Research Article

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The Effects of Trunk Function on Volume of Action in Manual Wheelchair Users

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ABSTRACT

The purpose of this study was to quantify the limits of stability of wheelchair users across a functional spectrum. Eight manual wheelchair users completed a seated limits of stability test to determine maximum range of motion of their trunk forward, backward, right, left, and rotation of the trunk. The low functional classification group had significantly less trunk excursion than the high functional classification group for trunk flexion, rotation, and left and right lateral flexion. Wheelchair basketball players in lower functional classifications have a lower capacity to control their trunk excursion in lateral, anterior, and posterior directions, as well as rotation. These results lend support to the validity of the functional classification system used in wheelchair basketball.

Keywords
Wheelchair, Trunk function, Limits of stability.

Introduction

The ability to maintain seated balance is an important skill for wheelchair users in the execution of activities of daily living. These include stationary activities where the wheelchair is not in motion (reaching to retrieve an object, grooming, bathing) and dynamic activities such as propelling the wheelchair. For example, when pushing up a ramp a wheelchair user will lean their trunk as far forward as possible to prevent the wheelchair from falling backward, and will lean their trunk back to prevent falling forward when descending a ramp [1]. Additionally, falls during the execution of functional activities can be a problem for this population [2].

When comparing groups of wheelchair users there is a need to differentiate between functional capacity, and one way of doing that is by using trunk function. This can be done by using spinal cord lesion level [3] or stratifying participants by paraplegia and tetraplegia [4]. While spinal cord injury lesion level provides a simple way of stratifying wheelchair users, not all wheelchair users have a spinal cord injury. There remains a need for a framework to examine wheelchair users based on functional ability regardless of mechanism of injury. The International Wheelchair Basketball Federation (IWBF) Functional Classification system is used to stratify wheelchair players based on the functional reach of their trunk, among other sport specific measures [5]. This system functions using a “Volume of Action” framework, based on the idea that the higher the classification, the greater the volume of action and by extension, more function. This system has strong correlations with field performance tests [6,7]. On average, players with higher classifications exhibit higher power output and VO^2 peak [8], and score higher on the Comprehensive Basketball Grading System [9]. However, very little work has been done to examine this system with respect to trunk range of motion.

Wheelchair basketball players are assigned a classification after being observed during sanctioned game play by a panel of three individuals called classifiers. Classifiers receive extensive training and observe trunk movement of players during game play, including during the execution of skills such as dribbling, passing, shooting, and rebounding. Players are given a classification, called points, ranging from 1.0 (minimal function) to 4.5 (maximal function) based on a consensus of the classification panel. Half points are given if "the player functionally blends characteristics, specific criteria or the volume of action of two classes" [10]. The panel provides for a level of objectivity, in that there must be a consensus between all three classifiers before a classification is awarded [5]. An overview of the functional capacities for each classification can be seen in table 1 and figure 2. Generally speaking, a class I is identified by an inability to rotate their trunk along the Z-axis. A class II player has the functional capacity to rotate their trunk but lacks the functional capacity to exhibit active hip flexion and extension. A class III player has the ability to execute the aforementioned movements of the trunk but lacks the functional capacity to actively move their trunk laterally to the left or right and return to an upright position. Finally, a class IV player has the functional capacity to move their trunk in all planes of motion (rotation, flexion/extension, and lateral movement). ½ points are given to players who exhibit some but not all of these movements (for example, a player may be classified as a 3.5 if they are able to control the movement of their trunk to one side laterally, but not the other).

There have been very few attempts at quantifying the Volume of Action of wheelchair basketball players. Santos et al., [11] used a limits of stability test to quantify trunk balance and found that trunk excursion increased progressively with classification. However, they were unable to measure trunk function with respect to rotation, which is a major aspect of the classification process and an important skill for a wheelchair user in the execution of activities of daily living. In a study comparing people with disabilities to able-bodied individuals, Rehm [12] determined that functional limitations play a large role in the differences seen between classifications with respect to volume of action.

A Volume of Action framework has practical applications outside the world of wheelchair sports, and the movements in the present investigation are consistent with activities of daily living for wheelchair users (picking an object up off the ground, leaning to reach into a cabinet, rotating to reach the back of a wheelchair). As such, the Volume of Action framework is applicable to a myriad of situations. In a longitudinal study examining the role of muscle synergy in postural control with spinal cord injury, Seelen et al. [13] found that participants developed unique muscle activation patterns to maintain balance during bimanual tasks. Specifically, increased use of the latissimus dorsi and trapezius muscle was seen as a compensatory strategy to maintain balance. In a study examining lateral perturbations in spinal cord-injured participants, Kamper et al. [14] found that the ability to perform static leaning was strongly correlated to dynamic lateral balance.

Therefore, the purpose of this study was to quantify the Volume of Action of wheelchair basketball players across a functional spectrum.

Method

Participants

Eight wheelchair users (4 men, 4 women) participated in this study. Mean age of wheelchair users was 24.75 ± 7.57 years, and mean mass was 65.10 ± 14.15 kg. Functional Classifications ranged from 1.0 to 3.5. Self-reported shoulder pain or injury within the last six months was considered exclusion criteria. Use of a wheelchair as primary means of locomotion were required to participate in this study. Participants were divided into two subgroups: high functional classification (HFC), in which the participant's functional classification was 3.0 or above, and low functional classification (LFC), in which the participant's functional classification was 2.5 or below [15]. All participants provided written informed consent, and all procedures were approved by the Institutional Review Board of the University of Texas at Arlington.

Experimental Procedures

Data collection took place during a single visit to the Applied Biomechanics Laboratory at the University of Texas at Arlington. Participants were asked to seat themselves on an adjustable seated platform (Per4max, Grand Prairie, TX) and place a strap around their waist for safety (figure 1). A 14 segment full-body marker set with 6 DoF joints was used to model the body. Reflective markers (14 mm) were attached bilaterally to the skin over anatomical landmarks. Acromion process (RAC, LAC), joint center of the shoulder complex (RADL, RPDL, LADL, LPDL), neck in line with C7 (RNECK, LNECK), C7, T8, T2, L1, L3, L5 vertebrae, superior most point of iliac crest in the sagittal plane (RPP, LPP), anterior superior iliac spine (RAS, LAS), posterior superior iliac spine (RPS, LPS), greater trochanters (RHP, LHP), medial and lateral epicondyles of the femur (RMK, RLK, LMK, LLK), medial and lateral epicondyle of the humerus (RMEL, RLEL, LLEL, LMEL), radial and ulnar epicondyles (RWRR, RWRU, LWRR, LWRU), second third, and fifth metacarpals (LHR, LHM, LHU, RHR, RHM, RHU) medial and lateral malleoli (RMA, RLA, LMA, LLA), first metatarsal, base and fifth of the metatarsals. Markers were also placed on the top of the head (THEAD), forehead (AHEAD), occipital bone (PHEAD), zygomatic bone (RHEAD, LHEAD). Non-collinear markers on molded thermo-plastic shells were placed on the posterior thorax, upper arms, forearms, proximal thighs, and distal shanks. Three tracking markers were placed on the medial, lateral, and posterior heel. A Vicon T-Series motion capture system (Vicon Motion Systems Ltd., Denver, CO) with sixteen MX T40S cameras (4 MP resolution 2336 x 1728) was used to track the position of the markers at 100 Hz. A static trial was then recorded. All anatomical markers were then removed for the limits of stability trials. During data collection, it became necessary to digitally define the RAS and LAS markers. A spring-loaded digitizing pointer (C-Motion, Germantown, MD, USA) was used to create digital markers to be used when adipose tissue occluded the physical markers, or when the markers became occluded due to changes in position. The tip of the digitizing pointer was placed on the soft tissue directly over the anterior superior iliac spine, after which the clinician depressed the digitizing pointer until it reached the underlying bone [16]. Prior to limits of stability trials, participants had the opportunity to practice each motion they would be asked to complete (trunk flexion/extension, left and right lateral extension, and trunk rotation). In the limits of stability trials participants completed ten trials in each direction where they were required to flex and extend the trunk as far as possible without falling. Trials were disqualified if the participant lost their balance, and the trial was repeated.

Data Analysis

Visual 3D (C-Motion, Germantown, MD, USA) was used to process three-dimensional kinematic data for each participant. Marker trajectories were filtered with a fourth order zero lag Butterworth low-pass filter with cutoff frequency of 6 Hz. Body segment parameters (mass, center of mass location) were obtained using de Leva [17]. Hip joint center locations were obtained using Bennett [18]. Three-dimensional joint angles were calculated using an x (flexion/extension), y (abduction/adduction), z (axial rotation) Cardan rotation sequence. The limits of stability were quantified using the orientation of the trunk relative to the laboratory reference frame (trunk segment angle) and the abdominal joint angle (angle between the pelvis local coordinate system and the trunk local coordinate system).

Statistical Analysis

Separate SAS version 9.4 proc GLIMMIX linear mixed effects models were used to compare differences in each dependent variable (trunk segment angles and abdominal joint angles) with functional capacity as a fixed effect grouping factor (high, low), participants as a random factor and trials as a covariate. Separate intercepts were fit for each participant using an unstructured variance-covariance matrix to account for the correlations between trials (10 trials per subject). A significant main effect for group was followed by post hoc analysis with Tukey correction for multiple comparisons between groups with alpha set at 0.05. Outcome data were reported as mean differences, standard error of the difference, 95% confidence intervals and Cohen's d effect sizes.

Results

Trunk Flexion/Extension and Anterior/Posterior Limits of Stability

Means and 95% confidence intervals for anterior/posterior limits of stability can be seen in upper left and upper right of Figure 3. The low function group had significantly less trunk segment flexion than the high group with a mean difference (MD) = -36.50, 95% confidence interval (CI) = -52.34 to -20.17, p < 0.0001, Cohen's d = 0.706. The trunk flexion angle represents the anterior limits of stability for a seated individual. The high classification group had a mean ± SE (95% CI) anterior limit of stability of 71.87 ± 5.78 degrees (60.33 to 83.43). In the low function group the mean anterior limit of stability was 35.37 ± 5.78 degrees (23.82 to 46.92).

There were no significant differences between groups for trunk segment extension angle MD = 9.28 degrees, CI: -21.12 to 39.67, p = 0.54, Cohen's d = 0.096. The high function group posterior limit of stability occurred with a mean ± SE (95% CI) trunk segment extension angle of 30.56 ± 10.75, (9.07 to 52.05 degrees). The low functional classification group posterior limit of stability occurred with a mean ± SE (95% CI) of 21.29 ± 10.75 (-0.21 to +42.77 degrees).

Trunk segment flexion-extension range of motion (ROM) was significantly different with MD = 45.78 ±16.80 degrees, CI: 12.21 to 79.34, p = 0.0083, Cohen's d = .431. Subjects in the high function group had a flexion-extension ROM of 102.44 ±16.80 degrees, CI: 78.70 to 126.17. Subjects in the low function group a flexion-extension ROM of 56.66 ± 11.88 degrees, CI: 32.92 to 80.39.

Abdominal joint flexion-extension ROM was also significantly different with a MD of 23.74 ± 9.77 degrees, CI: 4.21 to 43.28, p = 0.018, Cohen's d = .384. Low functioning subjects had a mean flexion – extension abdominal joint ROM of 19.02 ± 6.91 degrees, CI: 5.21 to 32.83, and whereas high functioning subjects had a mean flexion – extension abdominal joint ROM of 42.77 ± 6.91 degrees, CI: 28.95 to 56.58.

Lateral ROM for Trunk Segment Angle and Abdominal Joint Angle

Means and 95% confidence intervals for lateral range of motion can be seen in lower left of Figure 3. The high function group exhibited significantly more trunk segment lateral ROM than the low function group with a MD = 55.16 degrees, 95% CI: 22.51 to 87.81, p = 0.0013, Cohen's d = .534. In the high function group the mean ± SE (95% CI) trunk segment flexion ROM was 105.42 ± 11.55 degrees (82.33 to 128.50). For the low functional classification group, mean ± SE (95% CI) trunk segment ROM was 50.26 ± 11.55 degrees (27.17to 73.35). Furthermore, there was a significant difference in abdominal joint lateral range of motion with a MD of 8.41 ± 3.85 degrees, p = .033, 95% CI: 0.71 to 16.11, Cohen's d = 0.345. The mean ± SE (95% CI) abdominal joint ROM for high functional was 48.47 ± 8.47 degrees (31.54 to 65.39) compared to 40.06 ± 8.44 degrees (23.18 to 56.94) in the low function group (Figure 4, left).

Rotational ROM for Trunk Segment Angle and Abdominal Joint Angle

Means and 95% CI for longitudinal rotation of the trunk segment about the Z-axis can be seen in bottom right Figure 3. The high function group exhibited significantly more trunk segment rotational ROM than the low function group with a MD = 44.47 degrees, 95% CI: 28.68 to 28.68, p < 0.0001, Cohen's d = .890. The high functional classification group trunk segment angle had a mean ± SE (95% CI) ROM of 114.24 ± 8.54 degrees (97.18 to131.31) compared to 69.78 ± 8.45 degrees (52.89 to 86.65) of trunk segment rotation for the low classification group.

Means and 95% CI for longitudinal rotation of the abdominal joint about the Z-axis can be seen on the left of Figure 4. The high function group exhibited significantly more abdominal joint rotational ROM than the low function group with a MD = 38.51 degrees, 95% CI = 27.31 to 49.72, p = 0.0001, Cohen's d = 1.09. The high functional classification group abdominal joint angle had a mean ± SE (95% CI) ROM of 93.62 ± 6.35 degrees (80.92 to 106.32) compared to 55.10 ± 6.29 (42.53 to 67.68) for the low functional classification group.

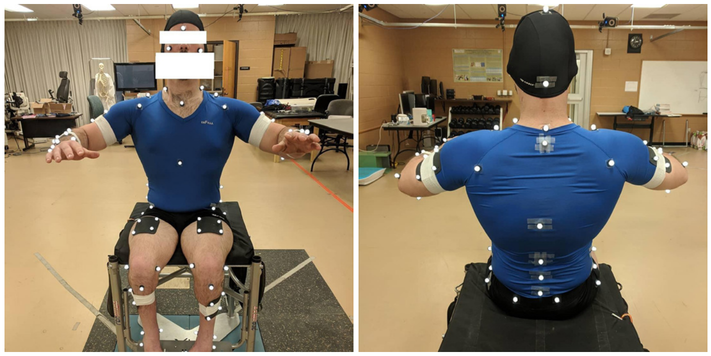

Figure 1:

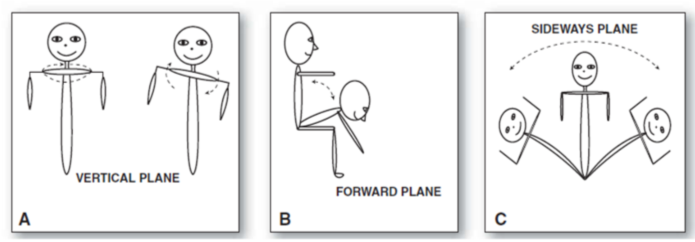

Figure 2: Volume of Action, adapted from IWBF [5].

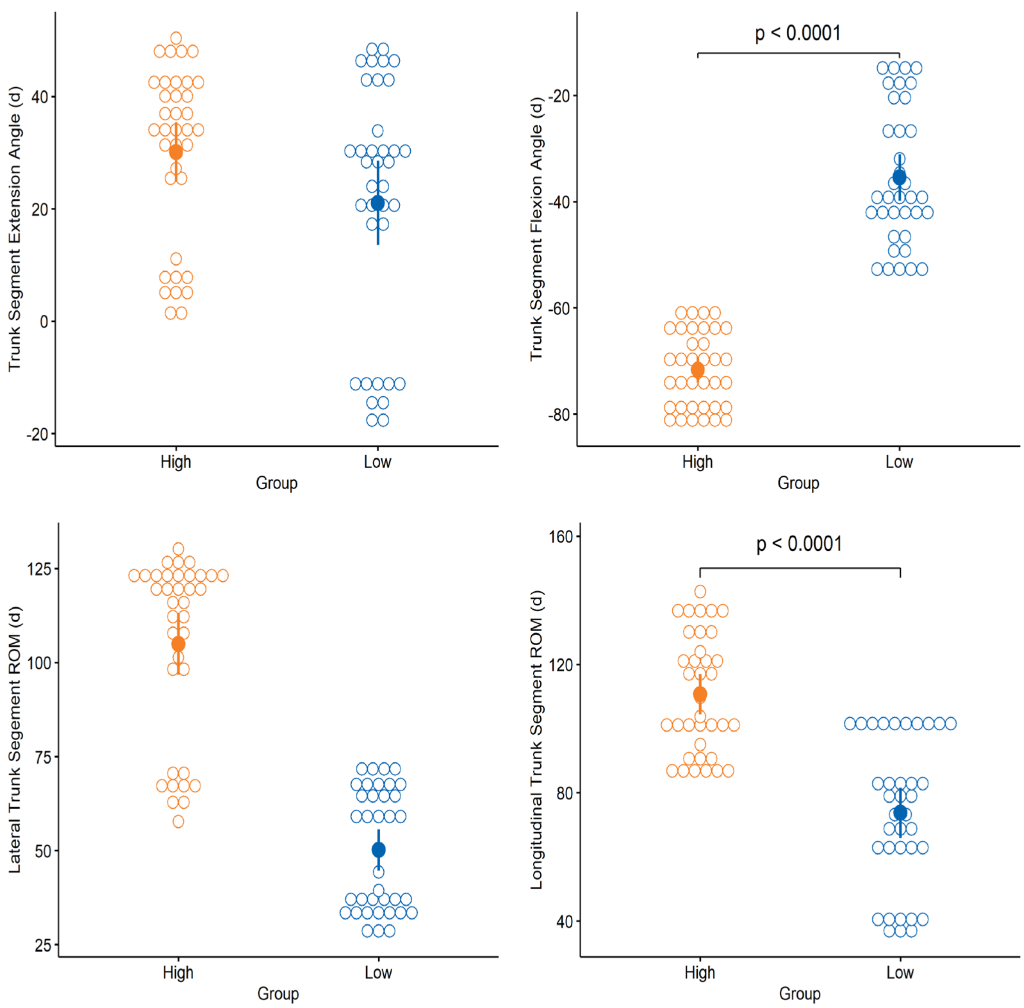

Figure 3

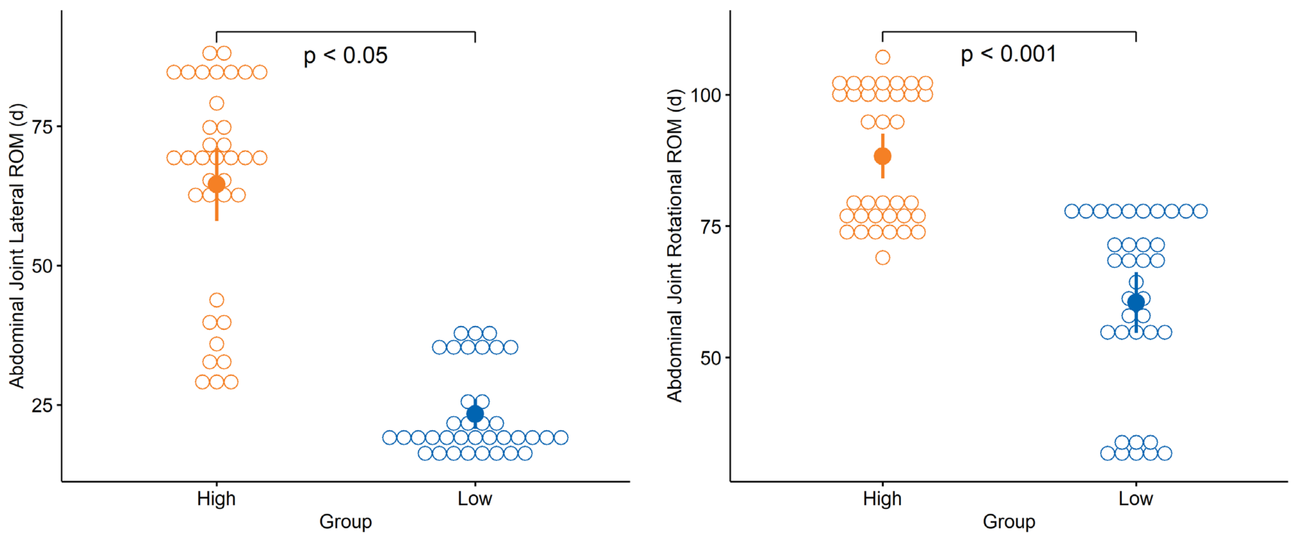

Figure 4

Discussion

The purpose of this study was to quantify the Volume of Action of wheelchair basketball players across a functional spectrum. The results of this study indicate that static limits of stability are significantly different across a functional spectrum using the functional classification system employed in wheelchair basketball. Limits of stability via lateral trunk flexion to the left and right, rotation of the trunk along the Z-axis, and flexion in the sagittal plane was lower in class 2.5 and below than it was in class 3.0 and above. These results lend further support to the validity of the functional classification system used in wheelchair basketball. Importantly, this investigation was among the first to observe rotation of the trunk, which is an integral part of the functional classification system.

The Volume of Action framework is the foundation of the functional classification system and is defined as *"the limit to which a player can move voluntarily in any direction, and with control return to the upright seated position, without holding the wheelchair for support or using the upper extremities to aid the movement"* [5]. As important as this concept is to both the sport of wheelchair basketball and independence in wheelchair users, very little work has been done to examine or quantify it. Indeed, the concept of limits of stability is particularly appropriate in the observation of volume of action, as it requires that the participant reach the limits of their ability to maintain their posture, then actively return to the upright position. Santos et al. [11] employed a modified limits of stability test using a Neurocom Balance Master to determine the maximum distance traveled by the center of gravity and found significant differences between classification groups for trunk flexion/extension and left and right lateral flexion. Importantly, they were unable to examine rotation of the trunk, which is the key differentiator between class I and class II individuals in this system [5]. The ability to rotate the trunk increases the ability of wheelchair users to execute numerous functional and contributes to overall stability [5], and as such is an accurate indicator of overall function within this functional classification system. In the present study, high functional classified participants were able to rotate the trunk about the longitudinal axis with a ROM of 114.24 degrees (95% CI of 97.18 to 131.31). In contrast, low functional classified individuals had significantly less longitudinal trunk ROM rotation (69.78 degrees, 95% CI of 52.90 to 86.66). Contrary to the results of Santos et al., we did not find a significant difference between groups for trunk extension. This may have been a result of a small sample size, as well as an absence of players with a classification of 4.0 or 4.5.

The requirement that participants return to the upright position is a key feature of this research, and to the concept of functional capacity [19]. The ability to flex and extend the trunk is the primary identifier of class III and above, and differentiates players between class II and class III. Individuals who are capable of this action are able to generate more power in their push [20,21] and also more competitive in other aspects of the game, such as rebounding or retrieving a ball from the ground. Additionally, this is applicable to activities of daily living, such as functional reach or stabilizing the trunk during ascending or descending a ramp. However, the key requirement is that the movement be active trunk flexion, as opposed to passive flexion due to gravity. If a player requires the use of their hands to push themselves back up into the upright position, they are not considered to demonstrate the appropriate level of function needed for a class III or above. This study sought to mimic that requirement by requiring participants to flex their trunk to the point at which they felt they would lose their balance and then return to an upright position.

Differences in the lateral limits of stability between the high and low function groups have real world implications when performing activities of daily living. The high function group in our study had 8.96 degrees more lateral range of motion in the trunk segment and 8.41 degrees of lateral abdominal joint range of motion when compared to the low function individuals. The high function individuals were able to laterally tilt the pelvis and laterally tilt the trunk further than the low function group. These differences in lateral limits of stability greatly impact lateral balance when bending to the side to grasp an object, placing the low function individual at great risk of fall in the lateral direction.

This study required participants to sit on a flat surface, which removed any potential passive stability that may be provided by the wheelchair during competition [5]. While this allowed us to examine functional capacity without having to elucidate the role of the wheelchair in providing stability, it does remove the wheelchair user from the system in which they operate on a day-to-day basis. Wheelchair configuration has been shown to influence the user's ability to stabilize themselves [22,23]. Curtis et al., [24] found that wheelchair users who used a strap to stabilize their trunk and lower body significantly increased their limits of stability when going through the motions that wheelchair basketball classifiers look for during competition. Future work should examine the role of wheelchair configuration in the manifestation of the Volume of Action framework as it applies to both wheelchair athletes and manual wheelchair users in general. Potential practical applications may exist for this framework in examining functional differences in activities of daily living, or important injury prevention techniques such as the wheelchair push-up to prevent pressure ulcers [4].

Limitations

There are some potential limitations to this study. First, this study used wheelchair basketball functional classification as a means of stratifying participants into functional groups, but all data was collected in a laboratory setting. This is potentially significant, as classifications are given to players only after observation during competition. While there is evidence to suggest that the functional classification system reasonably predicts functional capacity [25-27], it is unclear what role sport wheelchair set up plays in the demonstration of functional capacity. Second, similar to other researchers [15,28,29], we divided our participants into two groups due to a small sample size in each of the wheelchair basketball classifications. While this is a common practice in the literature, an appropriate sample size of each different classification may have provided more clarity in the role of trunk function in the limits of stability, as well as further differentiated between each classification (class I versus class II, for example). Third, we did not have any participants who were classified as 4.0 or 4.5. These two classifications are the highest functional classifications, and typically consist of amputees or semi-ambulatory individuals who have full trunk function but have lower limb impairments that preclude them from participating in able-bodied sports. It is expected that inclusion of individuals with these two classifications would have further increased the differences seen between the two groups. Inclusion of these classifications and increasing the sample size such that each classification is able to be grouped together (as opposed to two separate groups of "high classification" and "low classification") may further elucidate the role of active vs passive pelvic stabilization strategies for both sport purposes and activities of daily living. Finally, as mentioned there was no accounting for limb deficits that may have influenced classifications. Future studies should work with classification professionals to differentiate participants into groups based solely on trunk function in order to elucidate functional differences of the trunk in the wheelchair-using population.

Conclusions

In conclusion, the results of this study indicate that seated limits of stability differ significantly between high functioning and low functioning wheelchair users, and that these differences are consistent with the Volume of Action concept that is the basis of the wheelchair basketball functional classification system. Wheelchair users in higher classifications (3.0 and above) exhibited greater volume of action in all planes of movement. Taken together, these results indicate that the functional classification system used by the IWBF and NWBA objectively stratifies wheelchair users into classifications based on trunk function, and that a volume of action framework can be used to stratify wheelchair users to examine functional differences in movement.

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