

Examining the Feasibility of Supine-to-Stand as a Measure of Functional Motor Competence

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A person's ability to rise from the floor to a standing position is seen as a precursor for establishing and maintaining bipedal independence. It also is an important primer for the development of other fundamental movement skills and is associated with functional capacity in later life. Thus, the potential importance of developing this movement capability early in life and understanding how it may relate to global function (i.e., motor competence [MC]) across the lifespan may be underestimated. Therefore, this study examined the validity of supine-to-stand test (STS) as a developmental measure of functional MC across childhood into young adulthood using a pre-longitudinal screen approach and examining associations between movement components. STS time also provided a secondary measure of developmental validity in addition to an examination of the concurrent validity of STS against developmentally valid measures of MC (i.e., throwing, kicking, hopping, and standing long jump) in these age groups. Overall, results indicated that cross-sectional data "curves" for the STS components generally fit Robertson's hypothetical model curves. STS time demonstrated weak to moderate ($r = -.28$ to $-.64$) correlations to MC product measures across all age groups indicating that STS time can be considered a valid and reliable measure of MC across childhood into young adulthood.

Keywords: motor development, motor performance

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Motor competence (MC) is defined as the degree of skilled performance in a wide range of motor tasks (Stodden et al., 2008). Recent research emphasizes that the acquisition and maintenance of MC from early childhood into adulthood is a key component to living a healthy and active lifestyle (Robinson et al., 2015), specifically related to health-related fitness (Cattuzzo et al., 2016), physical activity (Lubans, Morgan, Cliff, Barnett, & Okley, 2010; Logan, Barnett, Goodway, & Stodden, 2016; Holfelder & Schott, 2014) and weight status (Cattuzzo et al., 2016). Research also suggests that MC is both a precursor and a consequence of weight status (Robinson et al., 2015). However, different assessments have been used to evaluate MC and its association to various aspects of health across the lifespan, making it difficult to track its potential impact across time. For example, many popular MC assessments used in childhood and adolescent populations have been designed to detect developmental delay and/or are only applicable up to a certain age (e.g., TGMD-2, M-ABC, BOT, and KTK). These assessments vary dramatically by the type of MC (e.g., gross vs. fine, fundamental movement skills vs. global coordination,) and what aspects of MC they are measuring (e.g., process vs. product, object control vs. locomotor). Thus, the design and intent of these various assessment protocols make it difficult to track changes in motor competence across time, particularly into adulthood.

Similar to MC measures used in children and adolescents, common measures of “functional capacity,” as assessed in aging populations, can be viewed as measures of MC (i.e., walking speed, supine-to-stand, timed up and go, etc.) (Corsonello et al., 2012; Rikli & Jones, 2001; Volpato et al., 2011). In essence, functional capacity assessments measure gross coordination and control, which can be defined as the capability of an individual to coordinate and control their center of mass and extremities in a gravity-based environment to effectively complete a goal (Stodden, Langendorfer, & Robertson, 2009). Tests within these batteries are linked to health outcomes, physical independence, mortality, and overall quality of life (Corsonello et al., 2012; Rikli & Jones, 2001; Smees, Anson, Waddington, & Berry, 2012; Volpato et al., 2011). Similar to the limitations of youth assessments, functional capacity measures are used only in adult, mostly elderly, populations and make it difficult to track changes across time.

In contrast to the many youth MC assessments, component developmental sequences have been used to assess changes in movement coordination patterns in fundamental movement skills (e.g., throwing, jumping and hopping) across the lifespan (Halverson, Robertson, & Langendorfer, 1982; Haubenstricker & Branta, 1997; Horton & Lipsitz, 2001; Lorson, Stodden, Goodway, & Langendorfer, 2013; Robertson & Konczak, 2001; Stodden, Langendorfer, Fleisig, & Andrews, 2006a, 2006b; VanSant, 1988a, 1988b, 1990; Williams, Haywood, & VanSant, 1991, 1998). Developmental sequences are useful across a wide age range as they were developed to address progression and regression across the lifespan (Halverson et al., 1982; Robertson, Williams, & Langendorfer, 1980; VanSant, 1988a, 1988b, 1990; Williams et al., 1991). However, the relationship of developmental sequences to health-related variables across the lifespan is limited (Lorson et al., 2013; Vansant, 1988a, 1988b; Williams et al., 1991).

The lack of MC measures that have been assessed across the lifespan has created a void in understanding not only how movement development occurs, but also in how it relates to health across various ages. Thus, it is logical and necessary

to identify developmentally valid and reliable motor competence assessments that can be effectively implemented across various age groups. The supine-to-stand test (STS) is one such test that may be a feasible option to test across the lifespan as the ability to independently rise from the ground is demonstrated throughout life (e.g., regaining an upright posture after a fall) and is a major precursor for establishing and maintaining bipedal physical independence (Bayley, 1936; VanSant, 1998). The time to stand from a supine position has been used as a clinically-based assessment for functional capacity and health in the elderly populations (Bohannon & Lusardi, 2004; Green & Williams, 1992; King & VanSant, 1995; VanSant, 1988a) and STS component developmental sequences have been examined in children to test for disability (e.g., Prader-Willi, muscular dystrophy, etc.) (Belt et al., 2001; Ng, Conway, Rigby, Priestman, & Baxter, 2013; Unrau, Hanrahan, & Pitetti, 1994). Thus, as STS would seem to have adequate face validity as a potential lifespan measure of MC, its potential value as a stand-alone assessment is appealing if its movement and performance properties demonstrate adequate developmental validity.

To initially understand developmental patterns of rising from a supine position, VanSant and colleagues conducted three different cross-sectional studies and described movement patterns in toddlers, children, and young adults. Overall, participants in the three different age groups demonstrated mostly similar types of movement patterns, although there were a few different movement descriptors noted across age. These data provided a snapshot of movement categories and potential progression in normally developing individuals (Marsala & VanSant, 1998; VanSant 1988a, 1988b). Component categories were divided into actions of three body regions: upper extremities (UE), axial region (AX), and lower extremities (LE). More advanced movements generally were demonstrated as individuals increased in age with the most advanced movements occurring during the teenage years (VanSant, 1990). Results also demonstrated that both young children and adults use asymmetrical movement patterns to maintain balance (e.g., rotating their trunk to the side and kneeling) when standing, whereas adolescents and young adults demonstrated more symmetrical movements (e.g., the head and trunk flex forward, with or without a slight degree of rotation) when rising from the floor (VanSant, 1990).

As described in the previous section, the use of descriptive categories (process-oriented measures) is important to understand how movement development occurs (i.e., the quality of movement); however, the association of these movements to the time it takes to stand has only been examined in childhood (Duncan, Lawson, Walker, Stodden, & Eyre, 2017; Nesbitt et al., 2017). Time to stand from a supine position is important because the ability to rise from the floor quickly demonstrates more effective control of coordinated body segment movements (i.e., increased functional capacity). Time to stand has been validated as a reliable measure of functional capacity for older adults (Alexander, Ulbrich, Raheja, & Channer, 1997; Bohannon & Lusardi, 2004; Hofmeyer, Alexander, Nyquist, Medell, & Koreishi, 2002; Schenkman, Morey, & Kuchibhatla, 2000; Ulbrich, Raheja, & Alexander, 2000) and is a predictor of morbidity and fall-related injuries in aging populations (Alexander et al., 1997). However, limited data are available on the time to stand in healthy children or young adults (Alexander et al., 1997; Duncan et al., 2017; Nesbitt et al., 2017; Ng et al., 2013). Ng et al. (2013) found that the average time it took to stand for healthy children was 2.08 seconds, although the average STS time

was averaged among all individuals with only two trials and the descriptive categories used to identify movement patterns were not validated developmentally. Duncan et al. (2017) examined the relationship between STS time and STS movement patterns, using validated sequences, to measures of MC (10 m running speed and standing long jump) in 5 to 9 year olds; however, the time it took to stand and the developmental sequence data were not provided. In addition, two studies have compared STS time of healthy young adults to older adults demonstrating that younger adults stood up twice as fast as their healthy older counterparts and three times as fast as their community dwelling counterparts (Alexander et al., 1997; Ulbrich et al., 2000). Although time to stand was assessed for these adults, it was not compared to validated movement patterns. To our knowledge only two studies (Duncan et al., 2017; Nesbitt et al., 2017) have examined the relationship between movement patterns and the time it takes to rise from the floor. Results from a sample of preschool children (Nesbitt et al., 2017) suggest axial and upper extremity components may be highly constrained and serve as one functional unit to promote rising from a supine position. Results also indicate the ability to control and coordinate one's core (axial movement) in conjunction with their upper extremities produces movements that are more effective (higher component levels) for rising quickly, while LE may not be as critical in rising quickly. Examining STS movement patterns and time across additional age groups is needed to confirm these findings.

Based on the aforementioned limitations of current MC measures and the lack of adequate MC measures across the lifespan, STS seems to be a logical assessment to examine an individual's motor competence across the lifespan. However, the previously developed and adapted movement categories have not been tested via a prelongitudinal screen across multiple age groups. The STS test has the capability to track changes in motor development over time (i.e., progression and regression) and thus, will allow researchers to more effectively assess the relationship of MC to aspects of health and function across the lifespan.

The first purpose of this study is to examine the validity of STS as a developmental measure of functional MC across childhood, adolescence, and young adulthood using a pre-longitudinal screen approach (Robertson et al., 1980). Examining associations between movement pattern levels and STS time will provide a secondary measure of developmental validity. The second purpose is to examine the concurrent validity of STS (movement patterns and time) against developmentally valid (product and process) measures of object projection and locomotor skills (i.e., throwing, kicking, jumping and hopping) in these age groups.

Methods

Participants

A convenience sample ($N = 265$) of four specific age ranges from early childhood through young adulthood (3–6, 9–12, 13–17, and 18–25 years old) was recruited to participate in this study. These age groups were selected because they cover developmental stages of early childhood, middle-late childhood, adolescence and early adulthood. Equal numbers of boys and girls from each age range were recruited from local private and public schools and from a university in the southeast United States (see Table 1 for participant data). Prior to participation, the

Table 1 Participant Characteristics

Age Group	Total		Boys/Men		Girls/Women	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
3–6 yrs	<i>N</i> = 63		<i>n</i> = 33		<i>n</i> = 30	
Age (years)	4.8	0.9	4.9	0.9	4.6	0.8
Height (cm)	109.3	7.9	110.2	8.2	108.3	7.6
Mass (kg)	19.3	3.2	19.5	3.1	19.2	3.4
BMI	16.3	2.2	16.0	1.7	16.7	2.6
9–12 yrs	<i>N</i> = 74		<i>n</i> = 30		<i>n</i> = 44	
Age	10.0	0.8	10.1	0.7	10.0	0.9
Height	143.9	10.5	141.9	7.9	145.2	11.9
Mass	41.3	12.9	40.8	13.8	41.6	12.4
BMI	19.8	4.2	20.1	5.0	19.6	3.7
13–17 yrs	<i>N</i> = 53		<i>n</i> = 26		<i>n</i> = 27	
Age	14.9	0.9	14.7	0.9	15.0	1.0
Height	168.9	9.3	173.3	9.0	164.6	7.6
Mass	62.4	11.0	63.8	12.1	61.0	9.7
BMI	22.1	3.4	21.6	3.2	22.6	3.6
18–25 yrs	<i>N</i> = 79		<i>n</i> = 48		<i>n</i> = 31	
Age	20.9	2.0	21.0	2.0	20.7	2.0
Height	173.1	8.7	177.8	6.4	166.0	6.8
Mass	82.4	20.7	87.3	18.4	75.1	22.0
BMI	27.0	5.7	27.6	5.4	26.2	6.2

Note. *M* = mean; *SD* = standard deviation.

study was approved by the University's Human Subject Review Board and parental consent and verbal assent from all participants was obtained. Individuals with any physical disabilities or medical conditions that prevented them from completing testing were not included in this study.

Procedures and Measures

Prior to testing, individuals performed a general warm-up for each session that included a 3–5 minute jog, followed by static and dynamic stretching exercises. In addition, participants were given three minutes to complete specific warm up trials for each skill performed. Testing was completed in a gymnasium and/or designated outdoor area. Individuals completed testing on five skills (throwing, kicking, jumping, hopping, and STS) with performance of skills assessed via movement patterns (component developmental sequences) and outcomes (product scores). Each skill was performed at a different station and all skills were video recorded from the side view (Green & Williams, 1992; VanSant, 1988a, 1988b). Participants were instructed to perform with maximum effort, which produces the most advanced movement pattern of ballistic skills (Langendorfer, Robertson, & Stodden, 2013).

Participant's throwing, jumping, and hopping developmental sequences were analyzed and coded based upon previously established methods for these three skills (Robertson & Halverson, 1984, 1988; Clark & Phillips, 1985; Lane et al., 2017; Halverson & Williams, 1985; Robertson et al., 1980). As developmental sequences are normally categorized based on their modal level (Stodden et al., 2006a, 2006b), participants performed five trials for each discrete skill with the exception of the hop. Hopping is classified as a continuous skill with repeated movements that are assessed according to their cyclical movements. Therefore, two trials of hopping on each leg were assessed for each participant with movement patterns and average distance/hop, as a percentage of participants' height, coded and analyzed at a later time. Participants were instructed to hop on their right leg as fast as they can down and return using their opposite leg, allowing 5 feet for acceleration and deceleration, then repeat. If a participant could not demonstrate three consecutive hops on at least one trial a score of 0 was recorded and included in analyses. Maximum throwing and kicking speed (m/s) was calculated using a radar gun (Stalker, Inc.) (Stodden et al., 2006a, 2006b). 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 the participant's height (Stodden, Gao, Goodway, & Langendorfer, 2014). Average distance/hop was calculated using a minimum of three consecutive hops (4 touches; from weight bearing toe to toe) using Dartfish Video Analysis Software (version 7.0; Dartfish USA Inc., Alpharetta, GA).

STS was assessed by having participants start in a supine position with their hands by their side in a yoga mat and their feet in line with the edge of the mat. A "go" command prompted participants to stand as quickly as possible and touch a designated spot on the wall (relative to shoulder height). Time between trials was self-selected to minimize fatigue. STS was analyzed using an adapted version of the VanSant (1988a, 1988b) developmental movement categories. The adapted version was used in order to provide a comprehensive range of possible movement patterns for all age groups (see Table 2). Modal component developmental sequences for upper extremity (4), axial (5), and lower extremities (5) (Marsala & VanSant, 1998; VanSant, 1988a, 1988b) were used for data analysis. Modal profiles were identified as the most occurring combination of movements demonstrated across the five trials for each participant. Time was calculated from the first initial movement to the point where the participant touched the designated spot on the wall. The modal profile times for each participant were averaged and used for data analysis (Nesbitt et al., 2017).

Developmental sequence coding for all skills was conducted by two trained raters. Modal profiles for each skill were identified using the most occurring movement patterns for each participant, and were used for descriptive data. Inter-(>.80) and intra-rater (>.80) reliability using *Kappa* were established for each skill based on 20% of the sample and were deemed acceptable.

Statistical Analysis

An *a priori* power calculation with alpha set at $p < .05$, and an f^2 of .28 yielded a sample size of 43 per age group with a power estimate of .80. Thus, an oversampling of 50 total participants per age group was sufficient to determine significance at $p < .05$ level.

Table 2 Movement Component Categories for Task of Rising from a Supine to a Standing Position (Adapted from Marsala & VanSant, 1998; Vansant, 1988a, 1988b)

Upper Extremity Movement Patterns	
Level 1	<i>Push and reach to bilateral push.</i> One hand is placed on the support surface beside the pelvis. The other arm reaches across the body, and the hand is placed on the surface. Both hands push against the surface to an extended elbow position. The arms are then lifted and used for balance.
Level 2	<i>Asymmetrical push.</i> One or both arms are used to push against the support surface. If both arms are used, there is asymmetry or asynchrony in the pushing action or a symmetrical push gives way to a single-arm push pattern.
Level 3	<i>Symmetrical push.</i> Both hands are placed on the support surface. Both hands push symmetrically against the surface prior to the point when the arms are lifted synchronously and used to assist with balance.
Level 4	<i>Symmetrical reach.</i> The arms reach forward, leading the trunk, and are used as balance assists throughout the movement.
Axial Region Movement Patterns	
Level 1	<i>Full rotation, abdomen down.</i> The head and trunk flex and rotate until the ventral surface of the trunk contacts the support surface. The pelvis is then elevated to or above the level of the shoulder girdle. The back extends up to the vertical, with or without accompanying rotation of the trunk.
Level 2	<i>Full rotation, abdomen up.</i> The head and trunk flex and/or rotate until the ventral surface of the trunk faces, but does not contact, the support surface. The pelvis is then elevated to or above the level of the shoulder girdle. The back extends from this position up to the vertical, with or without accompanying rotation of the trunk.
Level 3	<i>Partial rotation.</i> Flexion and rotation of the head and trunk bring the body to a side facing position, with the shoulders remaining above the level of the pelvis. The back extends up to the vertical, with or without accompanying rotation.
Level 4	<i>Forward with rotation.</i> The head and trunk flex forward, with or without a slight degree of rotation. Symmetrical flexion is interrupted by rotation or extension with rotation. Flexion with slight rotation is corrected by counter rotation in the opposite direction. One or more changes in the direction of rotation occur. A front or slightly diagonal facing is achieved before the back extends to the vertical.
Level 5	<i>Symmetrical.</i> The head and trunk move symmetrically forward past the vertical; the back then extends symmetrically to the upright position.
Lower Extremity Movement Patterns	
Level 1	<i>Jump to squat.</i> The legs are flexed and rotated to one side. Both legs are then lifted simultaneously off the support surface and derotated. The feet land back on the support surface with hips and knees flexing to a squat or semi-squat position. The legs then extend to the vertical.
Level 2	<i>Kneel.</i> The legs are flexed and rotated to one side with both knees contacting the support surface.

(continued)

Table 2 (continued)

Level 3	<i>Half-kneel.</i> Both legs are flexed toward the trunk as one or both legs are rotated to one side. Either a kneeling or half-kneeling pattern is assumed. If kneeling occurs, one leg is then flexed forward to assume half-kneeling. The forward leg pushes into extension as the opposite leg moves forward and extends.
Level 4	<i>Asymmetrical wide-based squat.</i> One or both legs are flexed toward the trunk assuming an asymmetrical, crossed-leg or wide-based squat. Internal rotation of the hips may cause the feet to be placed on either side of the pelvis. Asymmetry of hip rotation is common. The legs push up to an extended position. Crossing or asymmetries may be corrected during extension by stepping action
Level 5	<i>Symmetrical narrow-based squat with balance step.</i> The legs are brought into flexion with the heels approximating the buttocks in a narrow-based squat. Stepping action may be seen during assumption of the squat, or balance steps (or hops) may follow the symmetrical rise.

The data were separated by age groups and analyzed in six steps, starting with the pre-longitudinal screen. Observed frequencies of occurrence for each modal level within each component for each age group were calculated and those frequency percentages were plotted against chronological age (Robertson et al., 1980) to determine the developmental trajectories of each component. Next, Spearman’s Rho correlations were calculated to examine the associations between STS time and the three STS components of upper extremity (UE), axial (AX), and lower extremity (LE) by each age group.

Third, L-statistic multiple regression analysis was conducted with STS time as the dependent variable and the STS components as the independent variables while controlling for BMI, for each age group. The L-statistic analysis was conducted due to the non-parametric nature of the STS components. Nonparametric analysis of rank order data are allowed with the use of parametric analysis methods, such as multiple regression, when an L-statistic is calculated by hand (Puri & Sen, 1985) at the outset of the data analysis (Thomas, Nelson, & Thomas, 1999). The L-statistic was treated as an approximation for χ^2 and was acquired from the following equation, $L = (N - 1) r^2$, where N is equal to the number of participants within a grouping and r^2 is equal to the proportion of true variance (Thomas et al., 1999).

Fourth, Pearson’s correlations were calculated to compare performances between STS time and the MC product-oriented assessments of the standing long jump, kick, throw, and hop. Fifth, we conducted Spearman’s Rho correlations analysis on the STS component data and the MC product-oriented assessments of the standing long jump, kick, throw, and hop. Finally, Spearman’s Rho correlations were calculated to compare performances between STS time and the MC process-oriented assessment data (i.e., developmental sequences) of standing long jump, throw, and hop.

Results

The percentage of trials classified within each step by age is shown for each component in Figures 1–3. Cross-sectional data “curves” for the AX and LE

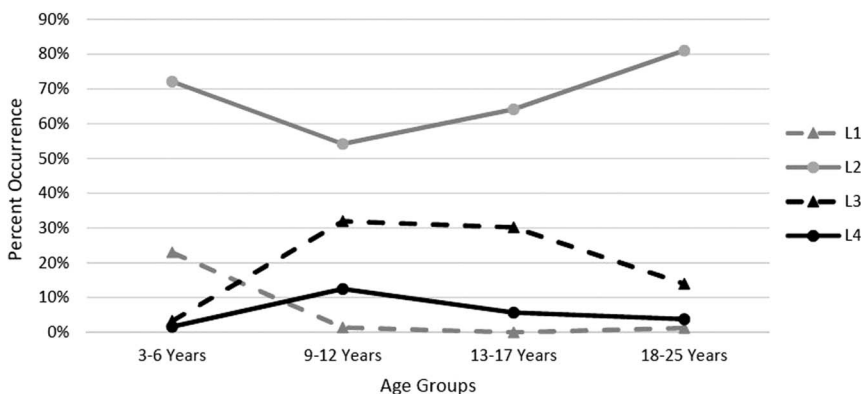


Figure 1 — Observed frequency of occurrence for upper extremity levels across age groups.

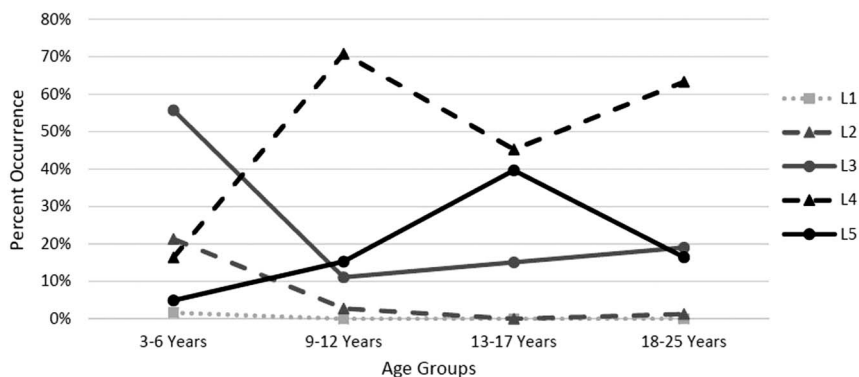


Figure 2 — Observed frequency of occurrence for axial levels across age groups.

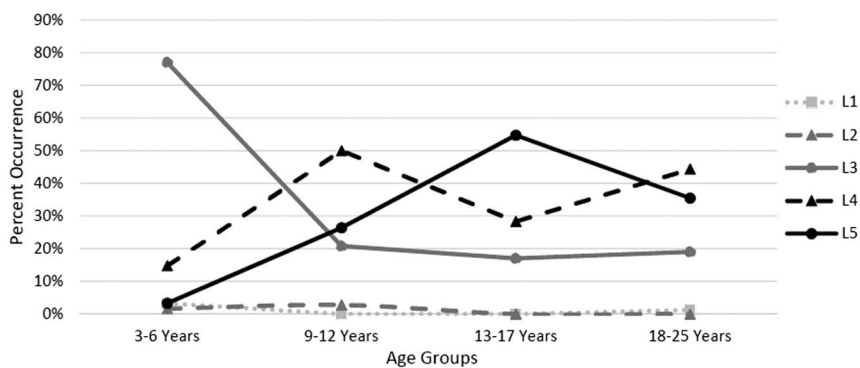


Figure 3 — Observed frequency of occurrence for lower extremity levels across age groups.

components generally fit the Robertson et al. (1980) hypothetical model curves. Indicating the plotted modal profile curves demonstrated a progression and regression for each component across age groups. However, observed frequencies of occurrence for the UE component did not specifically follow the developmental trajectory hypothesized by Robertson et al. (1980). The percentage of trials classified within the upper extremity components indicate the frequency of Level 1 (push and reach to bilateral push) was observed most often in the early childhood group and its occurrence declined thereafter. Level 2 (asymmetrical push) showed the most occurrences of any level across all four age groups; however, there was a slight decline during late childhood with the emergence of Levels 3 and 4. The occurrence of Level 2 again began to increase into young adulthood where it was observed in over 80% of the trials. Levels 3 (symmetrical push) and Level 4 (symmetrical reach) generally followed the same pattern across age groups with the occurrence of Level 3 being the most prominent of the two. Both levels increased from early childhood into late childhood, but gradually declined thereafter.

Axial region component levels 1 (full rotation, abdomen down) and level 2 (full rotation, abdomen up) declined across age groups, as would be expected in a developmental progression. Level 3 (partial rotation) also showed a dramatic decrease from early childhood into late childhood, but remained relatively constant across late childhood into young adulthood. Level 4 (forward with rotation) shows the highest percentage of occurrence with approximately 70% during late childhood then declined into adolescence. Trends in Level 4 are followed by an increased occurrence Level 5 (symmetrical) from late childhood (15%) into adolescence (40%). In the young adult group, the frequencies of symmetrical movements (Level 5) decreased back to 18% as the percentage of more asymmetrical movements (Level 4) increase from 45% (adolescent group) to 64% (young adults). According to the Robertson et al. model, Level 1 and 2 would be expected among younger individuals and Levels 3–5 would be observed most often in older individuals; however, the Level 5 component was never demonstrated most often at any age group.

The data for the lower extremities revealed Levels 1 (jump to squat) and 2 (kneel) were demonstrated less than 5% across all age groups. The occurrence of Level 3 (half-kneel) was most often demonstrated (77%) in early childhood, drastically declined (20%) into late childhood. This trajectory was maintained throughout the remainder of the age groups. Levels 4 (asymmetrical wide-based squat) and 5 (symmetrical narrow-based squat with balance step) began to increase from early childhood into late childhood. The occurrence of Level 4 during adolescence decreased as the occurrence of Level 5 continued to increase. However entering young adulthood, the two levels reversed their trajectories with the occurrence of Level 4 becoming more frequent.

Table 3 presents Spearman's Rho correlations examining the relationships between STS time and the three STS components. The analysis revealed that STS time was inversely related to upper extremity for all groups except 13–17 year-olds ($r = -.22$ to $-.32$, $p < .05$). Axial was negatively associated to STS time for all groups except 9–12 year-olds ($r = -.25$ to $-.37$, $p < .05$). The lower extremity component was not significantly correlated with STS time for any of the age groups.

Table 4 provides the results for the L-statistic multiple regression analysis with STS time as the dependent variable and the STS components as the independent

Table 3 Whole Group Spearman's Rho Correlations for STS Time and STS Components by Age Groups

Age Group	Variables	STS Time	Upper extremity	Axial
3–6 yrs (<i>n</i> = 61)	Upper extremity	–.32*		
	Axial	–.37**	.87**	
	Lower extremity	–.22	.45**	.66**
9–12 yrs (<i>n</i> = 73)	Upper extremity	–.30**		
	Axial	–.23	.52**	
	Lower extremity	–.06	.13	.58**
13–17 yrs (<i>n</i> = 53)	Upper extremity	–.18		
	Axial	–.32*	.76**	
	Lower extremity	–.08	.12	.42**
18–25 yrs (<i>n</i> = 79)	Upper extremity	–.22*		
	Axial	–.25*	.70**	
	Lower extremity	–.02	.20	.62**

p* < .05; *p* < .01.**Table 4 Regression results by age group for STS Time and Developmental Components Using BMI as a Covariate**

Independent variables	Age Group 3–6 (<i>n</i> = 60)		Age Group 9–12 (<i>n</i> = 70)		Age Group 13–17 (<i>n</i> = 53)		Age Group 18–25 (<i>n</i> = 78)	
	ΔR^2	<i>L</i>	ΔR^2	<i>L</i>	ΔR^2	<i>L</i>	ΔR^2	<i>L</i>
Upper Extremity	.07	4.25*	.00	0.00	.01	0.68	.02	1.46
Axial	.12	6.79**	.01	0.76	.08	4.21*	.02	1.54
Lower Extremity	.03	1.95	.00	0.00	.00	0.21	.00	0.23
Combined	.12	7.14	.03	1.93	.12	6.24	.06	4.62
BMI	.08	4.72*	.20	14.21**	.04	2.03	.12	8.93**

p* < .05; *p* < .01.

variables. Body mass index was included as a covariate in the analysis in order to understand the potential impact of weight status on STS time. BMI was a significant predictor for STS time for all of the age groups ($r^2 = .08-.20$, $p < .05$), with the exception of the 13–17 year-olds. Upper extremity and axial were both significant predictors of STS time for the 3–6 year-old group ($r^2 = .07$ and $.12$, $p < .05$, respectively). In addition, axial also predicted 8% of the variance ($p < .05$) in STS time for the 13–17 year-old group. The lower extremity component did not account for any of the variance in STS time across all ages.

Pearson's correlations were calculated to compare performances between STS time and the MC product-oriented assessments of the standing long jump distance,

kick, throw, and hop (see Table 5). Overall, approximately 11% of the 3–6 year old participants were unable to complete three consecutive hops in at least one trial. Standing long jump distance, throwing speed, and average distance/hop on the right foot were inversely associated to STS time for all age groups ($r = -.46$ to $-.60$, $r = -.28$ to $-.53$, $r = -.21$ to $-.48$, $p < .05$, respectfully). Kicking speed and average distance/hop on the left foot were all negatively associated to STS time for all groups except 9–12 year-olds ($r = -.48$ to $-.54$, $r = -.31$ to $-.46$, $p < .01$).

Spearman’s rho correlations analysis were conducted on the STS component data and the MC product-oriented assessments of the standing long jump distance, kick, throw, and hop (see Table 5). The upper extremity component revealed a positive relationship with standing long jump distance, throwing, and both average distance/hop ($r = .37-.42$, $p < .01$) for 3–6 year-olds and a positive relationship with both feet on hopping distances ($r = .39-.45$, $p < .01$) for 9–12 year-olds; however, the upper extremity component demonstrated no significant correlations with product scores after late childhood. Correlations were statistically significant for each of the MC product scores and the axial component scores for 3–6 year-olds ($r = -.26$ to $-.44$, $p < .05$) and significant correlations were found between both right and left average distance/hop and the axial component ($r = .30-.33$, $p < .01$)

Table 5 Whole Group Pearson’s and Spearman’s Rho Correlations for STS Time and Components with MC Product Factors by Age Groups

Age Group	Variables	SLJ	Kick	Throw	Hop R	Hop L
3–6 yrs ($n = 61$)	STS Time [†]	-.60**	-.48**	-.53**	-.48**	-.31*
	UE [‡]	.37**	.20	.37**	.37**	.42**
	AX [‡]	.40**	.26*	.36**	.44**	.44**
	LE [‡]	.29*	.23	.28*	.37**	.32*
9–12 yrs ($n = 68$)	STS Time [†]	-.34**	-.07	-.28*	-.21*	-.10
	UE [‡]	.18	.10	-.12	.39**	.45**
	AX [‡]	.17	.11	.09	.30*	.33*
	LE [‡]	.12	.07	-.08	.13	.17
13–17 yrs ($n = 53$)	STS Time [†]	-.53**	-.54**	-.51**	-.46**	-.45**
	UE [‡]	.22	.14	.21	.18	.19
	AX [‡]	.42**	.38**	.41**	.29*	.24
	LE [‡]	.24	.23	.23	.13	-.01
18–25 yrs ($N = 79$)	STS Time [†]	-.60**	-.54**	-.42**	-.46**	-.46**
	UE [‡]	.17	.03	-.14	.07	.01
	AX [‡]	.10	-.01	-.12	.10	.13
	LE [‡]	.01	-.00	-.14	-.01	-.00

Note. UE = upper extremity; AX = axial; LE = lower extremity.

* $p < .05$; ** $p < .01$.

[‡]Spearman’s rho.

[†]Pearson’s Correlation.

for 9–12 year-olds. axial component was positively associated with each of the MC product scores ($r = .29-.42$, $p < .05$) except hopping distance with the left foot for 13–17 year-olds. The upper extremity and lower extremity component correlations were statistically significant for standing long jump distance, throwing, average distance/hop right foot, and average distance/hop left foot for 3–6 year-olds ($r = -.29$ to $-.42$, $p < .05$). After early childhood the lower extremity component was not significantly correlated with any other age groups.

The Spearman's rho correlations with STS time and the MC process-oriented assessment data varied across the age groups with the greatest amount of statistically significant relationships demonstrated at the youngest age group (3–6 years; see Table 6).

Discussion

The first purpose of this study was to examine the validity of STS as a developmental measure of functional MC across childhood, adolescence, and

Table 6 Whole Group Spearman's Rho Correlations for Supine-to-Stand Test (STS) Time With Motor Competence Process Factors by Age Groups

Variables	STS Time			
	3–6 yrs (<i>n</i> = 60)	9–12 yrs (<i>n</i> = 74)	13–17 yrs (<i>n</i> = 52)	18–25 yrs (<i>n</i> = 79)
Throw				
Foot	-.24	-.16	-.37**	.02
Trunk	-.13	-.27*	-.22	-.05
Humerus	-.36**	.05	-.19	-.20
Forearm	-.43**	-.19	-.28*	-.07
SLJ				
Takeoff legs	-.27*	-.08	†	-.16
Takeoff arms	-.47**	-.35**	-.29*	-.37**
Landing shank	-.42**	-.05	-.13	-.15
Landing foot	-.34**	-.25*	-.14	-.16
Landing arms	-.63**	-.16	-.36**	-.24*
Hop				
Right leg	-.38**	-.34**	-.43**	-.24*
Right arm	-.10	-.33**	-.30**	-.21
Left leg	-.31*	-.39**	-.41**	-.33**
Left arm	.00	-.49**	-.26	-.32**

Note. SLJ = standing long jump.

* $p < .05$; ** $p < .01$.

†Due to a lack of variability in the takeoff legs scores in the 13–17 year-old group, there was no correlation data.

young adulthood using a pre-longitudinal screen approach (Robertson et al., 1980). Examining associations among movement pattern levels and STS time provided a secondary measure of developmental validity. Results of the pre-longitudinal screening procedure revealed sequences for STS generally met each criterion (Robertson et al., 1980). The findings generally supported the sequential progression and regression of the upper extremity, axial, and lower extremity developmental steps up through adolescence, which demonstrates that one's ability to stand may be characterized by sequential developmental changes in body component actions as a person ages and develops over time. However, there were some instances where the developmental 'curves' did not specifically follow developmental trajectories.

Previous research (VanSant, 1998) indicated upper extremity Level 1 (push and reach to bilateral push) is most often demonstrated in toddlers. Since our sample began at age 3, this might have been the cause for fewer incidences of upper extremity Level 1 in the youngest age group. The most advanced developmental patterns of axial and lower extremity were observed during adolescence, which supports previous research by VanSant (1990). However, our results demonstrated a higher frequency of the asymmetrical push – Level 2 of the upper extremity component than Sabourin's (1989) adolescent data. Secular trends have noted decreases in youth physical fitness and increased weight status (Malina, 2007; Tremblay, Esliger, Copeland, Barnes, & Bassett, 2008). Lower incidences of the symmetrical – Level 5 of the axial component were also found in young adult group compared to research by VanSant (1988a, 1988b). The discrepancy in axial levels between our data and VanSant's (1988a, 1988b) data is most likely due to average body weight status for males and females being classified as overweight. Thus, as BMI was associated with component levels, increased weight status may be partially responsible for the increased probability of a lower developmental level of upper extremity and axial in this sample. Future research should address the potential relationship of STS with aspects of health-related fitness as rising from the ground quickly would seemingly be linked to various aspects of strength, core function, and power.

Previous literature shows that individuals with physical impairments and the elderly generate slower STS times than those who are typically developing and younger in age (Alexander et al., 1997; Ulbrich et al., 2000). To our knowledge, Nesbitt et al., (2017) were the first to examine STS developmental sequences and time using a validated assessment. Results from Nesbitt et al., (2017) study suggest that in early childhood, the use of less advanced upper extremity and axial levels resulted in slower times to stand, which suggest that an individual's ability to control and manipulate their center of mass effectively is important for rising more quickly. The current study expanded upon Nesbitt and colleagues study (2017) and examined if STS components were associated with time across early childhood to young adulthood. Results from all age groups generally demonstrate that as children age, STS component levels become more advanced and STS times' decrease. In general, weak to moderate correlations between STS time and component levels were demonstrated across all age groups. Lower extremity movements were not correlated with STS time in any age group suggesting that lower extremity movements are primarily used as a source of balance or stability when standing. In essence, core (axial) and upper extremity movements function to

organize the body into a position where the lower extremities complete the process of standing upright.

Results from the current study demonstrate the average STS time in 3–6 year-olds (least advanced movement patterns) was 2.39 seconds, which was dramatically higher than in late childhood ($M = 1.64$ seconds) and adolescence ($M = 1.71$) where more advanced movement patterns were demonstrated. These findings are congruent with previous literature that demonstrates young children present less advanced movement patterns as compared to late childhood and adolescence. Overall, the adult data generally demonstrated a less advanced pattern for lower extremity (i.e., Level 5—symmetrical narrow-based squat to Level 4—asymmetrical wide-based squat); however, the time to stand did not effectively change ($M = 1.73$) perhaps reflecting an increase in overall strength. Furthermore, these findings indicate component level trajectories provide sufficient evidence for developmental trends for each of the components used by participants to stand, which are congruent with age-related trends shown in other motor skills (Halverson & Williams, 1985; Keller, Lamenoise, Testa, Golomer, & Rosey, 2011; Messick, 1991).

The second purpose of this study was to examine associations of STS (movement patterns and time) to other developmentally valid measures of MC (e.g., fundamental motor skills). Positive associations among STS components and measures of MC and an inverse relationship with STS time suggest that the STS task can be used to assess gross motor skill development, similar to other common MC measures.

STS time demonstrated weak to moderate ($r = -.21$ to $-.60$) correlations to MC product measures across all age groups. As the STS task and the other fundamental motor skills tested involve large, force-producing muscles of the trunk, arms, and legs (Clark, 1994), performance of these skills is influenced by a person's ability to effectively coordinate and control his or her body. STS is similar to other fundamental motor skills in that advanced levels of coordination and control involve higher muscle activity levels that impact both strength and power output and the resultant product of the movement (e.g., jumping distance, throwing/kicking speed, time to stand) (Escamilla & Andrews, 2009; Lees, Asai, Andersen, Numome, & Sterzing, 2010; Langendorfer et al., 2013). Therefore, it would be expected that STS time and MC product scores would be associated.

Significant associations among STS component levels and MC product scores were most prevalent during early childhood. The significant associations during early childhood are most likely related to the global level of coordination and control of the trunk and limb segments. The lack of coordination and control of multiple body segments is a critical constraint on the effectiveness of resultant force production (i.e., related to STS and MC product scores) and also results in more asymmetry and variability in movement patterns within trials. Positive associations between the axial component and MC product scores during early childhood and adolescence may be explained by changes in body proportions segments during growth. Unfortunately, anthropometric data was not collected for this study; thus, future research is needed to examine if body proportions relative to age is associated with STS components.

In addition, STS time demonstrated weak to moderate ($r = -.24$ to $-.63$) inverse correlations with MC process scores, indicating more advanced component

levels of fundamental motor skills are associated with faster times when standing. Furthermore, STS time was correlated with all developmental sequences for standing long jump in early childhood, though only the arms component at takeoff was significantly correlated to the late childhood, adolescent, and adulthood groups. Similar to the upper extremity components of STS, more advanced arm action during the takeoff phase of the standing long jump provide greater balance and control resulting in improvements in performance (i.e., distance and time to stand) (Ashby & Heegaard, 2002). Additionally, STS time was consistently associated with developmental sequences for hopping for every age group. Single leg hopping involves dynamic balance, with the non-stance leg aiding in both counterbalancing and/or force production, assisting with the continuous movement of the skill. Individuals that demonstrate more advanced component levels while hopping were able to rise from the floor faster.

Despite the novelty of this study, several limitations should be noted. Although a pre-longitudinal screen is an important step to establish testable component sequences, longitudinal validation of these sequences is necessary to understand whether they are truly developmental. Another limitation is that the current study only assessed STS from early childhood up to young adulthood. Further examination of STS across the lifespan is needed to understand the progression and regression of MC from a lifespan perspective. However, the current data supported Sabourin's (1989) findings demonstrating that the advancement of STS component levels peaked during adolescence. In addition, although hop and standing long jump were assessed relative to individual's height, leg length (not collected in this study) may be a more sensitive anthropometric variable to assess performance of both measures. Lastly, although this study examined a combination of both object projection and locomotor MC measures (i.e., kicking, throwing, hopping, and standing long jump) further research should examine the associations of STS (sequences and time) to other individual MC skills (e.g., catching, running, etc.) as well as other MC test batteries to better understand its predictive utility as a stand-alone or global lifespan assessment of MC.

Conclusion

In conclusion, results of this study and Duncan et al. (2017) indicate STS time can be considered a valid and reliable measure of MC across childhood, adolescence, and into young adulthood. As, strong evidence indicates that MC is inversely associated with body weight status and positively associated with physical activity, (Logan, Webster, Getchell, Pfeifer, & Robinson, 2015) cardiorespiratory fitness and musculoskeletal fitness across childhood and adolescence (Cattuzzo et al., 2016), STS represents one task that may be a valuable assessment to understand the impact of MC on health as it is a lifespan measure of functional capacity.

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