Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: http://www.tandfonline.com/loi/rjsp20

Comparison of performance on process- and product-oriented assessments of fundamental motor skills across childhood

Samuel W. Logan, Lisa M. Barnett, Jacqueline D. Goodway & David F. Stodden

To cite this article: Samuel W. Logan, Lisa M. Barnett, Jacqueline D. Goodway & David F. Stodden (2017) Comparison of performance on process- and product-oriented assessments of fundamental motor skills across childhood, Journal of Sports Sciences, 35:7, 634-641, DOI: 10.1080/02640414.2016.1183803

To link to this article: https://doi.org/10.1080/02640414.2016.1183803

JOURNAL OF SPORTS SCIENCES, 2017
VOL. 35, NO. 7, 634–641
http://dx.doi.org/10.1080/02640414.2016.1183803

Comparison of performance on process- and product-oriented assessments of fundamental motor skills across childhood

Samuel W. Logan[a], Lisa M. Barnett[b], Jacqueline D. Goodway[c] and David F. Stodden[d]

[a]College of Public Health and Human Sciences, Oregon State University, Corvallis, OR, USA; [b]School of Health and Social Development, Deakin University, Burwood, VIC, Australia; [c]Department of Human Sciences, The Ohio State University, Columbus, OH, USA; [d]Department of Physical Education and Athletic Training, University of South Carolina, Solomon Blatt Physical Education Center, Columbia, SC, USA

ABSTRACT

Process-oriented motor competence (MC) assessments evaluate *how* a movement is performed. Product-oriented assessments evaluate the *outcome* of a movement. Determining the concurrent validity of process and product assessments is important to address the predictive utility of motor competence for health. The current study aimed to: (1) compare process and product assessments of the standing long jump, hop and throw across age groups and (2) determine the capacity of process assessments to classify levels of MC. Participants included 170 children classified into three age groups: 4–5, 7–8 and 10–11 years old. Participants' skills were examined concurrently using three process assessments ((Test of Gross Motor Development-2nd edition [TGMD-2]), Get Skilled; Get Active, and developmental sequences) and one product measure (throw speed, jump and hop distance). Results indicate moderate to strong correlations between (1) process assessments across skills and age groups (r range = .37–70) and (2) process and product assessments across skills and age groups (r range = .26–.88). In general, sensitivity to detect advanced skill level is lowest for TGMD-2 and highest for developmental sequences for all three skills. The use of process and product assessments is suggested to comprehensively capture levels of MC in human movement.

ARTICLE HISTORY
Accepted 21 April 2016

KEYWORDS
Skill development; childhood; motor

Objectives for studying motor competence (MC) include describing, understanding and explaining how the process and product of movement patterns (i.e., movement coordination and control) change over time (Haywood & Getchell, 2009). Recent research has emphasised the relationship between MC and important health outcomes (see Robinson et al. (2015) for a review) such as physical activity (Logan, Webster, Robinson, Getchell, & Pfieffer, 2015), weight status (Cattuzzo et al., 2015; Logan, Scrabis-Fletcher, Modlesky, & Getchell, 2011) and health-related fitness (Cattuzzo et al., 2015; Lubans, Morgan, Cliff, Barnett, & Okely, 2010). Due to the increased interest and evidence surrounding associations between MC and health, it is imperative that assessments used to quantify MC are accurate and informative.

One aspect of MC routinely examined in the literature is the performance of fundamental motor skills (FMS). FMS are defined as gross motor skills "…that involve the large, force-producing muscles of the trunk, arms, and legs" (Clark, 1994, p. 245). FMS are typically classified as locomotor (e.g., jump, hop and run) and object control (e.g., throw, kick and strike) skills (Haywood & Getchell, 2009) and are considered the building blocks of more advanced movements that are required to successfully participate in physical activity such as sports and games (Clark & Metcalfe, 2002). FMS assessments are commonly used as evaluative tools for physical education, motor development and performance profiles. These assessments may vary in the type (i.e., product or process) and number of skills measured (i.e., individual or subscales), ease of administration and scoring procedures.

Process-oriented assessments evaluate *how* a movement is performed and describe qualitative movement patterns. Three examples often used in the literature include the Test of Gross Motor Development-2nd edition (TGMD-2; Ulrich, 2000), Get Skilled; Get Active (GSGA; New South Wales Department of Education and Training, 2000) and developmental sequences (Clark & Phillips, 1985; Clark, Phillips, & Peterson, 1989; Roberton & Halverson, 1984, 1988). Specifically, the TGMD-2 evaluates children's FMS based on the presence or absence of 3–5 performance criteria for 12 skills including object control and locomotor skills (Ulrich, 2000). Scores across two trials are then summed to provide a raw score for that particular skill. The GSGA skills are scored in a similar fashion. Alternatively, developmental sequences assess coordination patterns of individual components of individual skills that are aligned with parts of the body (Roberton & Halverson, 1984). Each qualitatively different component level is evaluated on an ordinal developmental scale (e.g., 1–4) with higher levels equalling more advanced movement pattern. For example, the developmental sequences of throwing include three body components: trunk, humerus and forearm and each component has three levels. Process-oriented assessments differ in their complexity to administer due to the number of skills included, number of performance criteria for each skill and whether or not performance can be observed and

CONTACT Samuel W. Logan ✉ sam.logan@oregonstate.edu College of Public Health and Human Sciences, Oregon State University, 160 SW 26th St., Women's Building 203b, Corvallis, OR 97331, USA

recorded live or whether video analysis is required for accurate scoring. In contrast, a product-oriented assessment evaluates the *outcome* of a movement, which is typically identified as a quantitative score (e.g., speed, distance or number of successful attempts). Run, throw or kick speed, jump or hop distance and the number of successful catches or target "hits" are examples of product-oriented assessments.

Previous research has examined the associations between process- and product-oriented assessments of motor competence with mixed results. Recent studies have found low (5.3%; 4–11 year olds; Valentini et al., 2015) to moderate amounts of variance explained (24%; 3–6 year olds; Logan, Robinson, & Getchell, 2011; 27%; 5–8 year olds; Logan, Robinson, Rudisill, Wadsworth, & Morera, 2014) between overall performance on the process-oriented TGMD-2 and the product-oriented Movement Assessment Battery for Children-2nd edition. However, due to differences in specific skills measured between the two assessments, comparisons of individual skill performances could not be addressed. Alternatively, a few studies have compared both the product and process of individual skills that are classified as FMS; again, the strength of associations appears to vary depending upon the skill and the assessment. For example, throwing developmental sequence levels predict 69–85% of ball speed in children aged 6–13 years (Roberton & Konczak, 2001) and also are strongly predictive of kinematic and temporal variables and ball velocity in children 3–15 years of age (Stodden, Langendorfer, Flesig, & Andrews, 2006a, 2006b). In contrast, only 22% of the variance in standing long jump distance was explained by whole-body developmental sequences in 3–5 year-old-children (Haubenstricker & Branta, 1997). Similarly, whole-body developmental sequences of running explained 29% of variance in running speed in 2–5-year-old children (Fountain, Ulrich, Haubenstricker, & Seefeldt, 1981). It is apparent that there is neither a clear nor a comprehensive understanding of the relationship between process- and product-oriented assessments of FMS competence in children.

It is important to understand how and why the strength of associations between motor assessments may change across age as certain assessments were developed primarily to focus on the identification of developmental delay (e.g., TGMD-2) or to address how change in movement occurs across childhood (e.g., developmental sequences or product scores). It is possible that while assessments are able to detect developmental delay, they may not be able to adequately discriminate levels of skilfulness in typically developing children. Thus, existing assessments may not provide adequate sensitivity in the research context to determine how FMS competence relates to health outcomes and behaviours (Stodden et al., 2008). There is also a need to determine how performances on different process-oriented FMS assessments are related, as their scoring protocols (e.g., sum of dichotomously scored criteria such as the TGMD-2 or GSGA, or ordinal ranked component levels for developmental sequences) are quite different from a measurement perspective. To date, there are no studies that have compared individuals' performance on two or more process-oriented FMS assessments.

Overall, comparisons of assessment outcomes will provide critical information to the scientific community as it relates to how different FMS assessments may provide different types of information relating to MC. In the current study, only assessments that specifically measure FMS were included. There are two purposes of the current study: (1) to compare process- and product-oriented assessments of the standing long jump, hop and throw across three age groups and (2) to determine the capacity of process-oriented assessments to classify advanced and non-mastery levels of skilfulness.

Method

Participants and setting

Participants included a convenience sample of 170 children between the ages of 4 and 11 years old (86 girls, 84 boys) from two rural towns in the Southwestern United States. All participants were enrolled in public schools and attended physical education class on a regular basis. Data from these participants were part of a larger study and data for the current study were uniquely analysed to address the research questions of interest. Participants were Hispanic (n = 94), Caucasian (n = 70), African American (n = 5) and Native American (n = 1). Participants were classified into three age groups: 4–5 years, 7–8 years and 10–11 years. See Table 1 for participants' demographic information. The university's human participants review board approved this study prior to data collection. Verbal assent and written informed consent was obtained from all participants and their legal guardians, respectively. Potential participants with a physical disability or health condition that prevented them from completing any of the assessments were excluded from testing.

Procedures and assessment

Children completed three skills (standing long jump, hop and throw) that are each included in the TGMD-2 (Ulrich, 2000), and the GSGA (New South Wales Department of Education and Training, 2000). Validated developmental sequences exist for these three skills (Clark & Phillips, 1985; Clark et al., 1989; Roberton & Halverson, 1984, 1988). Children performed these skills at different stations and all skills were video recorded from the side view, with an additional camera positioned behind to assess throwing. Although the different assessments have slightly different procedures for scoring administration, the procedures in terms of assessment protocol were identical for all three skills. After a researcher demonstrated each skill and exhibited all behavioural components (TGMD-2), children were then allowed two warm-up trials of each skill. Participants also were instructed to perform with maximum effort, which produces the most advanced movement pattern of ballistic skills (Langendorfer, Roberton, & Stodden, 2011). As

Table 1. Children's demographic information by age group.

				Age (years)		Height (cm)		Weight (kg)	
Age group	*n*	Boys	Girls	*M*	SD	*M*	SD	*M*	SD
4–5 year olds	55	23	32	5	0.54	109.7	6.7	19.5	3.7
7–8 year olds	61	33	28	8.1	0.62	127.7	6	30.1	8.4
10–11 year olds	54	28	26	10.7	0.42	142.1	7.6	44.6	14.6

M: Mean; SD: Standard deviation.

developmental sequences are normally categorised based on their modal level, children performed five trials of the throw and standing long jump in order to provide adequate trials to assess modal levels (Stodden et al., 2006a, 2006b). Due to the level of specificity required to score developmental sequences, it was not possible to use less than five trials to accurately assess performance of each skill. To be consistent with the number of trials assessed for the TGMD-2 and GSGA and satisfy the necessity of a modal level of component sequences, the two standing long jump and throwing trials scored for the TGMD-2 and GSGA were the two trials with the highest speed and longest jump distance. These trials were also consistent with the highest modal level trials for each component of each skill. Children hopped approximately 5 m on each foot twice, thus satisfying requirements for all assessments. These procedures also ensured that the same trials were being used for all four assessments. While the GSGA typically involves children completing five trials, for the purpose of this study two trials (as mentioned earlier) were used for scoring to modify the procedures to be consistent with the TGMD-2 and the product assessment (i.e., Maximum standing long jump and hop distance and throwing speed).

For the TGMD-2 and GSGA, each skill was evaluated on performance criteria for the selected trials. A score of zero was given for each trial if a criterion was not performed. A score of one was given for each trial if a criterion was performed. Developmental sequence levels were evaluated based on the specific qualitative coordination pattern level that was demonstrated for each component of each skill. The number of levels ranges from 3 to 5 per component depending on the specific component for each skill (Clark & Phillips, 1985; Roberton & Halverson, 1984, 1988). See Table 2 for criteria descriptions of the standing long jump, hop and throw on the TGMD-2, GSGA and developmental sequences.

Maximum standing long jump distance (i.e., distance from the take-off line to the back of the closest heel on landing) was assessed as a percentage of children's height (Stodden, Gao, Goodway, & Langendorfer, 2014). Maximum throwing

Table 2. Criteria descriptions for each process-oriented assessment.

Standing long jump		
TGMD-2	GSGA	DevSeq
(1) Preparatory movement includes flexion of both knees with arms extended behind body (2) Arms extend forcefully forward and upward reaching full extension above the head (3) Take off and land on both feet simultaneously (4) Arms are thrust downward during landing	(1) Eyes focused forward or upward throughout the jump (2) Crouches with knees bent and arms behind the body (3) Forceful forward and upward swing of the arms (4) Legs straighten in the air (5) Lands on balls of the feet and bends knees to absorb landing (6) Controlled landing with no more than one step in any direction	Leg Action Component (1) Stepping out; a one-footed take-off (2) Knee extension precedes heels up (3) Knee extension and heels up simultaneously (4) Knee extension follows heels up Arm Action Component (1) No arm action (2) Shoulder flexion only (3) Incomplete biphasic arm action (4) Complete biphasic arm action
Hop		
(1) Nonsupport leg swings forward in pendular fashion to produce force (2) Foot of nonsupport leg remains behind body (3) Arms flexed and swing forward to produce force (4) Takes off and lands three consecutive times on preferred foot (5) Takes off and lands three consecutive times on non-preferred foot	(1) Support leg bends on landing, then straightens to push off (2) Lands and pushes off on the ball of the foot (3) Non-support leg bent and swings in rhythm with the support leg (4) Head stable, eyes focused forward throughout the jump (5) 5. Arms bent and swing forward as support leg pushes off	Leg Action Component (1) Momentary flight (2) Flight 2. Fall and catch; swing leg inactive (3) Projected takeoff; swing leg assists (4) Projection delay; swing leg leads Arm Action Component (1) Bilateral inactive (2) Bilateral reactive (3) Bilateral assist (4) Semi-opposition (5) Opposing assist
Throw		
(1) Windup is initiated with downward movement of hand/arm (2) Rotates hip and shoulders to a point where non-throwing side faces the wall (3) Weight is transferred by stepping with the foot opposite the throwing hand (4) Follow-through beyond ball release diagonally across the body towards the non-preferred side	(1) Eyes focused on target area throughout the throw (2) Stands side-on to target area (3) Throwing arm moves in a downward and backward arc (4) Steps towards target area with foot opposite throwing arm (5) Hips then shoulders rotate forward (6) Throwing arm follows through, down and across the body	Trunk Component (1) No trunk action or forward–backward movements (2) Upper trunk rotation or total trunk "block" rotation (3) Differentiated rotation Humerus Component (1) Humerus oblique (2) Humerus aligned but independent (3) Humerus lags Forearm Component (1) No forearm lag (2) Forearm lag (3) Delayed forearm lag

speed was calculated using a radar gun (Stalker, Inc.) (Stodden et al., 2006a, 2006b). Hop distance as a percentage of children's height was assessed using Dartfish (Dartfish Motion Analysis Corporation, Marietta, GA). Hop distance was calculated based on a child's ability to hop at least three times in a row on each leg for at least one of the two trials on that foot. Average hop distance (i.e., distance from heel to heel) was calculated based on the average of a minimum of three hops for each foot.

Two researchers with prior training and experience in analysing TGMD-2 and GSGA performances coded all of the data for these two assessments using the same video recordings for the children's standing long jump, hop and throw performances. Inter- and intra-rater agreement (>90%) for the GSGA and TGMD was established prior to formal data coding using the ratio of agreements/disagreements × 100 to establish a percentage of agreement. Inter- and intra-rater reliability was established on 10% of the data set. That is, each rater double coded 10% of data to determine intra-rater reliability and every rater coded the same 10% of data to determine inter-rater reliability. One researcher with training and expertise coded all the developmental sequence data. Intra-rater reliability was established (>90%) on 10% of the developmental sequence data.

Data analysis

Raw scores of standing long jump, hop and throw performances on each assessment were used for all analyses. Spearman's Rho correlations were calculated to compare performances between process- and product-oriented assessments of the standing long jump, hop and throw. Spearman's Rho correlations and Cochran's *Q* tests were conducted to compare performances between three process-oriented assessments of the standing long jump, hop and throw. Strength of correlations is interpreted as defined by Cohen (1988): 0.10–0.29 = low; 0.30–0.49 moderate; 0.50 and above = strong. Spearman's Rho correlations (non-parametric) have been used in previous research to compare performances between FMS assessments (Logan, Robinson, Rudisill, Wadsworth, & Morera, 2014; Logan, Robinson, et al., 2011; Valentini et al., 2015).

An additional analysis for examining agreement between process-oriented assessments included categories of skilfulness that were defined for each skill: mastery (all criteria of a skill demonstrated), near mastery (all but one criterion of a skill demonstrated) and non-mastery (more than one criterion of a skill not demonstrated). This classification is based on a previous method for the Get Skilled; Get Active assessment (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009). For example, the maximum raw score for two trials on the TGMD-2 for the hop is 10. A score of 10, 8–9 and 7≤ were classified as mastery, near mastery and non-mastery, respectively. Near mastery was defined with a score of 8 or 9 because a child could demonstrate all but one criterion of the hop on each trial. The same procedures were used for the GSGA and developmental sequences (DevSeq). Then, near mastery and mastery classifications were combined to form a category of "advanced skilfulness". Cochran's *Q* tests were calculated for each specific skill to determine if the TGMD-2, GSGA and DevSeq were equally effective in classifying skill level as advanced or non-mastery. Cochran's *Q* is a non-parametric test for repeated measures of a binary variable (i.e., advanced vs. non-mastery). *Post hoc* pairwise comparisons were calculated as appropriate.

Results

Correlations

Table 3 presents Spearman's Rho correlations, calculated to compare performances between process- and product-oriented assessments on the standing long jump, hop and throw. All correlations were statistically significant for the standing long jump ($P < .05$; $r = .26$–$.65$) with the exception of the GSGA and DevSeq to product scores for the 7–8 year olds. Correlations between assessments for the standing long jump were classified as moderate except for the TGMD-2 to product scores ($r = .26$).

All correlations were statistically significant for the hop ($P < .05$; $r = .41$–$.88$) with the exception of the TGMD-2 to product scores for the 10–11 year olds. Correlations between assessments in hopping were moderate (7–8 year olds; 10–11 year olds) and strong (4–5 year olds).

All correlations were statistically significant for the throw ($P < .05$; $r = .29$–$.71$). Correlations between assessments in throwing generally were low (4–5 year olds), moderate (7–8 year olds) and strong (10–11 year olds) across age groups. Specifically, when comparing the product assessment to the three process assessments, developmental sequences generally demonstrated stronger correlations with product scores when compared with the TGMD (six of nine comparisons were higher across age groups). The GSGA also generally demonstrated stronger correlations with product scores (five of nine comparisons) when compared to the TGMD. The TGMD demonstrated the strongest relationship to product scores on only one of nine comparisons (standing long jump in 7–8 year olds).

Spearman's Rho correlations were calculated to compare performances between process-oriented assessments on the standing long jump, hop and throw (See Table 4). All correlations were statistically significant for the standing long jump ($P < .05$; $r = .37$–$.57$) with the exception of the TGMD-2 to GSGA

Table 3. Spearman's Rho correlations between process and product scores.

	Age group		
Skill	4–5 year olds	7–8 year olds	10–11 year olds
Jump		Product	
TGMD-2	.46**	.26*	.47**
GSGA	.53**	0.17	.41**
DevSeq	.56**	0.17	.65**
Hop		Product	
TGMD-2	.65**	.41**	0.25
GSGA	.88*	.48**	.47**
DevSeq	.76**	.56**	.59**
Throw		Product	
TGMD-2	.30*	.47**	.62**
GSGA	.29*	.45**	.71**
DevSeq	.31*	.46**	.71**

* and ** indicate significance at the .05 and .01 levels, respectively.

Table 4. Spearman's Rho correlations between process scores.

	Age group					
	4–5 year olds		7–8 year olds		10–11 year olds	
Skill	TGMD-2	GSGA	TGMD-2	GSGA	TGMD-2	GSGA
Jump						
TGMD-2	1		1		1	
GSGA	.50**	1	.48**	1	0.17	1
DevSeq	.51**	.53**	.55*	.37**	.57**	.47**
Hop						
TGMD-2	1		1		1	
GSGA	.68**	1	.51**	1	.47**	1
DevSeq	.59**	.79**	.47**	.50**	0.17	.48**
Throw						
TGMD-2	1		1		1	
GSGA	.59**	1	.66**	1	.70**	1
DevSeq	.52**	.48**	.42**	.37**	.60**	.67**

* and ** indicates significance at the .05 and .01 levels, respectively.

for the 10–11 year olds. Correlations between assessments for the standing long jump were moderate across age groups.

All correlations were statistically significant for the hop ($P < .05$; $r = .47–.79$), with the exception of the TGMD-2 to DevSeq in 10–11 year olds. Correlations between assessments for hopping were moderate (7–8 year olds; 10–11 year olds) and strong (4–5 year olds).

All correlations were statistically significant for the throw ($P < .05$; $r = .37–.70$). Correlations between assessments for throwing were moderate (4–5 year olds), moderate to strong (7–8 year olds) and strong (10–11 year olds).

Cochran's Q tests

A Cochran's *Q* test revealed that assessments were not equal in classifying advanced and non-mastery skill levels of the standing long jump ($Q(2) = 14.1$, $P < .01$). Pairwise comparisons revealed a significant difference between the TGMD-2 and DevSeq ($P < .01$). The TGMD-2 classified a greater number of children as advanced for the standing long jump compared to DevSeq (see Figure 1).

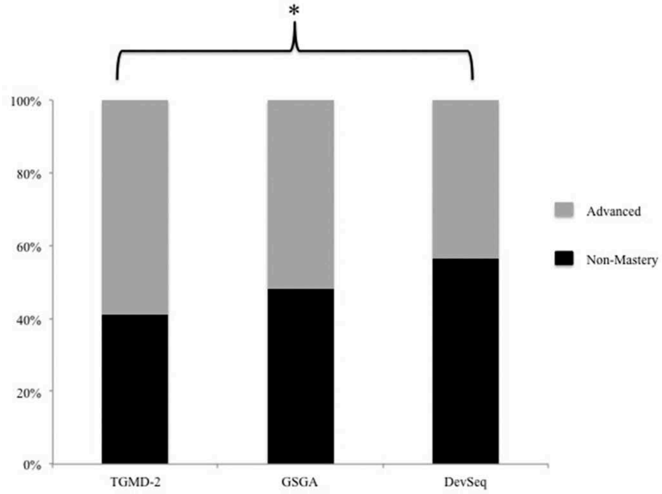

Figure 1. Percentage of advanced and non-mastery skill classifications on the TGMD-2, GSGA and DevSeq for the standing long jump. * Indicates a significant difference between the TGMD-2 and DevSeq.

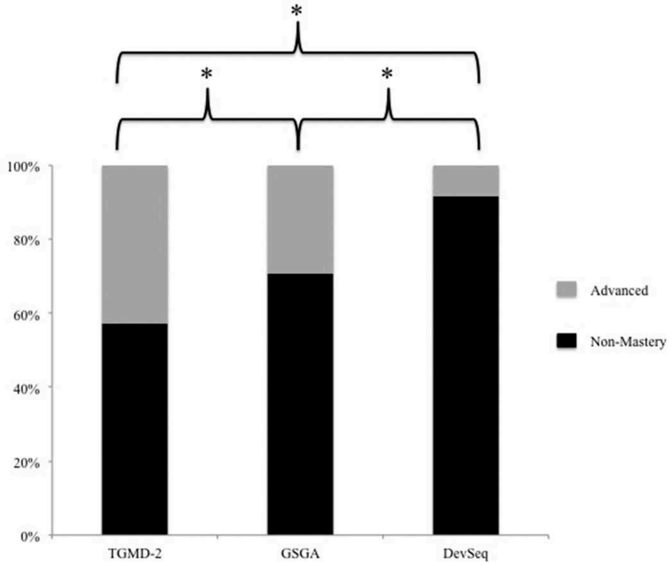

Figure 2. Percentage of advanced and non-mastery skill classifications on the TGMD-2, GSGA and DevSeq for the hop. * Indicates a significant difference between each assessment.

A Cochran's *Q* test revealed that assessments were not equal in classifying advanced and non-mastery skill levels of hopping ($Q(2) = 67.2$, $P < .001$). Pairwise comparisons revealed significant differences between the TGMD-2, GSGA and DevSeq ($P < .01$). The TGMD-2 classified the greatest number of children as advanced for hopping while DevSeq classified the least children as advanced (see Figure 2).

A Cochran's *Q* test also revealed assessments were not equal in classifying advanced and non-mastery skill levels of throwing ($Q(2) = 100.2$, $P < .001$). Pairwise comparisons revealed significant differences between the TGMD-2 and GSGA ($P < .001$) and between the TGMD-2 and DevSeq ($P < .001$). The TGMD-2 classified the greatest number of children as advanced for throwing compared to the GSGA and DevSeq (see Figure 3).

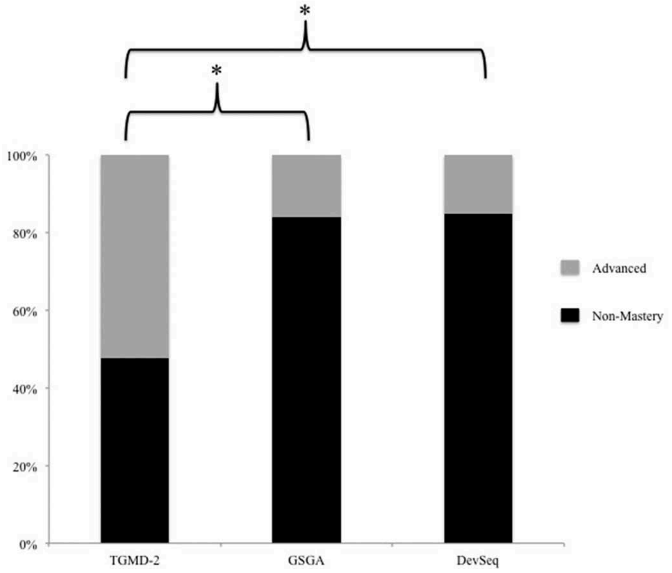

Figure 3. Percentage of advanced and non-mastery skill classifications on the TGMD-2, GSGA and DevSeq for the throw. * Indicates a significant differences between the TGMD-2 and GSGA and the TGMD-2 and DevSeq.

Discussion

The first purpose of the current study was to compare process- and product-oriented assessments of the standing long jump, hop and throw across three age groups. Our results generally indicate moderate to strong correlations between the process- and product-oriented assessments across skills and age groups (*r* range = .26–.88). For the standing long jump and hopping, there was a decrease in strength of correlations between 4–5 year olds and the 7–8 year olds with standing long jump demonstrating weak or non-significant relationships at 7–8 years. Jumping again demonstrated moderate to strong associations for 10–11 year-olds. Hopping correlations decreased from strong to moderate as children's ages increased. For the throw, there was an increase in strength of correlations across age groups. The decreased strength of correlations in the standing long jump and hop between the two younger age groups may be a combined function of the global increase of locomotor skill movement pattern development in this age group that was facilitated by the increase in consistent movement-related experiences specific to this sample. The 4–5-year-old children in this sample had not received daily physical education in their preschool classes, but the 7–8-year-old children had two years of daily physical education for 30 min · day^{-1}. The physical education curriculum in both elementary schools was focused on developing FMS and fitness. While only speculative, noted changes (i.e., improvements) in coordination patterns of these types of complex skills (i.e., ballistic in nature), as assessed by limited number of qualitative movement levels, may not necessarily lead to changes in outcome variables (i.e., speed or distance). For example, an increase in an ordinal level of a component (i.e., developmental sequences) or being able to note the "presence of a characteristic" (i.e., TGMD and GSGA) will not necessarily capture biomechanical variables (e.g., relative timing, increased segmental angular velocities) or the exploitation of neuromuscular mechanisms (e.g., stretch shortening cycle, recovery of elastic potential) that are critical for increases in performance (Stodden & Rudisill, 2006; Stodden et al., 2006a, 2006b, 2014). Essentially, limitations of qualitative assessments to adequately capture certain aspects of "coordination" may be reflective of an increase in a qualitative assessment value without an immediate and concomitant quantitative performance improvement. Another potential reason for the correlations in the locomotor skills being less strong in the older age category is a potential ceiling effect with the TGMD-2, which is another limitation of many qualitative assessments. The instrument is only recommended through age 10 and according to the normed values it is clear that as children reach this age, scoring levels out towards maximum values (Ulrich, 2000).

In contrast, strength of correlations in throwing increased across age groups. This could be due to the complex organisation of segmental interactions associated with the kinetic chain in object control skills, such as throwing. The realisation of an increased ball speed associated with changes in kinematics, kinetics and relative timing aspects of the movement pattern may not be realised with less discriminating process-oriented assessments (Stodden et al., 2006a, 2006b). Furthermore, for girls at least, there does not appear to be a ceiling effect for object control skills as assessed by the TGMD-2 (Ulrich, 2000).

No clear pattern emerged in the strength of associations between process-oriented assessments across skills or age groups. For example, for 10–11 year olds, the highest correlations include: between the TGMD-2 and developmental sequences (standing long jump, .57); between the GSGA and developmental sequences (hop, .48) and between the TGMD-2 and GSGA (throw, .70). When examining comparisons between process and product assessments and among the process assessments, these data would seem to suggest that any one of the three process-oriented assessments would be as equally effective in assessing levels of skilfulness. However, when examining data based on the second set of analyses (i.e., second purpose of the study), a more clear understanding of the predictive utility of the three different process assessments emerges.

The second purpose of the current study was to determine the agreement in the capacity of process-oriented assessments to classify advanced and non-mastery levels of skilfulness. Our results indicate that in general, sensitivity to detect advanced skill level is lowest for TGMD-2 and highest for developmental sequences for all three skills. This is an intuitive result since the TGMD-2 has the least number of performance criteria while developmental sequences have the most. In addition, developmental sequences also generally demonstrated higher correlations with product scores compared to the TGMD-2 (six of nine comparisons across age groups), which suggests sequences have stronger predictive utility with product scores across developmental time than the TGMD-2. The demonstrated cross-sectional and longitudinal validity of developmental sequences provides additional rationale to explain why the sequences may be more strongly linked to product scores than the TGMD-2 (Roberton & Halverson, 1984, 1988). The GSGA also demonstrated higher correlations on five of nine product-process comparisons across age groups. Thus, the capability to discriminate among different levels of skilfulness may be best assessed using developmental sequences or the GSGA assessments. However, it is important to note that the GSGA assessment includes five trials, not two trials, and therefore it was not administered according to protocol. The discriminative ability of the GSGA may have increased even further if all five trials were used. Increased discrimination capabilities of MC assessments are becoming increasingly important, specifically when attempting to link the level or development of MC to other constructs such as health-related or cognitive variables.

From a practical and research perspective, there is a trade-off in terms of more performance criteria and the amount of time and therefore cost involved to analyse video recordings of skill performance. Based on the authors' experiences with coding all three process assessments, individual skill performances on the TGMD-2 and GSGA generally can be completed in less time than developmental sequences when analysing an equal number of skills. In addition, the TGMD-2 (12 skills) and GSGA (12 skills) have scoring procedures for many skills, whereas only three skills (jump, hop, throw) have validated developmental sequences. Thus, development of additional validated sequences is important to provide a more comprehensive view of FMS competence and how performances across assessments are related.

It is always important for a researcher to choose an assessment based on the research question. The GSGA seems to be an appropriate process-oriented assessment to use for typically developing children, as it had some capacity to detect advanced skilfulness and appears to be more closely aligned with product scores than the TGMD-2. The full GSGA assessment also has a broad range of skills and includes static balance, vertical jump, sprint run, catch, hop, leap, side gallop, kick, skip, two-hand strike, overarm throw and the dodge (i.e., an agility skill), although subscales are not identified for types of skills. However, even though it is a well-utilised instrument in Australia (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Hardy, Barnett, Espinel, & Okely, 2013), aside from one publication on inter-rater reliability (Barnett, van Beurden, Morgan, Lincoln, et al., 2009), no previous validity, test retest reliability or normative scores have been published in regard to the GSGA. Based on the current study, the GSGA appears to have discriminant and convergent validity and thus further research is warranted to determine reliability and establish normative scores.

One of the primary purposes of the TGMD-2 is for the identification and screening of children delayed in demonstrating FMS competence. Although the TGMD-2 is less capable of discriminating advanced skill levels, its capability to identify developmental delay is consistent with other assessment batteries with the same purpose (Logan et al., 2014; Valentini et al., 2015).

In conclusion, the results of the present study generally demonstrate moderate to strong correlations across process- and product-oriented assessments of the standing long jump, hop and throw across three age groups. The use of developmental sequences may be most informative when attempting to determine advanced levels of skilfulness within those three skills; however, the feasibility of only assessing three skills is problematic from a research standpoint. Also, practitioners and researchers may not be well trained on coding developmental sequences and/or do not have access to Dartfish software which further decreases feasibility of this approach. The GSGA may be a more attractive alternative than the TGMD-2 based on its convergent validity against both process and product assessments. As suggested by other authors, we support the use of both process- and product-oriented assessments when including motor competence as a dependent variable of interest (Robinson et al., 2015; Rudd et al., 2016). Of course, it is always import to keep in mind the purpose of assessment and there may be a rationale for choosing one assessment over another. Considerations of time, effort, cost and level of expertise required all contribute to choice of assessment.

Based on the variability in correlations among assessments, it appears that FMS process- and product-oriented assessments, although related, provide different information with regard to competence levels. By including both types of assessments, it allows researchers to more fully understand and delineate how MC relates to other variables. Overall, there is a need for a MC assessment that measures both process- and product-oriented outcomes. One such assessment (in the form of an obstacle course) has been recently developed in Canada (Longmuir et al., in press) and found to be feasible in an Australian Physical Education setting (Lander, Morgan, Salmon, & Barnett, 2015). An assessment that measures process- and product-oriented outcomes will potentially provide researchers with one assessment that captures multiple salient descriptors of MC, although it remains to be seen how this new assessment compares existing skill assessments. Accurate and comprehensive assessment of MC is becoming increasingly important as it will provide researchers with a better understanding of the relationship between MC levels and health outcomes.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was funded by the National Institutes of Health [grant number R21HD055621-01A2].

References

Barnett, L. M., van Beurden, E., Morgan, P. J., Brooks, L. O., & Beard, J. R. (2009). Childhood motor skill proficiency as a predictor of adolescent physical activity. *Journal of Adolescent Health*, *44*(3), 252–259. doi:10.1016/j.jadohealth.2008.07.004

Barnett, L. M., van Beurden, E., Morgan, P. J., Lincoln, D., Zask, A., & Beard, J. R. (2009). Interrater objectivity for field-based fundamental motor skill assessment. *Research Quarterly for Exercise and Sport*, *80*(2), 363–368. doi:10.1080/02701367.2009.10599571

Cattuzzo, M. T., Henrique, R. S., Re, A. H., Oliveira, L. S., Melo, B. M., Moura, M. D., … Stodden, D. (2015). Motor competence and health related physical fitness in youth: A systematic review. *Journal of Science and Medicine in Sport*, *19*(2), 123–129.

Clark, J. E. (1994). Motor development. In V. S. Ramachandran (Ed.), *Encyclopedia of human behavior* (3rd ed., pp. 245–255). New York, NY: Academic Press.

Clark, J. E., & Metcalfe, J. S. (2002). The mountain of motor development: A metaphor. In J. E. Clark & J. H. Humphrey (Eds.), *Motor development: Research and review* (Vol. 2, pp. 62–95). Reston, VA: National Association for Sport and Physical Education.

Clark, J. E., & Phillips, S. J. (1985). A developmental sequence of the standing long jump. In J. E. Clark & J. H. Humphrey (Eds.), *Motor development: Current selected research* (pp. 73–85). Princeton, NJ: Princeton Book.

Clark, J. E., Phillips, S. J., & Peterson, R. (1989). Developmental stability in jumping. *Developmental Psychology*, *25*(6), 929–935. doi:10.1037/0012-1649.25.6.929

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillside: Erlbaum.

Fountain, C., Ulrich, B., Haubenstricker, J., & Seefeldt, V. (1981, March). *Relationship of developmental stage and running velocity in children 2.5 to 5 years of age*. Paper presented to the Midwest District Convention of the American Association for Health, Physical Education, Recreation, and Dance, Chicago, IL.

Hardy, L. L., Barnett, L. M., Espinel, P., & Okely, A. D. (2013). Thirteen-year trends in child and adolescent fundamental movement skills: 1997–2010. *Medicine & Science in Sports & Exercise*, *45*(10), 1965–1970. doi:10.1249/MSS.0b013e318295a9fc

Haubenstricker, J. L., & Branta, C. F. (1997). The relationship between distance jumped and developmental level on the standing long jump in young children. In J. Clark & J. Humphrey (Eds.), *Motor development: Research and reviews* (Vol. 1, pp. 64–85). Reston, VA: National Association for Sport and Physical Education.

Haywood, K. M., & Getchell, N. (2009). *Lifespan motor development* (5th ed.). Champaign, IL: Human Kinetics.

Lander, N. J., Morgan, P. J., Salmon, J., & Barnett, L. M. (2015). Teachers' perceptions of a fundamental movement skill (FMS) assessment battery in a school setting. *Measurement in Physical Education and Exercise Science*, *20*(1), 1–13. doi:10.1080/1091367X.2015.1095758

Langendorfer, S. J., Roberton, M. A., & Stodden, D. F. (2011). Chapter 9: Biomechanical aspects of the development of object projection skills. In D. S. C. Korff (editor), *Paediatric biomechanics and motor control: Theory and application*. Oxford: Routledge.

Logan, S. W., Robinson, L. E., & Getchell, N. (2011). The comparison of performances of preschool children on two motor assessments. *Perceptual and Motor Skills*, *113*(3), 715–723. doi:10.2466/03.06.25.PMS.113.6.715-723

Logan, S. W., Robinson, L. E., Rudisill, M. E., Wadsworth, D., & Morera, M. (2014). The comparison of school-age children's performance on two motor assessments: The Test of Gross Motor Development and the Movement Assessment Battery for Children. *Physical Education & Sport Pedagogy*, *19*(1), 48–59. doi:10.1080/17408989.2012.726979

Logan, S. W., Scrabis-Fletcher, K., Modlesky, C., & Getchell, N. (2011). The relationship between motor skill proficiency and body mass index in preschool children. *Research Quarterly for Exercise and Sport*, *82*(3), 442–448. doi:10.1080/02701367.2011.10599776

Logan, S. W., Webster, E. K., Robinson, L. E., Getchell, N., & Pfieffer, K. A. (2015). The relationship between motor competence and physical activity engagement during childhood: A systematic review. *Kinesiology Review*, *4*, 416–426. doi:10.1123/kr.2013-0012

Longmuir, P. E., Boyer, C., Lloyd, M., Borghese, M. M., Knight, E., Saunders, T. J., … Tremblay, M. S. (in press). Canadian agility and movement skill assessment of motor skill: Validity, objectivity and reliability evidence for children 8 to 12 years of age. *Journal of Sport and Health Science*. Advance online publication. doi:10.1016/j.jshs.2015.11.004.

Lubans, D. R., Morgan, P. J., Cliff, D. P., Barnett, L. M., & Okely, A. D. (2010). Fundamental movement skills in children and adolescents: Review of associated health benefits. *Sports Medicine*, *40*(12), 1019–1035. doi:10.2165/11536850-000000000-00000

New South Wales Department of Education and Training. (2000). *Get skilled: Get active*. (DET Product number: 10614/DVD). Sydney: Author.

Roberton, M. A., & Halverson, L. E. (1984). *Developing children – Their changing movement: A guide for teachers*. Philadelphia, PA: Lea & Febiger.

Roberton, M. A., & Halverson, L. E. (1988). The development of locomotor coordination: Longitudinal change and invariance. *Journal of Motor Behavior*, *20*(3), 197–241. doi:10.1080/00222895.1988.10735443

Roberton, M. A., & Konczak, J. (2001). Predicting children's overarm throw ball velocities from their developmental levels in throwing. *Research Quarterly for Exercise and Sport*, *72*(2), 91–103. doi:10.1080/02701367.2001.10608939

Robinson, L. E., Stodden, D. F., Barnett, L. M., Lopes, V. P., Logan, S. W., D'Hondt, E., & Rodrigues, L. P. (2015). Motor competence and its effect on positive developmental trajectories of health. *Sports Medicine*, *45*(9), 1273–1284. doi:10.1007/s40279-015-0351-6

Rudd, J., Butson, M. L., Barnett, L., Farrow, D., Berry, J., Borkoles, E., & Polman, R. (2016). A holistic measurement model of movement competency in children. *Journal of Sports Sciences*, *34*(5), 477–485. doi:10.1080/02640414.2015.1061202

Stodden, D. F., Gao, Z., Goodway, J. D., & Langendorfer, S. J. (2014). Dynamic relationships between motor skill competence and health-related fitness in youth. *Pediatric Exercise Science*, *26*(3), 231–241. doi:10.1123/pes.2013-0027

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest*, *60*, 290–306. doi:10.1080/00336297.2008.10483582

Stodden, D. F., Langendorfer, S. J., Flesig, G. S., & Andrews, J. R. (2006a). Kinematic constraints associated with the acquisition of overarm throwing part I: Step and trunk actions. *Research Quarterly for Exercise and Sport*, *77*(4), 417–427.

Stodden, D. F., Langendorfer, S. J., Flesig, G. S., & Andrews, J. R. (2006b). Kinematic constraints associated with the acquisition of overarm throwing part II: Upper extremity actions. *Research Quarterly for Exercise and Sport*, *77*(4), 428–436.

Stodden, D. F., & Rudisill, M. E. (2006). Integration of biomechanical and developmental concepts in the acquisition of throwing: Effects on developmental characteristics and gender differences. *Journal of Human Movement Studies*, *51*, 117–141.

Ulrich, D. A. (2000). *Test of gross motor development* (2nd ed.). Austin, TX: PRO-ED.

Valentini, N., Getchell, N., Logan, S. W., Liang, L., Golden, D., Rudisill, M. E., & Robinson, L. E. (2015). Exploring associations between motor skill assessments in children with, without, and at-risk for developmental coordination disorder. *Journal of Motor Learning and Development*, *3*(1), 39–52. doi:10.1123/jmld.2014-0048