THE KINEMATICS AND KINETICS OF THE SIT-TO-STAND MOVEMENT IN YOUNG CHILDREN

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The purpose of this study was to assess the kinematics and kinetics of the sit-to-stand (STS) movement in young children. The subjects were 12 children in three age groups: 12-18 (N=5), 24-36 (N=3), and 48-60 (N=4) months. Subjects were videotaped as they stood up from a seat adjusted to knee height. Data on forces at the feet and buttocks were collected simultaneously using two force platforms. Overall, the STS movement in the children was characterized by fast movement times (c. 1.2 s), large hip joint range of motion, large hip flexion angles, large vertical ground reaction forces at the feet, and hip joint moments of greater magnitude than knee joint moments. There was a trend toward increasing joint ranges of motion, velocities, forces, and moments with increasing age, with the oldest children having results quite similar to adults.

KEY WORDS: sit-to-stand, fundamental motor skill, children.

INTRODUCTION: The sit-to-stand (STS) movement—rising from a seated position on a seat or bench—is an important movement pattern used throughout life and is crucial for mobility and independence. Despite the fact that children begin performing the STS movement at a young age, few studies have investigated the STS in children, and only one prior study (Cahill, Carr, & Adams, 1999) has specifically assessed the biomechanics of the movement in able-bodied children, and in a somewhat limited fashion. While the STS movement has not been tradionally considered a fundamental motor skill as has, for example, running, jumping, and throwing, literature of the past decade suggests that this view is changing (Shumway-Cook & Woollacott, 1995). In addition to its role as a fundamental movement pattern of daily living, the STS represents a constrained (by the presence of the seat) squat-type movement with joint patterns similar to those seen in the squat-lift in weightlifting and similar movements inherent in many sports. Thus the STS movement provides the opportunity to study the fundamental patterns of a squat-type movement, which for very young children would likely be otherwise impossible to study in a defined manner. Therefore, the purpose of the present study was to assess the kinematics and kinetics—including joint kinetics—of the STS movement in young children in order to fully describe this fundamental squat-type movement pattern.

METHOD:

Subjects: 12 children, 4 males and 8 females, in one of three age categories: 12-18 months, or Group 1 (N=5; mean age 14.7±1.7 months); 24-36 months, or Group 2 (N=3; mean age 26.5±2.3 months); and 48-60 months, or Group 3 (N=4; mean age 51.5±5.2 months); one additional subject had to be eliminated from the study due to an unwillingness to cooperate. During the trials subjects wore only a diaper or swimsuit, depending on the age of the subject. Ultimately no joint markers were placed on the subjects as this proved a distraction, especially for the youngest children.

Data Collection: As the STS has been shown to be primarily a sagittal plane movement pattern (Lundin, Grabiner, & Jahnigen, 1995), 2-D videography was used to capture each subject's movement pattern while rising from a seated position on a custom-made bench. The bench height was adjustable and was set to each individual's knee height, thus standardizing an initial position in which the thighs were parallel to the ground. Video data were collected using a single Panasonic S-VHS camera with a field rate of 60 Hz and a shutter speed of 1/1000 s; the optical axis of the camera lens was oriented perpendicular to the sagittal plane of the subject. Force data were collected simultaneously with the videographic data using two force platforms (AMTI model OR6-5-2000), one placed beneath the subject's feet and the other on the surface of the bench; force data were collected at 1000 Hz. The Ariel Performance Analysis System (APAS) was used to acquire analog data from the force platforms, to capture and digitize video data, and to filter and smooth the kinematic data. Subjects performed at least twenty trials of the STS movement (ten per side of the body) to ensure that a minimum of ten trials would be acceptable for analysis; arm movement was constrained by having the subject hold a small stuffed animal. A trial was defined as beginning when movement was initiated (typically with trunk flexion) and ending when the subject reached an upright position. The speed of the movement was not constrained and thus varied from subject to subject, and to a lesser extent from trial to trial.

Data Analysis: Upon review of the video, the first five acceptable trials from each side of the body were selected for digitization and the movement time for each trial was noted. The following anatomical landmarks were manually digitized in each video field: base of the fifth metatarsal, lateral malleolus, center of the knee joint, greater trochanter, and the acromion process. This provided for a four-segment model of the body: foot, shank, thigh, and trunk. Analog force data were passed through an A-to-D converter, reduced to 60 Hz (to match the frequency of the video data) and synchronized with the digitized video data. Using APAS standard kinematic variables were obtained—position, velocity, and acceleration of each joint and body segment—along with vertical and horizontal forces at the feet and buttocks and the moment about the medio-lateral axis at the feet. Using the method and models described by Jensen (1986), position of segment and whole body centers of gravity, along with segment masses, were calculated. These were used, along with the kinematic and kinetic data, to derive the forces and moments at the knee and hip joints using standard inverse dynamics. Ultimately the following variables were considered: movement time, joint ranges of motion, peak hip flexion angle, peak joint angular velocities, peak velocity of the whole-body center of gravity (CG), peak ground reaction forces, and peak joint moments at the hip and knee joint (normalized by dividing by the subject's body weight in newtons, multiplying by the subject's height in meters, and then multiplying by 100). The small number of subjects precluded statistical comparisons between groups.

RESULTS: No meaningful differences were found for any of the variables discussed below between the left and right sides of the body, therefore in the results and discussion that follow the data from the right- and left-side trials are treated collectively. Table 1 summarizes the mean (± s.d.) for each group for each STS temporal variable.

Table 1. Mean (± s.d.) for each STS movement temporal variable across groups. With the exception of movement time, time is reported as a percent of total movement time.

Variable	**Group 1**	**Group 2**	**Group 3**
Movement time	1.23 ±0.38 s	0.88 ±0.21 s	1.16 ±0.31 s
Time to peak hip flexion angle	37.6 ±12.1%	43.0 ±8.3%	40.0 ±6.4%
Time to peak hip flexion angular velocity	18.1 ±11.5%	26.2 ±9.1%	25.4 ±5.8%
Time to peak hip extension angular velocity	75.4 ±11.2%	72.3 ±11.9%	75.7 ±11.3%
Time to peak knee extension angular velocity	74.2 ±13.8%,	72.3 ±12.2%	77.1 ±12.7%
Time to peak horizontal velocity of whole-body CG	57.6 ±26.6%	55.7 ±17.1%	39.7 ±13.6%
Time to peak vertical velocity of whole-body CG	67.6 ±14.9%	70.7 ±13.2%	65.4 ±14.2%
Time to peak vertical ground reaction force at the feet	66.0 ±21.0%	66.5 ±23.1%	53.0 ±12.9%

Table 2. Mean (± s.d.) for each STS movement spatial variable across groups.

Variable	Group 1	Group 2	Group 3
Hip joint range of motion	90.3 ±16.9º	86.2 ±13.9º	113.3 ±16.3º
Knee joint range of motion	60.6 ±16.3º	60.4 ±14.7º	82.8 ±22.0º
Peak hip flexion angle	109.9 ±12.5º	103.3 ±12.2º	127.3 ±9.0º
Peak hip flexion angular velocity	64.3 ±23.7º/s	88.6 ±24.9º/s	105.3 ±46.0º/s
Peak hip extension angular velocity	206.1 ±67.9º/s	277.7 ±77.1º/s	263.7 ±81.9º/s
Peak knee extension angular velocity	143.3 ±62.3º/s	207.5 ±73.2º/s	206.1 ±72.5º/s
Peak horizontal velocity of whole-body CG	22.5 ±14.5 m/s	33.9 ±10.7 m/s	37.0 ±15.2 m/s
Peak vertical velocity of whole-body CG	19.4 ±7.5 m/s	33.4 ±7.6 m/s	37.0 ±13.9 m/s
Peak vertical ground reaction force at the feet	136.7 ±31.1% BW	162.6 ±49.2% BW	155.3 ±37.7% BW
Peak normalized hip joint moment	9.0 ±6.6	14.6 ±6.4	31.0 ±13.4
Peak normalized knee joint moment	6.2 ±5.8	9.4 ±5.8	15.2 ±5.4

DISCUSSION: The first thing that should be noted, as is evident in the standard deviations for each variable, is that a reasonable amount of variability in the performance of the STS existed among the children in each group. Though data from individual trials is not reported above, less variability existed from trial to trial within subject, though it was still greater than that typically reported in the literature for adults (here, and in the discussion that follows, a representative study of the STS in adults would be that by Schenkman, et al., 1990). This degree of variability is consistent with that reported by Cahill, et al. (1999) who postulate that the greater variability exhibited by children is due to a lack of postural control. Movement times for the children in the present study were similar to those reported previously for children by Cahill, et al. but were at the lower range (i.e., faster) of movement times generally reported for adults. That children have faster movement times than adults may be due to a more conscious, deliberate (and therefore slower) movement on the part of the adults, or simply to the fact that children, due to their shorter stature, have to raise the center of gravity a shorter distance. It is unclear why subjects in Group 2 had on average a substantially faster movement time than the other two groups. The overall joint motion pattern of the children in the present study was similar to that reported for adults. Hip joint range of motion for the children in the present study was greater than that generally reported for adults, suggesting greater trunk and hip flexion during the early part of the movement, while knee joint range of motion was less than that for adults, mainly due to the fact that the children tended to keep their knees flexed slightly at the end of the movement, possibly to increase stability by keeping the center of gravity slightly lower. Peak hip flexion angles were comparable to those reported by Cahill, et al. for children, but slightly greater than those typically reported for adults, again suggesting that children have greater trunk and hip flexion during the early phase of the movement. Peak joint angular velocities and the timing of those peaks found in the present study were similar to those reported in the literature for children (Cahill, et al.) and adults, though there was a trend of increasing peak angular velocities with increasing age, with Group 3 having values closest to that of adults. Likewise, the peak horizontal and vertical velocities of the whole-body center of gravity tended to increase with increasing age, though these values were still substantially less than those reported for adults, perhaps reflecting a lack of postural control on the part of the children, as noted above. As with adults, the peak horizontal velocity occurred before the peak vertical velocity, though they tended to occur later for the children when compared to those values typically reported for adults, though there was a slight trend toward earlier occurrence with increasing age. The pattern of forces at the feet and the buttocks was similar to that reported for adults. The peak vertical ground reaction force at the feet was close to 150% of body weight for the children in the present study, which is substantially larger than the values reported in the literature for children (Cahill, et al.) and adults, which were typically 115 to 125% of body weight. It is possible that these higher values are due, at least in part, to the relatively fast movement times found in the present study. The time to reach peak vertical ground reaction force at the feet was later for the children in the present study than for those reported for adults, which is consistent with less postural control in the children. There was, however, a trend toward sooner occurrence of the peak force with increasing age. Peak hip and knee joint moments were quite variable, tended to increase with increasing age, and were, in the case of hip joint moments, comparable to those reported for adults. Peak knee joint moments, however, were less than those typically reported for adults. These results suggest that the children in the present study employed a STS strategy favoring hip and trunk flexion to generate momentum in the early part of the movement instead of relying primarily on knee extension.

CONCLUSION: The purpose of the present study was to fully assess the kinematics and kinetics of the STS movement—a movement that can be considered a fundamental motor skill and which shares characteristics of squat-type exercises and movements in sport—in young children. Those physical educators and others working with young children should note that the overall pattern of the STS is well-developed in young children and is similar to that seen in adults. These similarities include the overall joint motion pattern and the pattern of forces at the buttocks and the feet. When compared to adults, notable differences found for the children in the present study included: faster movement times, greater hip range of motion and peak hip flexion angle, lower peak velocities of the whole-body center of gravity, greater peak vertical reaction force at the feet, and a longer time taken to reach the peak force at the feet. On the whole, many of these differences can be explained by the children having faster movement times, having a relative lack of postural control, and using a "momentum transfer" strategy favoring hip and trunk flexion. In addition, there was a trend toward more adult-like values for each variable with increasing age.

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