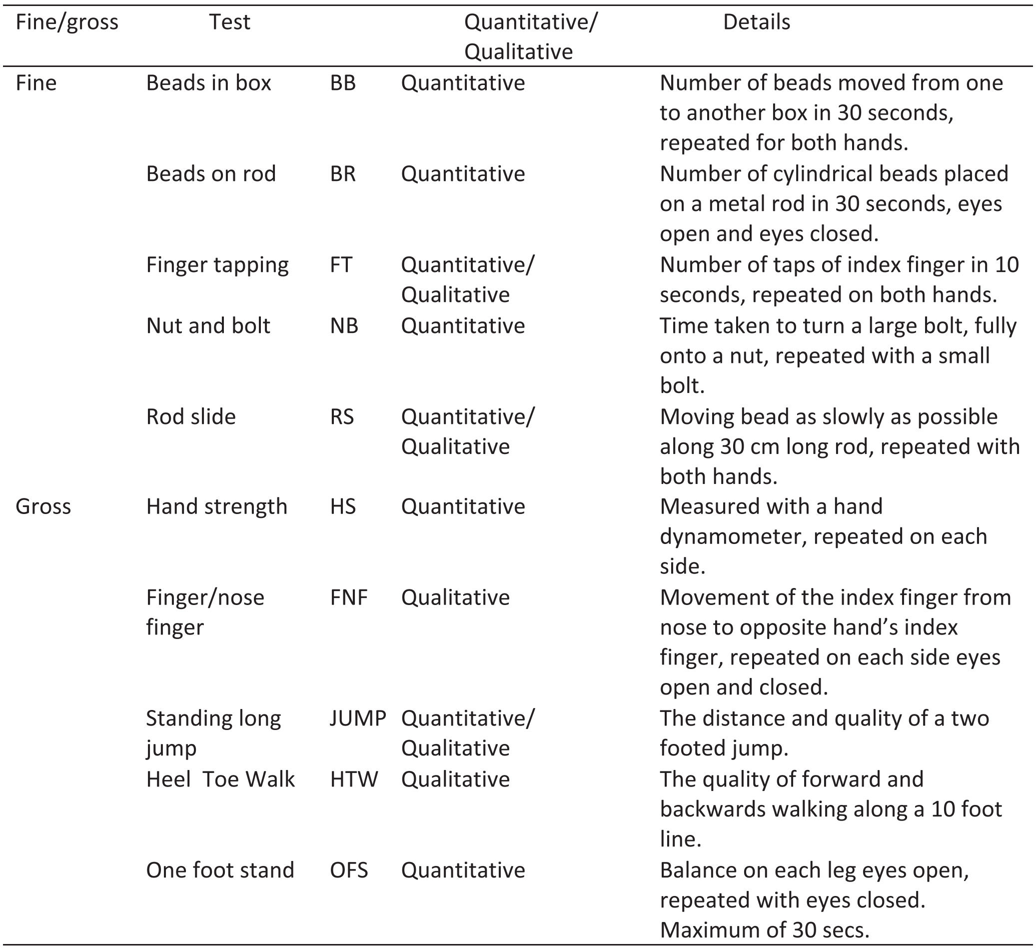
Some researchers assume the measure of motor performance can be validly used as an indicator of change in performance as a function of intervention. However such inferences may not be appropriate if the measure is not able to account for developmental differences independent of the intervention. Where motor development researchers have used motor performance tests to assess longitudinal change (Cantell, Smyth, & Ahonen, 1994), few have questioned the longitudinal suitability of the measure.

Sex differences in motor skills are apparent from an early age and will affect test outcomes. For example, males perform better on items requiring strength and ball skill, whereas females perform better on items involving balance, fine motor control and flexibility (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Hands & Larkin, 1997; Thomas & French, 1985). The motor performance tests most commonly used are the US developed Bruininks–Oseretsky Test of Motor Proficiency (BOT-2; Bruininks & Bruininks, 2005), the McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997), and the UK developed Movement Assessment Battery for Children-2 (Movement ABC-2; Henderson, Sugden, & Barnett, 2007) (Blank, Smits-Engelman, Polatajko, & Wilson, 2012). Sex specific standards are provided for all items from 4 years of age in the BOT-2 (Bruininks & Bruininks, 2005), for 2 items from 14 years of age in the MAND (McCarron, 1997) and for none in the Movement ABC-2 (Henderson et al., 2007). The developers of the latter test challenge the need to take sex differences into account (Barnett, 2008).

Tests developed and validated with one population may not be appropriate with another for several reasons. Motor development results from an interaction between biological and cultural influences (Adolph et al., 2010; Cintas, 1995; Hopkins & Westra, 1989). Fausto-Sterling, Coll, and Lamarre (2011, p. 5) propose motor development as a process that is "at once biological and experiential". Thus, when assessing motor development in one culture, this interplay should not be ignored. For example, Cintas (1995) found that even in early infancy there were significant cultural variations in parental care and expectations that would impact on how children performed motor tasks. Variations in motor development have been described in infants from many African and Caribbean cultural groups that can be directly related to child-rearing practices (Cintas, 1995). By adolescence, such cultural aspects in the process of socialization may significantly impact on motor development and how males and females perform movement tasks.

Second, norms derived in one culture may not be appropriate in another. For example the Movement ABC norms and individual test items compared across cultures showed that North American norms are appropriate in Europe (Smits-Engelsman, Henderson, & Michels, 1998) but not so well suited to Asian populations (Chow, Henderson, & Barnett, 2001; Miyahara et al., 1998). Finally, individuals from different countries and cultural backgrounds may use different strategies to perform test items. Ruiz, Graupera, Gutierrez, and Miyahara (2003) compared Spanish, Japanese and American children using the Movement ABC and found significant cultural and sex differences for a number of tasks. For example, Spanish children prioritized accuracy whereas the Japanese and American children prioritized speed when completing the flower trail task.

The MAND (McCarron, 1997; see Fig. 1) was developed in the United States in 1982 as a screening and evaluation tool for clinicians, educators, allied health professionals and researchers. In Australia, it is one of the most commonly used tests of motor performance (Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; Chia, Guelfi, & Licari, 2010; Hands, Larkin, Parker, Straker, & Perry, 2009; O'Beirne, Larkin, & Cable, 1994; Piek, Dawson, Smith, & Gasson, 2008; Raynor, 2001; Rose, Larkin, & Berger, 1997). Compared to the other commonly used tests, the MAND has a number of advantages. For example, it can be employed with children from 3 years through to adulthood, it can be administered in a confined space, and caters for people with disabilities (including those in wheelchairs). A particular advantage is that it includes both qualitative and quantitative components. Like the



Fine/gross	Test		Quantitative/ Qualitative	Details
Fine	Beads in box	BB	Quantitative	Number of beads moved from one to another box in 30 seconds, repeated for both hands.
	Beads on rod	BR	Quantitative	Number of cylindrical beads placed on a metal rod in 30 seconds, eyes open and eyes closed.
	Finger tapping	FT	Quantitative/ Qualitative	Number of taps of index finger in 10 seconds, repeated on both hands.
	Nut and bolt	NB	Quantitative	Time taken to turn a large bolt, fully onto a nut, repeated with a small bolt.
	Rod slide	RS	Quantitative/ Qualitative	Moving bead as slowly as possible along 30 cm long rod, repeated with both hands.
Gross	Hand strength	HS	Quantitative	Measured with a hand dynamometer, repeated on each side.
	Finger/nose finger	FNF	Qualitative	Movement of the index finger from nose to opposite hand's index finger, repeated on each side eyes open and closed.
	Standing long jump	JUMP	Quantitative/ Qualitative	The distance and quality of a two footed jump.
	Heel Toe Walk	HTW	Qualitative	The quality of forward and backwards walking along a 10 foot line.
	One foot stand	OFS	Quantitative	Balance on each leg eyes open, repeated with eyes closed. Maximum of 30 secs.

Fig. 1. Brief description of MAND test items.

BOT-2, the MAND generates a broad range of motor performance scores so that researchers and clinicians can look at both high and low levels of competence.

Of issue is the relevance of the MAND and its norms for youth of today and for populations from countries other than the US. In earlier studies of preadolescents, we found that while the derived composite score, the Neuromuscular Developmental Index (NDI), compared well with the normative sample, Australian children scored higher for the jumping task (JUMP) and lower for the hand strength (HS) task (Larkin & Rose, 1999). Although there were sex differences among items in this younger population, they were balanced out so that there were no overall significant differences in the NDI. A study of Malaysian adolescents also showed significant sex differences with girls performing better on the task of beads in a box (BB), beads on a rod (BR), nut and bolt (NB) and one foot stand (OFS), whereas boys were better at JUMP, finger–nose–finger (FNF) and finger-tapping (FT) (Ibrahim, 2009). To date, however, no studies have examined the appropriateness of the test with adolescents. McCarron based his factor structures on analyses involving 39 seven-year-olds and 31 adults with intellectual disabilities. These results are questionable given the small sample sizes, the identification of factors based on only two variables and the claim that the factors account for 100% of the variance (McCarron, 1997, p. 3).

In the Western Australian Pregnancy Cohort (Raine) Study researchers are following a cohort born between 1989 and 1991 (Newnham, Evans, Michael, Stanley, & Landau, 1993). Motor performance was assessed at 10, 14 and 17 years of age using the MAND (McCarron, 1997). The primary purpose of the paper is to examine the stability of the psychometric properties of the MAND with an Australian cohort at ages 10, 14 and 17 years. We considered the data for the cohort as a whole, and separately for males and females. At each time point, we examined the raw and scaled scores for test items, two composite scores based on the US norms and on the raw scores, and the identified factor structures based on the raw scores. This enabled us to establish whether the NDI scores derived from Australian adolescents were consistent with the US derived norms and whether sex was an issue when examining the factor structure of the test. To date, test developers have largely ignored male and female differences in motor developmental pathways. However, Sex differences and cultural variations in motor performance have been observed from an early age (Cintas, 1995; Hands & Larkin, 1997; Hopkins & Westra, 1989; Thomas & French, 1985); therefore an examination of these issues is warranted.

2. Methods

2.1. Participants

The Western Australian Pregnancy Cohort (Raine) study has been described in detail (Newnham et al., 1993, www.rainestudy.org.au). The initial cohort of 2868 were followed at birth, and, where available, at ages 1, 2, 3, 5, 8, 10, 14 and 17 and now at 20 years. Their socio-demographic characteristics are similar to those of the general Western Australian population, except for the lower proportion of fathers employed in managerial positions and the higher proportion of fathers employed in professional positions (Li et al., 2008).

Motor performance was assessed at the 10 year ($N = 1619$), 14 year ($N = 1584$) and 17 year ($N = 1215$) follow ups. In this paper we examine the data for the 986 participants (501 males and 485 females) who completed the MAND component in all three surveys. All data collection was approved by the Princess Margaret Hospital ethics committee. Primary caregivers and participants provided informed consent.

2.2. Measures

2.2.1. Motor performance

Motor performance was measured using the MAND (McCarron, 1997). The test comprises 10 items which are briefly described in Fig. 1. Raw scores for each item, based on quantitative and/or qualitative performance, are converted to scaled scores ($M = 10$, $SD = 3$) based on the participant's age. From 14 years of age, sex specific scaled scores are available for HS and JUMP. These scores are summed and converted to the NDI which has a normal distribution ($M = 100$, $SD = 15$; McCarron 1997). The scaled scores can be used to develop a profile of an individual's strengths and deficits for each task and to derive factor scores (persistent control, muscle power, kinesthetic integration, and bimanual dexterity) for groups of motor behaviors. The norms were derived from a representative sample of over 2000 3–35-year-olds individuals living in the US in the 1970s. Evidence of the content, construct, predictive and concurrent validity of the MAND is provided from studies involving typically developing 7-year-old children and adults with mental disabilities (McCarron, 1997). For example, the test has a high predictive validity of $r = .70$ for work-related behaviors among adults with mental disabilities. Test–retest reliability correlations after one month for individual items ranged between .67 and .98 for 31 adults with mental disabilities (McCarron, 1997). Concurrent validity of the test with the BOT-1 was established by an Australian research team (Tan, Parker, & Larkin, 2001) and other studies have validated its appropriateness as a motor assessment tool (O'Beirne et al., 1994; Raynor, 2001).

2.3. Data analysis

Continuous descriptive data are presented as means and standard deviations as all data were parametrically distributed. Data were examined for sex difference using *t*-tests. To deal with potential confounding, separate *z*-scores were derived for males and females for the scaled score of each test item. These scores were summed and then standardized again to create an overall sex specific *z*-score. To further examine sex differences in NDI over time, a repeated measures ANOVA with sex as a covariate was undertaken.

Factorial validity was explored using confirmatory factor analysis (AMOS v20). Because the model failed to fit, we then used principal components analysis using direct oblimin oblique rotation to explore the factor patterns in the MAND raw scores at each survey year. Factors were retained based on eigenvalues of more than one, an examination of the scree plots and then confirmed using parallel analysis (O'Connor, 2000). Factor loadings of .3 or more were considered when interpreting factors. Factor structures were first compared for the total sample. A gender group analysis was then completed to determine whether the inter-item correlations were invariant across sex for each survey year. Consequently the factor structures for males and females at each survey year were reported separately. Pearson's product moment correlations were calculated between the NDI, sex specific *z*-scores and standard scores (for 17 year data) across all survey years to examine the strength of the relationships. A *p*-value of .05 was considered to be statistically significant for the ANOVA and as multiple analyses (30) were undertaken an adjusted *p*-value of .002 was considered to be statistically significant for the *t*-tests.

3. Results

3.1. Sample characteristics

The mean and standard deviation of the NDI and sex specific overall *z*-scores at each survey for both males and females are presented in Table 1. The mean NDI for our whole sample was slightly lower than the McCarron standardization sample at 10 years ($M = 94.73$, 95% CI = 95.62–93.83) and 17 years ($M = 96.80$, 95% CI = 95.71–97.90) and similar at 14 years ($M = 98.34$, 95% CI = 97.26–99.41). When separated for males and females, it was apparent that these mean differences could be attributed to the males at 10 years ($M = 92.71$, 95% CI = 91.43–92.99) and the females at 17 years ($M = 91.72$, 95% CI = 90.41–93.03).

The repeated measures ANOVA using NDI scores at 10, 14 and 17 years with sex as a covariate confirmed a significant difference over time ($F = 125.08$, $p < .001$) which was further clarified by the significant sex by time interaction ($F = 121.46$, $p < .001$), described above. As expected, the sex-specific *z*-scores did not support the pattern of sex differences. An examination of the raw and scaled scores for each test item, reported below, provide some insight into these performance differences.

3.2. Item performance

Raw and scaled scores for each test item are reported in Table 2. There were significant sex differences in raw scores for most items at 10, 14 and 17 years with the exception of NB at 10 years, FT, NB, HTW and OFS at 14 years and RS, FNF, OFS and HTW at 17 years. As can be calculated from Table 2,

Table 1
Characteristics of participants at age 10, 14 and 17 years ($N = 986$).

	Total $N = 986$ *M* (*SD*)	Males $n = 501$ *M* (*SD*)	Females $n = 485$ *M* (*SD*)	Gender difference
Year 10				
Age (months)	126.12 (2.15)	126.15 (2.26)	126.09 (2.04)	$p = .67$
NDI	94.73 (14.24)	92.71 (14.59)	96.81 (13.56)	$p < .001$
Range	43–131	43–131	51–129	
Overall *z*-score (sex specific)	.03 (1.00)	−.01 (1.00)	.07 (.99)	$p = .22$
Year 14				
Age (months)	168.16 (2.12)	168.08 (2.10)	168.24 (2.14)	$p = .24$
NDI	98.34 (17.16)	98.26 (18.03)	98.42 (16.24)	$p = .88$
Range	53–155	53–155	57–153	
Overall *z*-score (sex specific)	.09(1.00)	.07(.97)	.11(.94)	$p = .88$
Year 17				
Age (months)	203.83 (2.72)	203.60 (2.48)	204.06 (2.93)	$p < .01$
NDI	96.80 (17.53)	101.72 (18.59)	91.72 (14.75)	$p < .001$
Range	54–155	54–155	58–147	
Overall *z*-score (sex specific)	.03 (.99)	.01(1.05)	.06 (.93)	$p = .49$

Table 2
Raw and scaled scores for test items at 10, 14 and 17 years for subsample ($N = 986$).

	10 years						14 years						17 years					
	Raw score			Scaled score			Raw score			Scaled score			Raw score			Scaled score		
	M	F	All	M	F	All	M	F	All	M	F	All	M	F	All	M	F	All
Beads in box	**43.0 (4.9)**	**45.6 (4.8)**	44.7 (5.0)	6.7 (3.4)	8.6 (3.5)	7.6 (3.5)	**47.2 (5.4)**	**50.8 (4.9)**	49.0 (5.5)	7.4 (3.1)	9.5 (2.9)	8.4 (3.2)	**49.8 (5.6)**	**53.6 (5.0)**	51.7 (5.6)	7.7 (3.24)	9.9 (2.3)	8.8 (3.3)
Beads on rod	**19.4 (3.0)**	**20.3 (3.1)**	19.9 (3.1)	10.3 (3.0)	11.2 (3.0)	10.8 (3.0)	**22.5 (3.0)**	**23.8 (2.9)**	23.2 (3.0)	10.6 (3.4)	12.1 (3.3)	11.4 (3.4)	**23.0 (3.1)**	**24.3 (2.8)**	23.7 (3.0)	10.1 (3.4)	11.6 (3.2)	10.8 (3.4)
Finger-tapping	**90.9 (17.4)**	**94.4 (15.6)**	92.6 (16.6)	13.4 (5.0)	14.5 (4.3)	14.0 (4.7)	96.2 (14.5)	94.2 (13.3)	95.2 (13.9)	10.4 (3.6)	9.9 (3.3)	10.2 (3.4)	**107.3 (15.9)**	**101.0 (13.9)**	104.2 (15.3)	11.7 (3.9)	10.1 (3.4)	10.9 (3.7)
Nut and bolt	157.5 (8.1)	157.9 (6.9)	157.7 (7.6)	8.5 (2.5)	8.6 (2.3)	8.5 (2.4)	164.5 (6.8)	163.4 (6.0)	163.9 (6.5)	7.5 (2.5)	7.1 (2.2)	7.3 (2.4)	**165.9 (6.5)**	**164.1 (5.9)**	165.0 (6.3)	7.3 (2.4)	6.6 (2.1)	7.0 (2.3)
Rod slide	**82.7 (10.7)**	**85.2 (8.0)**	83.9 (9.6)	9.6 (4.2)	10.5 (3.7)	10.0 (4.0)	**86.8 (8.3)**	**88.5 (5.8)**	87.7 (7.2)	10.1 (4.9)	11.0 (4.1)	10.5 (4.6)	87.5 (7.2)	87.6 (5.9)	87.6 (6.6)	9.5 (4.2)	9.2 (4.1)	9.3 (4.1)
Hand strength	**31.8 (6.2)**	**29.1 (5.8)**	30.4 (6.2)	5.2 (3.3)	3.8 (2.9)	4.5 (3.2)	**56.9 (14.3)**	**46.4 (9.1)**	51.7 (13.1)	9.2 (3.8)	7.1 (3.8)	8.2 (4.0)	**81.7 (15.7)**	**49.8 (9.5)**	66.0 (20.6)	11.4 (4.1)	5.7 (3.8)	8.6 (4.9)
Fing–nose–fing	**68.4 (6.1)**	**70.4 (5.3)**	69.4 (5.8)	11.2 (2.6)	12.2 (2.3)	11.7 (2.5)	**71.8 (7.2)**	**73.7 (5.5)**	72.8 (6.5)	7.8 (4.8)	9.1 (4.4)	8.5 (4.6)	73.3 (5.8)	73.4 (5.9)	73.3 (5.8)	6.9 (4.3)	7.1 (4.3)	7.0 (4.3)
Jumping	**65.9 (8.8)**	**62.3 (8.3)**	64.1 (8.7)	10.6 (3.7)	9.1 (4.1)	9.9 (3.7)	**77.9 (12.0)**	**66.7 (10.2)**	72.4 (12.4)	11.0 (4.0)	8.8 (4.2)	9.9 (4.2)	**85.8 (13.7)**	**63.7 (11.9)**	75.0 (16.9)	12.3 (4.3)	7.8 (4.7)	10.1 (5.1)
Heel toe	**32.2 (5.4)**	**33.8 (4.7)**	33.0 (5.1)	7.7 (4.2)	9.1 (4.1)	8.4 (4.2)	36.5 (4.3)	36.5 (3.8)	36.5 (4.1)	9.6 (2.9)	9.7 (2.6)	9.7 (2.8)	37.3 (3.5)	36.7 (3.5)	37.0 (3.5)	9.8 (2.5)	9.3 (2.7)	9.6 (2.6)
One foot stand	**78.3 (20.4)**	**84.2 (20.2)**	81.2 (20.5)	6.6 (3.2)	7.5 (3.3)	7.0 (3.3)	93.4 (20.6)	94.5 (18.6)	93.9 (19.6)	8.2 (3.0)	8.4 (2.7)	8.3 (2.8)	99.3 (19.9)	97.8 (17.7)	98.5 (17.9)	8.8 (2.7)	8.6 (2.7)	8.7 (2.7)

Note: Significant gender differences at each age are bolded $p \leqslant .002$.

effect sizes (Cohen's *d*) ranged from small (0.03 for HTW at 14 years) to large (1.16 for HS at 17 years). An interesting pattern emerged for the items where significant sex differences were observed. At 10 years, the females had significantly higher raw and scaled scores on seven of the nine items. Males scored higher on the two items involving strength; HS and JUMP. At 14 years, the females scored significantly higher for BB, BR, RS and FNF and the males scored higher on the HS and JUMP tasks. This was the case even though sex specific standards were used for HS and JUMP. At 17 years, the males out-performed the females on more tasks (FT, NB, OFS, HS and JUMP), while the females continued to score significantly higher on BB and BR.

3.3. Factor structure

The CFA testing McCarron's two factor scale (gross motor and fine motor) at 10 years did not provide adequate fit statistics (χ^2 (df = 34) = 324.474 p = .000; RMSEA = .055 [CI = .049–.060]; CFI = .864; TLI = .780). Further, it was not possible to complete a CFA testing the four factor model as McCarron reported only 2 variables to represent each factor (McCarron, 1997, p. 4). Subsequently, we used the raw scores for the ten test items at 10, 14 and 17 years to complete a principal components analysis (PCA). First, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix for each data set revealed many coefficients above .3. The Kaiser–Meyer–Olkin measure of sampling adequacy was .76 at 10 years, .71 at 14 years and .69 at 17 years, all exceeding the recommended value of .60 (Kaiser, 1974). The Bartlett's Test of Sphericity (Bartlett, 1954), which examines the hypothesis that the variables are uncorrelated, was significant for each set. These results support the factorability of the correlation matrices.

Principal components analyses with direct oblimin rotation were completed with the raw scores at each age for the whole sample and for males and females separately (Tables 3–6). Analysis of the data for the whole sample revealed the presence of similar components for each survey year (except at 14 years one factor separated into 2 factors), explaining total variance of 49.96% at 10 years, 63.96% at 14 years and 56.29% at 17 years (Table 3). Using data from 39 seven-year-old children, McCarron (1997) identified four factors involving 8 of the 10 test items; persistent control (RS and FNF), muscle power (HS and JUMP), kinesthetic integration (HTW and OFS) and bimanual dexterity (BR and NB) which together accounted for 100% of the variance. In our data, persistent control and kinesthetic integration merged into one factor which could be labeled postural control. We called the other two components muscle power and manual control. There is evidence of some factor stability across the years, the FT item appeared to be the most variable. In the 17 year survey, FT had a higher loading on the strength factor, which is different to the earlier surveys.

The gender group analyses revealed that the inter-item correlations were not invariant across sex for each survey year ($p < .001$ for all survey years), indicating the data should not be pooled. When the data were analyzed separately for males and females, different patterns emerged at each survey year

Table 3
Summary of principal components analysis for MAND at 10, 14 and 17 years.

Test item	10 years			14 years				17 years		
	1 (2)	2 (1)	3	1	2	3	4	1 (3)	2	3 (1)
Beads in box	.71			.80				.81		
Beads on rod	.76			.77				.78		
Finger-tapping	.38	.37				.30	.69			.49
Nut and bolt	.66			.70		.32		.57		.48
Rod slide		.67			.48		.51		.62	
Hand strength			.82			.84				.86
Finger–nose–finger		.62					.74		.62	
Jump			.64		.37	.74				.81
Heel toe walk	.33	.55			.73				.71	
Stand on one foot		.65			.81				.70	
% of variance	11.77	27.42	10.77	27.27	14.98	11.50	10.21	12.06	17.96	26.27

Note: Loadings <.3 have been removed.

Table 4
Summary of Principal Components Analysis for MAND at 10 years, Males and Females Separately.

Test item	Males			Females			
	1 (2)	2 (1)	3	1	2	3	4
Beads in box	.74			.71			
Beads on rod	.74			.72			
Finger-tapping		.63		.42			.58
Nut and bolt	.70			.33		.66	
Rod slide			.81		.82		
Hand strength		.58				.86	
Finger–nose–finger			.64				.73
Jump	.32	.39		.44			−.49
Heel toe walk		.71		.56			
Stand on one foot		.61	.44	.41	.66		
% of variance	11.78	29.31	10.52	25.20	11.31	10.61	10.46

Table 5
Summary of Principal Components Analysis for MAND at 14 years, Males and Females separately.

Test item	Males			Females			
	1 (2)	2 (1)	3	1	2	3	4
Beads in box	.77			.79			
Beads on rod	.80			.77			
Finger-tapping		.51	.32			.62	
Nut and bolt	.70			.68			
Rod slide		.73			.40	.44	−.37
Hand strength			.89				.90
Finger–nose–finger		.50				.80	
Jump			.69		.66		.31
Heel toe walk		.75			.71		
Stand on one foot		.65			.71		
% of variance	12.72	30.20	11.49	26.51	12.65	11.02	10.23

Table 6
Summary of Principal Components Analysis for MAND at 17 years, Males and Females Separately.

Test item	Males			Females		
	1 (2)	2 (1)	3	1	2	3
Beads in box	.79			.77		
Beads on rod	.74			.77		
Finger-tapping	.36		.55	.62		
Nut and bolt	.67		.30	.55		.37
Rod slide		.63			.54	
Hand strength			.84			.71
Finger–nose–finger		.46			.67	
Jump		.48	.37			.74
Heel toe walk	.30	.72			.71	
Stand on one foot		.74			.68	
% of variance	11.18	30.81	10.71	24.76	14.71	11.12

(Tables 4–6). While some items consistently loaded together across sex and survey (BB, BR, NB; HTW, SOF) others behaved very differently. The data for the boys loaded onto three factors at each survey year, whereas the data for the girls loaded onto four factors at 10 and 14 years and three factors at 17 years.

Table 7
Correlations between NDI, Sex Specific z-scores and Standard Score at 10, 14 and 17 years ($N = 986$).

	NDI		z-Scores			Standard Score
	14 years	17 years	10 years	14 years	17 years	17 years
NDI						
10 years	.63**	.51**	.98**	.66**	.61**	.44**
14 years		.54**	.64**	1.00**	.59**	.48**
17 years			.55**	.56**	.92**	.90**
z-Scores						
10 years				.68**	.62**	.50**
14 years					.52**	.64**
17 years						.79**

** $p < .01$

3.4. Suitability of the composite scores: NDI and sex specific-overall z-scores

The correlations between the NDI and z-scores were strong at 10 years (.98), 14 years (1.00) and 17 years (.99), but weaker when compared across time (Table 7). NDI at 10 years was moderately related to NDI at 14 years (.63) and 17 years (.51), whereas the correlations were stronger (but still moderate) between the z-scores at 10 years and 14 years (.67) and 17 years (.62). For the 17 year survey, two outcome measures are reported as the MAND does not provide age-based standards above 16 years of age. After 16 years, the sum of the raw scores (not the scaled scores) for each item is converted to a final Standard Score. In Table 7, we have reported the NDI, based on the standards for 16-year-olds, and the Standard Score based on the recommended procedure for adults just described. At 17 years the correlation was stronger between the sex-specific overall z-scores and the NDI (.90) than with the Standard Score (.79).

4. Discussion

The main purpose in this study was to examine the psychometric properties and the factorial structure of the MAND using data from a longitudinal study. The two factor structure of the MAND identified by McCarron based on a small sample was not supported by the CFA. This was not surprising as the analysis was based on data from 31 mentally disabled adults. It was appropriate, therefore, when examining the psychometric properties of the test that we undertook exploratory factor analyses with the larger Australian data base, and considered the stability of the factors across age and between males and females. Overall, the MAND remains a useful test of motor performance for Australian children, however further consideration is warranted regarding sex differences, the suitability of the US normative tables and factor structures, and the interpretation of the results using standard scores for those over 16 years of age. The mean NDI scores were within the range of McCarron's standardization sample (although slightly lower). The test results at each age covered a wide range of scores indicating the ability to discriminate between motor performance levels.

The significant Sex x Time interaction for the NDI is difficult to interpret. It could reflect different developmental pathways for male and female adolescents, cultural differences or unsuitable standardization tables for the Australian population. In our sample, the males had a lower mean NDI (92.71) than the females (96.81) at 10 years, a similar mean NDI at 14 years and a higher NDI (by 10 points) at 17 years. On the other hand, the mean NDI for the females was lower at 17 years than at 10 or 14 years. Interestingly, the range of scores showed the males received the lowest and highest NDI scores at each age with the whole sample scoring lower at 10 years compared to 14 and 17 years. Using the US conversion table, more boys than girls at 10 years (30.5% vs 20.4%), and more girls than boys at 17 years (36.9% vs 20.4%), were identified with a mild motor disability (an NDI at or below 85; McCarron, 1997). This prevalence, which is higher than would be expected, perhaps reflects the lower NDI in our sample, and a normative issue rather than a higher prevalence of motor disability.

An analysis of individual item scores (Table 2) showed significant sex differences for most test items at each age, with some interesting patterns. First, the better performing sex changed with age for some items. At 10 years, the girls had higher mean scores than the boys for all items except the two strength items, HS and JUMP. At 17 years, the males had higher scores than the females on most tasks except two manipulative tasks, BB and BR. The males continued to score substantially higher on HS and JUMP even when sex specific standards were used at 14 and 17 years, whereas the girls' scaled scores, but not the raw scores, for the JUMP reduced from 10 to 14 to 17 years. These results may represent differences in activity opportunities and interests between Australian and US children but are more likely due to sex differences in strength that have not been accommodated for in the normative tables (Malina, Bouchard, & Bar-Or, 2004). The revision of the BOT-2 (Bruininks & Bruininks, 2005) also reported better test performances among females on the manipulative items, and for males on the running speed, agility and strength tasks and, as with the original test, included sex specific as well as combined tables of norms (Bruininks, 1978; Bruininks & Bruininks, 2005). There were some MAND items that received standard scores more than one standard deviation above or below the mean established by McCarron (1997) which could be due to cultural variations (see Table 2). Finally, the changes in JUMP and HS raw scores for the girls do not mirror the scaled scores across ages which suggest problems with the scaling process. Together, these results lead us to question the appropriateness of these US derived standardization tables for Australian males and females. Variations in motor development arising from differences between cultures are expected and are important considerations when using tests developed in other countries.

Our factor analysis of the whole sample identified three fairly consistent factors across the three surveys; muscle power, manual control and postural control. These have some similarities to the four factors identified by McCarron (1997); persistent control, muscle power, kinesthetic integration and bimanual dexterity when using data from a sample of 39 seven-year-old children. The muscle power factor is similar, and our postural control factor is a combination of persistent control and kinesthetic integration factors. As BB always loaded with BR and NB, we labeled our third factor manual control rather than bimanual dexterity. Our three factors are also similar to three of the four identified by Bruininks and Bruininks (2005) based on the 53 items of the BOT-2; strength and agility (muscle power), manual control (manual control), body coordination (postural control). They identified a fourth factor called manual coordination. As the BOT-2 is also designed to measure motor competence and given the factors are similar, these results provide evidence for the concurrent validity of the MAND.

Important differences emerged when we considered sex. There were more changes in factor structure between 10, 14 and 17 years for the females (4, 4, 3 factors) than the males (3, 3, 3). For example at 10 years (Table 4), HS and JUMP loaded with the postural control items of FT, HTW and OFS for the males, but loaded on separate factors for the females. HS loaded with NB and JUMP loaded fairly evenly onto a strong manual dexterity/postural control factor and negatively with FT and FNF. The items do not differentiate for muscle power at 10 years. We hypothesize this is reflecting different developmental pathways between males and females.

We found no evidence in any of the analyses to support the fine and gross motor subscales proposed by McCarron (1997), although our factor analyses showed a manual control factor represented by three of the five tasks designated as fine motor by McCarron. McCarron defines fine motor tasks as those that involve the "small muscles of the fingers, hands and arm" (McCarron, p. 4). We would expect BB, BR, NB and FT to load onto a fine motor factor but not RS which involves the larger postural muscles and steadiness. Similarly the gross motor tasks require a number of different motor abilities. McCarron identified the subscales using data from 31 adults with mental disabilities, whereas our factors were derived from a larger, more representative sample of adolescents. Although the fine or gross motor subscales did not emerge as reliable factors in our study, previous studies showed these scores can be clinically useful (for example Parker, Larkin, & Wade, 1997).

The moderate correlations across time for both the NDI and sex-specific *z*-scores (Table 7) are consistent with the notion of varying developmental pathways and timing of growth spurts. Researchers using test performance scores across time need to be very careful about the interpretation of any changes in these scores as motor development is a fluid construct, that changes over time in response to numerous socio-biological and environmental factors.

When the two composite scores; the NDI and the sex specific *z*-scores, were compared, some interesting differences emerged between males and females. These highlight the difficulty of designing a test capable of measuring motor competence independent of sex across a wide age span, particularly adolescence. The process of converting raw scores to a NDI advantaged the females at age 10 years but advantaged the males at age 17 years. This result was despite the sex specific conversion tables provided in the MAND for HS and JUMP from 14 years. The differences in mean scaled scores between males and females for these 2 tasks at 17 years (Table 2) were 5.7 and 4.5 respectively, suggesting that scaling problems or strategy differences between males and females might be responsible.

The muscle power factor was represented by different items for males and females and even across age group, but was largely driven by HS. This was most apparent in the sex-specific analyses. For example, at 17 years the factor analyses showed a loading of .86 and .81 for HS and JUMP respectively for the whole sample (Table 3) but the two items loaded onto different factors when the data for males and females were analyzed separately (Table 6).

While overall the test appears appropriate for Australian youth, we identified several issues that warrant further examination. First, the distinctly different outcomes for males and females on scores for individual items, the NDI, and the factor analyses, support the need for better sex-specific standardization tables for all items across ages. For many years sex specific norms have been derived for motor skill and fitness tests involving children and adolescents as young as 5 years (ACHPER, 1996; Calder, 1975; Jenkins, 1930; Willee, 1973). It is interesting to note, that the revised Movement ABC-2 (Henderson et al., 2007) does not have separate standards for males and females as the developers did not find significant sex differences in item scores (Barnett, 2008). This could be due to the task types and the narrow score range. The test includes manual (fine motor), aiming and catching, and balance tasks, with minimal strength and speed requirements. The Movement ABC-2 is designed to identify motor impairment (Henderson et al., 2007). However given this specific purpose, this instrument has a limited ability to assess a wide range of motor performance or gender differences.

Second, the process recommended by McCarron for deriving a composite score for young adults needs further examination as the *z*-scores correlated more highly with the NDI based on the 16-year-old norms (.92) than with the 17 year Standard Score (.79). The sex-specific overall *z*-scores might provide an alternative way of using the MAND in a research context. Finally, interpreting test results using the McCarron factor profiles should be used with caution with an Australian population. We found little evidence to support the allocation of the tasks to fine and gross motor factors or to the four factors of persistent control, muscle power, kinesthetic integration and bimanual dexterity.

It cannot be assumed that motor development norms are similar across different cultures. Cultural socialization factors significantly interact with motor development (Cintas, 1995). The process with which a person learns motor skills, attitudes, values and behaviors will vary from one culture to another (Cintas, 1995). For example there are cultural variations in parental care and expectations of motor behavior in infancy, childhood and adolescence and these interact with gender expectations for societies (Hopkins & Westra, 1989).

The strength of our study lay in the large sample size, its longitudinal nature and the separate examination of males and females. Few studies report repeated measures of a motor performance test over a 7 year period, particularly among adolescents. Our results provide us with evidence of changes in motor performance between late childhood and adolescence and that these differ for males and females. If motor performance was only measured cross-sectionally, these important changes might not have been detected. The challenge lies in developing tests and test items that minimize sex-related confounds, accommodate physical maturation and yet provide a valid measure of motor competence.

Further research is needed to consider the type, range, and number of tasks required to comprehensively measure motor development. For example, the long form of the BOT-2 includes 53 items and the MAND has 10 items, yet both are comprehensive measures of motor performance. It is unclear how many test items are required to adequately cover the range of motor performance and represent specific factors. We found three consistent factors; muscle power, manual control and postural control, but the items representing these constructs differed with age and sex. We also need to better understand the degree of precision of measurement needed to detect change in motor performance over time. Finally, we need to address how task performances change with sex, culture and age, and the extent that results are confounded by physical size and maturity.

Acknowledgments

We are grateful to all the Raine study participants and their families who took part in this study and the Raine Study Team for cohort coordination and data collection. The Western Australian Pregnancy Cohort (Raine) study has been supported by long term funding by the NH&MRC and Telethon Institute for Child Health Research. Funding for Core Management of the Raine Study has been provided by The University of Western Australia (UWA), Raine Medical Research Foundation, UWA Faculty of Medicine, Dentistry and Health Sciences, and the Women and Infants Research Foundation. Cohort reviews used for this research were specifically supported by NH&MRC and The Raine Foundation.

References

ACHPER. (1996). *Australian Fitness Education Award*. Richmond, SA: Australian Council for Health, Physical Education and Recreation.

Adolph, K. E., Karasik, L. B., & Tamis-LeMonda, C. S. (2010). Motor skill. In M. Bornstein (Ed.), *Handbook of cultural developmental science* (pp. 61–88). New York, NY: Psychology Press.

Barnett, A. L. (2008). Motor assessment in developmental coordination disorder: From identification to intervention. *International Journal of Disability, Development and Education, 55*, 113–129.

Barnett, L., van Beurden, E., Morgan, P. J., Brooks, L. O., & Beard, J. R. (2010). Gender differences in motor skill proficiency from childhood to adolescence: A longitudinal study. *Research Quarterly for Exercise and Sport, 81*, 162–170.

Bartlett, M. S. (1954). A note on the multiplying factors for various X^2 approximations. *Journal of the Royal Statistical Society Series B, 16*, 296–298.

Blank, R., Smits-Engelman, B., Polatajko, H., & Wilson, P. (2012). European Academy for Childhood Disability (EACD): Recommendations on the definition, diagnosis and intervention of developmental coordination disorder. *Developmental Medicine & Child Neurology, 54*, 54–93.

Bruininks, R. H. (1978). *Bruininks–Oseretsky Test of Motor Proficiency: Examiner's manual*. Circle Pines, MN: American Guidance Service.

Bruininks, R. H., & Bruininks, B. D. (2005). *Bruininks–Oseretsky Test of Motor Proficiency: Examiner's manual* (2nd ed.). Windsor, UK: NFER-Nelson.

Caeyenberghs, K., Tsoupas, J., Wilson, P. H., & Smits-Engelsman, B. C. (2009). Motor imagery development in primary school children. *Developmental Neuropsychology, 34*, 103–121.

Calder, J. (1975). *The Queensland motor performance screening test for young children*. Brisbane: University of Queensland.

Cantell, M. H., Smyth, M. M., & Ahonen, T. P. (1994). Clumsiness in adolescence: Educational, motor, and social outcomes of motor delay detected at 5 years. *Adapted Physical Activity Quarterly, 11*, 115–129.

Chia, L. C., Guelfi, K. J., & Licari, M. K. (2010). A comparison of the oxygen cost of locomotion in children with and without developmental coordination disorder. *Developmental Medicine and Child Neurology, 52*, 251–255.

Chow, S. M., Henderson, S. E., & Barnett, A. L. (2001). The movement assessment battery for children: A comparison of 4-year-old to 6-year-old children from Hong-Kong and the United States. *American Journal of Occupational Therapy, 55*, 55–61.

Cintas, H. L. (1995). Cross-cultural similarities and differences in development and the impact of parental expectations on motor behavior. *Pediatric Physical Therapy, 7*, 103–111.

Fausto-Sterling, A., Coll, C. G., & Lamarre, M. (2011). Sexing the baby: Part 2 applying dynamic systems theory to the emergences of sex-related differences in infants and toddlers. *Social Science and Medicine*. http://dx.doi.org/10.1016/j.socscimed.2011.06.027.

Hands, B., & Larkin, D. (1997). Gender bias in measurement of movement. *ACHPER Healthy Lifestyles Journal, 44*, 12–16.

Hands, B., Larkin, D., Parker, H., Straker, L., & Perry, M. (2009). The relationship among physical activity, motor competence and health-related fitness in 14-year-old adolescents. *Scandinavian Journal of Medicine and Science in Sports, 18*, 655–663.

Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement Assessment Battery for Children-2: Examiner's manual* (2nd ed.). London: Pearson Assessment.

Hopkins, B., & Westra, T. (1989). Maternal expectations of their infants' development: Some cultural differences. *Developmental Medicine and Child Neurology, 31*, 384–390.

Ibrahim, H. (2009). *Assessing general motor ability and tests for talent identification of Malaysian adolescents*. PhD, University of Western Australia, Perth.

Jenkins, L. M. (1930). *A comparative study of motor achievements of children of five, six and seven years of age*. New York: Teachers College Columbia University.

Kaiser, H. F. (1974). *An index of factorial simplicity. Psychometrika, 39*, 31–36.

Larkin, D., & Rose, B. (1999). Use of the McCarron Assessment of Neuromuscular Development for DCD identification. *Paper presented at the 4th biennial workshop on children with a developmental coordination disorder*, Groningen, The Netherlands.

Li, C., Kendall, G. E., Henderson, S., Downie, J., Landsborough, L., & Oddy, W. H. (2008). Maternal psychosocial well-being in pregnancy and breastfeeding duration. *Acta Pædiatrica, 97*, 221–225.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation and physical activity*. Champaign, IL: Human Kinetics.

McCarron, L. T. (1997). *McCarron Assessment of Neuromuscular Development* (3rd ed.). Dallas, TX: McCarron-Dial Systems Inc.

Miyahara, M., Tsujii, M., Hanai, T., Jongmans, M., Barnett, A., Henderson, S. E., et al (1998). The Movement Assessment Battery for Children: A preliminary investigation of its usefulness in Japan. *Human Movement Science, 17*, 679–697.

Newnham, J. P., Evans, S. F., Michael, C. A., Stanley, F. J., & Landau, L. I. (1993). Effects of frequent ultrasound during pregnancy: A randomised controlled trial. *Lancet, 342*, 887–891.

O'Beirne, C., Larkin, D., & Cable, T. (1994). Coordination problems and anaerobic performance in children. *Adapted Physical Activity Quarterly, 11*, 141–149.

O'Connor, B. (2000). SPSS and SAS programs for determining the number of components using parallel analysis and Velicer's MAP test. *Behaviour Research Methods, Instruments, & Computers, 32*, 396–402.

Parker, H., Larkin, D., & Wade, M. G. (1997). Are timing problems subgroup specific in children with Developmental Coordination Disorder? *The Australian Educational and Developmental Psychologist, 14*, 35–42.

Piek, J. P., Dawson, L., Smith, L. M., & Gasson, N. (2008). The role of early fine and gross motor development on later motor and cognitive ability. *Human Movement Science, 27*, 668–681.

Raynor, A. (2001). Strength, power and coactivation in children with developmental coordination disorder. *Developmental Medicine and Child Neurology, 43*, 676–684.

Rose, B., Larkin, D., & Berger, B. G. (1997). Coordination and gender influences on the perceived competence of children. *Adapted Physical Activity Quarterly, 14*, 210–221.

Ruiz, L. M., Graupera, J. L., Gutierrez, M., & Miyahara, M. (2003). The assessment of motor coordination in children with the Movement ABC test: A comparative study among Japan, USA and Spain. *International Journal of Applied Sport Sciences, 15*, 22–35.

Smits-Engelsman, B. C., Henderson, S. E., & Michels, C. G. J. (1998). The assessment of children with developmental coordination disorder in the Netherlands: The relationship between the Movement Assessment Battery for Children and the Korperkoordinations Test Fuer Kinder. *Human Movement Science, 17*, 699–709.

Tan, S. K., Parker, H. E., & Larkin, D. (2001). Concurrent validity of motor tests used to identify children with motor impairment. *Adapted Physical Activity Quarterly, 18*, 168–182.

Thomas, J. R., & French, K. E. (1985). Gender differences across age in motor performance: A meta-analysis. *Psychological Bulletin, 98*, 260–282.

Visser, J., Geuze, R. H., & Kalverboer, A. F. (1998). The relationship between physical growth, the level of activity and the development of motor skills in adolescence: Differences between children with DCD and controls. *Human Movement Science, 17*, 573–608.

Willee, A. W. (1973). *Australian Youth Fitness Survey 1971*. Canberra: Australian Government Publishing Service.