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Increased Seat Dump Angle in a Manual Wheelchair is Associated with Changes in Thoracolumbar Lordosis and Scapular Kinematics during Propulsion

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Abstract

Objective—To quantify and compare spinal curvature and shoulder kinematics throughout the manual wheelchair propulsion cycle for individuals with spinal cord injury (SCI) who were seated at 2 different seat dump angles.

Design—Single-group, repeated-measures study.

Setting—Academic medical center.

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Presentations of Manuscript Content: Beth Cloud previously presented aspects of this work during a PhD thesis defense (July 2015, Mayo Clinic, Rochester, MN) and at a Physical Medicine and Rehabilitation Department Education Conference (August 2015, Mayo Clinic, Rochester, MN). Part of this work has been accepted for a podium presentation by Beth Cloud at the Academy of Spinal Cord Injury Professionals Educational Conference and Expo (September 2016, Nashville, TN)

Conflicts of interest: The authors have no conflicts of interest that are relevant to this work to report.

Participants—Twenty-eight individuals completed the telephone screening; 21 were eligible and completed the study.

Interventions—Participants' personal manual wheelchairs were modified to have seat dump angles of 0° or 14°, with a vertical backrest. Participants completed at least 3 propulsion cycles in each condition, during which spine and shoulder motion data were collected with fiber optic and electromagnetic sensors, respectively.

Main Outcome Measures—Thoracolumbar spinal curvature, glenohumeral kinematics, and scapulothoracic kinematics at the start of push (SP), mid push (MP), end of push (EP), and mid recovery (MR).

Results—Participants had significantly less lordosis in the 14° condition for all propulsion events. Median differences ranged from 2.0° to 4.6°. Lordosis differences were more pronounced in those with low SCI. Scapulothoracic internal rotation was increased in the 14° condition at SP and MP (mean differences of 2.5° and 2.7°, respectively). Relative downward rotation increased in the 14° condition at SP and MP (mean differences of 2.4° and 2.1°, respectively). Scapulothoracic differences were more pronounced in those with high SCI. No glenohumeral rotations were significantly different between the conditions.

Conclusions—Scapulothoracic kinematics and spinal curvature differences during propulsion may be associated with the position of other body segments or postural stability. Because no differences were observed at the glenohumeral joint, risk of subacromial impingement may not be affected by this seat angle change.

Keywords

shoulder; spinal cord injuries; spine; seating; wheelchair

Individuals with spinal cord injury (SCI) rely heavily on their upper extremities for activities of daily living and mobility. This population has a high prevalence of shoulder pain, and most cases are speculated to result from subacromial impingement or rotator cuff pathology.^{1–3} Effective movement strategies are vital to reduce the risk of injury, particularly for frequently performed activities such as propulsion. Characterization of factors, including equipment parameters and movement strategies, is essential to determine how they influence propulsion kinematics.

Manual wheelchair (MWC) seating parameters are known to affect upper-extremity kinematics and function.^{4–7} Shoulder kinematics can be altered by adjusting the seat height and anterior-posterior position relative to the axle. Specifically, the humerus has less internal rotation when the shoulder is further behind and above the wheel axle.⁵ Posterior positioning of the seat relative to the axle also advantageously increases push angle and decreases stroke frequency.⁴ Additionally, lower backrest height facilitates greater range of motion of the shoulder,⁷ which can mean fewer push strokes to attain a particular speed, effectively reducing repetitive propulsion movements. However, decreasing height of the backrest and posterior positioning of the seat should be used only if stability is maintained. The extensive characterization of seating parameters, particularly with regard to anterior-posterior seat position, has led to clinical recommendations for seating prescriptions.⁸ A better

understanding of other seating parameters can improve the effectiveness of seating prescriptions for optimal function and prevention of overuse injuries.

The seat dump angle, a wheelchair parameter defined as the inclination of the seat relative to horizontal, has been evaluated for its effects on posture, reaching, and other functional activities.^{9, 10} An increased seat dump angle, where the front of the seat is higher than the back, with vertical backrest increases reach height in individuals with SCI (compared with a horizontal seat with vertical backrest or increased seat dump angle with reclined backrest).¹⁰ Additionally, increases in seat dump angle, in a non-MWC seat, have been associated with more anterior pelvic tilt in some individuals with SCI during a bilateral reaching task.¹¹ Clinically, seat dump angles are increased to improve seated stability in the MWC, even though such changes may also increase difficulty of transfers. Despite the current knowledge and application of seat dump angles, little is known about their effect on propulsion mechanics.

Spinal and trunk posture can affect shoulder motion in different activities. A more flexed seated posture during MWC propulsion is associated with more shoulder flexion and elbow extension at contact and release of the push rim.¹² In able-bodied individuals, the effect of posture on scapula and humeral kinematics has been evaluated during arm-raise tasks.^{13, 14} A slouched seated posture is associated with increased scapular internal rotation and decreased posterior tilt during an arm-raise compared with sitting in an upright posture.

Evidence suggests that upper extremity movement during propulsion is influenced by certain MWC seat changes. The effect of seat dump angle on propulsion has not been reported but is known to affect seated posture and reaching. Posture itself is known to influence shoulder kinematics during propulsion and arm raises. The various known interactions between posture, the shoulder, and seating parameters warrant further investigation. The purpose of this study was to quantify and compare spinal curvature and scapulothoracic and glenohumeral kinematics throughout the MWC propulsion cycle while individuals with SCI were seated at 2 different seat dump angles (0° and 14°) with a vertical backrest. We hypothesized that participants would have more lordosis (due to anterior tilting of the pelvis) in the 14° condition, leading to a more upright posture. Additionally, we hypothesized that individuals would propel with increased scapulothoracic posterior tilt and decreased scapulothoracic internal rotation (due to a more upright posture) in the 14° seat dump angle.

Methods

Participants

Individuals with SCI or spinal cord disease who used MWCs participated in 1 study session from August 2014 through April 2015. This study was approved by our Institutional Review Board. All participants provided written informed consent before engaging in study procedures. We recruited subjects from Minnesota, Wisconsin, and Iowa via clinical databases, clinician referrals, and study flyers. Eligibility for participation was determined via telephone screening and physical examination. Briefly, inclusion criteria were as follows: at least 1 year of MWC use, independent MWC use, active shoulder range of motion within limits needed to perform propulsion during the study procedures, and ability to perform

transfers without assistance. Exclusion criteria were as follows: spinal rods or other hardware prohibiting movement of the entire lumbar spine, limited hip or spine range of motion preventing positioning in experimental seating conditions, allergy to medical-grade adhesive tape, MWC with a seat-to-back angle too acute to create the 0° condition, peripheral nerve entrapment, shoulder joint instability, marked scapular muscle denervation, or a history of surgery or serious injury that precluded restoration of pre-injury functionality in the tested arm.

Participants completed the Wheelchair User's Shoulder Pain Index (WUSPI), a previously validated tool that quantifies shoulder pain during 15 common MWC-based tasks.^{15, 16} The severity of shoulder pain, if present, was indicated using a 10-cm visual analog scale for each task. The total score was calculated by summing the distance in centimeters for all tasks; the highest possible score of 150 indicates extreme pain. Activities not performed by the individual were excluded from the analysis, per WUSPI scoring procedures. Participant scores were adjusted by dividing the total length measured by the items completed and then multiplying by 15.

Experimental Conditions

Participants propelled their personal MWCs on a set of custom rollers (Biomechanics Laboratory, Mayo Clinic). The order of experimental seating conditions (0° and 14° seat dump angle) was randomly determined, and both conditions used a vertical backrest (Figure 1A–B). A 14° seat dump angle is comparable to a 4-inch height difference between the front and back of a 17-inch seat. The seat dump angle conditions were chosen because they were the extreme ends of the spectrum for seat angles with a vertical backrest. The conditions were consistent with prior studies evaluating the effect of seat angles on reach height, pelvic posture,¹⁰ and seated pressure.¹⁷

Measurement of each participant's MWC were obtained to describe baseline seating and to determine the approach for creating the experimental seating conditions. Measurements included seat dump angle and seat-to-back angle. Experimental seating conditions were created by modifying baseline parameters—height of the support surface under the caster wheels was increased, and wedges were placed between the MWC frame and cushion. Foam blocks were placed between the participant's feet and footplates for support when wedges were used. Two individuals had MWCs that were incompatible with the data collection setup. One chair interfered with the electromagnetic system and the other had power-assist wheels. For these participants, alternate MWCs were used.

Before data collection, participants completed several propulsion cycles to become familiar with the experimental seating conditions. Participants were instructed to complete at least 3 cycles of propulsion at a self-selected speed for data capture. If more cycles were completed, only the first 3 were used for data analysis. Because some participants had only 3 cycles of propulsion, selecting the first 3 allowed for consistency in the analysis.

Spinal Curvature

Thoracolumbar sagittal plane spinal curvature was measured during propulsion with a fiber optic system, ShapeTape^a (Measurand, Inc.), and collected at 60 Hz with ShapeRecorder

software^b (Measurand, Inc.). The fiber optic system comprised 16 sensor regions, 46 mm each; sensors were placed over the spinous processes from the seventh cervical vertebra to the first sacral vertebra. Aside from the origin, which was taped directly to the skin at the first sacral vertebra, the fiber optic system was housed within a flexible sleeve (Figure 1C). Spinal curvature was defined as previously described.¹⁸ In brief, Cartesian coordinates along the thoracolumbar spine were fit with a spline curve. Regions of lordosis and kyphosis were identified and defined as angles created by the intersection of the normal vectors at the end points of each region. Spinal curvature was quantified for each frame of each propulsion cycle.

Shoulder Complex Kinematics

During propulsion, shoulder kinematics of the dominant arm (determined by handedness) were measured with an electromagnetic system^c (Liberty; Polhemus) and recorded at 120 Hz with MotionMonitor software^d (Innovative Sports Training, Inc). Sensors were placed on the thorax (over the manubrium), scapula (at the superior surface of the acromion), and humerus (via a thermoplastic cuff) (Figure 1D–E). Local coordinate systems were defined using the International Society of Biomechanics (ISB) standards.¹⁹ The right-hand rule was used to determine positive and negative convention for describing glenohumeral and scapulothoracic rotations. The ISB-recommended Euler sequence was used to define scapulothoracic motion (YX'Z''). An alternative sequence was used for definition of glenohumeral motion (XZ'Y'').²⁰

Identification of Propulsion Cycles

Synchronizing pulses were generated simultaneously in MotionMonitor and ShapeRecorder to align the data for analysis. A custom Matlab program^e (MathWorks) was used to identify individual propulsion cycles using the humerothoracic plane of elevation motion. The start of the propulsion cycle, start of push (SP), was defined as the first minimum peak of humerothoracic plane of elevation (most horizontally abducted position). The next peak minimum represented the end of the current propulsion cycle and start of the next cycle. The transition between push and recovery phases (end of push [EP]) within each cycle was determined by the maximum peak of humerothoracic plane of elevation (most horizontally adducted position). Mid push (MP) and mid recovery (MR) were also identified and defined as the midpoint, based on time, of the push and recovery phases, respectively. The approach used to identify propulsion cycles has been validated against measurements of force applied on the push wheels during propulsion using a SMARTWheel^f (Three Rivers Holdings, LLC) (unpublished data).

Data Analysis

Lordosis, kyphosis, and scapulothoracic and glenohumeral kinematics were quantified at 4 events across the propulsion cycle (i.e., SP, MP, EP, and MR). The Supplemental Figure shows a sample time series for all motions across the propulsion cycle. The outcome variables were averaged across 3 propulsion cycles for each participant in each seating condition.

All outcomes were compared between the 2 seating conditions for the full group and subgroups stratified by SCI level: high SCI (T9 and above, n=11) and low SCI (T10 and below, n=10). A parametric test (paired *t* test) was used if the data demonstrated a normal distribution, as determined by the Shapiro-Wilk test, and had similar variance in each of the seating conditions, as determined by the Levene test. If these criteria were not met, a nonparametric test (Wilcoxon signed-rank test) was applied. All analyses were completed with $\alpha=0.05$ and using JMP software^g (SAS Institute Inc). A sample of 20 participants allowed us to detect a large effect size in outcomes (0.66) with 80% power.

Results

Participants

Twenty-eight individuals completed the telephone screening; 21 were deemed eligible and participated in the study. The mean (SD) age of participants was 42 (5) years. SCI levels ranged from C6/7 to L2; one participant had spinal cord disease without a specific level. Although we did not specifically attempt to recruit individuals with shoulder pain, 18 participants (86%) reported some level of pain on the WUSPI. Additional details regarding participant characteristics, MWC parameters, and shoulder pain are presented in Table 1.

All participants but one completed propulsion in both seating conditions. The one who did not complete propulsion was from the high-SCI group (level C6/7) and felt too unstable in the 0° seat dump angle condition.

Most of the shoulder kinematics (glenohumeral and scapulothoracic) and kyphosis values at the events were normally distributed in the full group and subgroups. Lordosis values for the full group and high-level subgroup at all events in the 14° condition were not normally distributed, and the low group had unequal variances at most events between the 2 seating conditions.

Spinal Curvature

The full group of participants had significantly less lordosis in the 14° condition compared with the 0° condition at all propulsion events (Table 2). No significant differences were detected between seating conditions for kyphosis (Supplemental Table 1).

The low-level SCI group had, on average, less lordosis in the 14° condition during all events (Table 2). The high-level SCI group did not have any significant differences in lordosis or kyphosis (data not shown).

Spinal curvature data from the participants' usual seating condition is provided as reference (Supplemental Table 1).

Shoulder Complex Kinematics

For the full group of participants, no significant differences were noted in any of the 3 glenohumeral rotations between the 0° and 14° seat dump angle conditions for all events (Supplemental Table 2). Similarly, no differences were detected in the subgroup analyses that stratified participants by SCI level (data not shown).

For the full group of participants, we observed significant differences in scapulothoracic motion between the seating conditions at SP and MP. Internal rotation was higher in the 14° seat dump angle condition at SP and MP (Table 3). The upward/downward rotation value was also larger in the 14° condition at SP and MP (Table 4).

Individuals in the high-level SCI group had significantly higher values of internal rotation in the 14° condition for 3 of 4 events across the propulsion cycle (Table 3). Increased values of upward/downward rotation (indicating relatively more downward rotation) were also observed across propulsion in the 14° condition, except for EP (Table 4). No significant differences were observed in any scapulothoracic value in the low-level SCI group (data not shown).

Shoulder kinematics data from the participants' usual seating condition is provided as reference (Supplemental Tables 2–3).

Discussion

For individuals with SCI, spinal curvature and scapulothoracic kinematics differed during propulsion when MWC seat dump angles were set at 0° and 14°. Specifically, they have less lordosis across the propulsion cycle in the 14° vs 0° condition, the opposite effect than hypothesized. Kyphosis was not significantly affected. Small but significant differences were detected in scapulothoracic internal rotation and upward/downward rotation at events across the propulsion cycle, particularly at the SP and MP. Participants tended to propel with more internal rotation (contrary to our hypothesis) and more relative downward rotation across the propulsion cycle when in the 14° condition. No differences were detected at the glenohumeral joint between seat conditions. The changes observed in lordosis and scapulothoracic motion between the seating conditions may represent two different strategies to adjust to the seating change.

Reduced lordosis in the 14° condition may be due to the position of the femurs when the front of the seat is higher than the back. Increasing the seat dump angle effectively places the femurs in a greater amount of flexion compare to a horizontal seat. Hip flexion can then cause the pelvis to tilt posteriorly, which flattens the lumbar spine (ie, decreases lordosis).²¹ We hypothesized that the 14° seat dump angle condition would create a barrier against posterior tilting of the pelvis. However, this seat inclination may not guarantee a particular starting position of the pelvis. Over time, the greater seat dump angle may prevent movement of the pelvis, particularly increased posterior tilting resulting from anterior translation of the ischial tuberosities. The reported evaluations of propulsion were completed shortly after the seating change occurred, so long-term effects remain unknown.

The difference in scapular motion could be associated with the differences in stability and balance attributed to seat inclination. Individuals with paraplegia, particularly those with higher-level SCI, engage scapular musculature, including the latissimus dorsi and ascending fibers of the trapezius, for stability during reaching tasks.^{11, 22} With seat inclination, activation of the trapezius decreases, suggesting a decreased reliance on the trapezius for stability.¹¹ In our study, the 14° condition may have also decreased reliance on scapular

muscles for stability and allowed the scapula to move more freely. Whether these changes are advantageous for the shoulder health of MWC users is unknown. During arm raises in able-bodied individuals and during transfers in individuals with SCI, increased scapular internal rotation is commonly observed when the individual has subacromial impingement vs being pathology-free.^{23–28} However, because of the cross-sectional nature of those past studies, we cannot determine whether the increased internal rotation is a cause or effect of subacromial impingement.

Glenohumeral kinematics are directly associated with risk of subacromial impingement because the orientation of the humerus relative to the scapula dictates the size of the subacromial space. We did not detect a difference in glenohumeral kinematics between the two seating conditions, which suggests that their risk of subacromial impingement is similar. Therefore, although the seating changes showed differences in kinematics for propulsion tasks, these changes did not appear to affect risk of subacromial impingement. Further investigation is warranted to directly evaluate the subacromial space and risk to structures contained therein during MWC-based activities.

Level of SCI appears to influence how an individual responds to changes in the seat dump angle. Overall, participants adapted their movement strategies to propel in the different seating conditions but their SCI level affected how that change occurred. Those with low-level injuries may have a greater ability to adjust the spine through greater preservation of trunk musculature. Individuals with high-level SCI may have a smaller range of spinal postures that provide stability and thus compensate for the seating change at the shoulder complex instead.

Study Limitations

Our study captured propulsion over a limited period shortly after implementing the seating condition. Therefore, these results may not reflect long-term effects of these seating changes. Additionally, other body segments (e.g., pelvis, forearm, and hand) were not measured because of technical constraints. We are unable to conclude how these segments may have adapted or interacted with the spine and shoulder complex in response to the seating conditions. Lastly, although temporal variables could have been influenced by this seat angle change, they were not measured in this cohort.

Conclusions

During propulsion, scapular kinematics and spinal curvature differed between 0° and 14° seat dump angle conditions. The adaptation at the scapula appeared to be strongest in those with high-level SCI, whereas the changes in spinal curvature were strongest in those with low-level SCI. These differences may be associated with the position of other body segments or postural stability that occurs with varying seat angles. Although the different seat angles affect motion approaches, they do not appear to directly influence the risk of subacromial impingement because no differences were observed in the glenohumeral joint.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Supplier List

- a. ShapeTape: Measurand, Inc., Fredericton, New Brunswick, Canada
- b. ShapeRecorder: Measurand, Inc., Fredericton, New Brunswick, Canada
- c. Liberty: Polhemus, Colchester, VT
- d. MotionMonitor: Innovative Sports Training, Inc., Chicago, IL
- e. Matlab: Mathworks, Natick, MA
- f. SMARTWheel: Three Rivers Holdings, LLC, Mesa, AZ
- g. JMP software: SAS, Cary, NC

Abbreviations

EP	end of push
IQR	interquartile range
ISB	International Society of Biomechanics
MP	mid push
MR	mid recovery
MWC	manual wheelchair
SCI	spinal cord injury
SP	start of push
WUSPI	Wheelchair User's Shoulder Pain Index

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Figure 1. Seating conditions and sensor placement

A–B, 0° and 14° seat dump angles, respectively. Orientation of the seating surface is shown with a light gray line. C, Fiber optic system along spinous processes from C7 to S1. D–E, Placement of electromagnetic sensors on the thorax (T), scapula (S), and humerus (H) via a thermoplastic cuff.

Table 1**Participant Characteristics**

Characteristic	All Participants (N=21)	High - Level SCI (n=11)	Low - Level SCI (n=10)
Male sex, No. (%)	16 (76.2)	10 (90.9)	6 (60)
Age, mean (SD), y	41.9 (10.2)	41.8 (10.9)	42.0 (9.84)
Body mass, mean (SD), kg	81.2 (22.3)	87.5 (24.5)	74.2 (18.4)
Time using MWC, mean (SD), y	17.0 (9.7)	17.5 (11.2)	16.5 (8.27)
Personal MWC [*]			
Seat dump angle, mean (SD), °	7.4 (3.0)	7.6 (3.0)	7.3 (3.1)
Seat - to - back angle, mean (SD), °	90.6 (2.8)	91.5 (2.6)	89.6 (2.7)
Shoulder pain reported, No. (%)	18 (85.7)	10 (90.9)	8 (80)
WUSPI score, mean (SD) [†]	23.3 (21.6)	21.9 (24.5)	25.0 (18.8)
Injury level, No. (%)			
C6 – C7	2 (9.5)	2 (18.2)	...
T1 – T9	9 (42.8)	9 (81.8)	...
T10 – T12	7 (33.3)	...	7 (70)
L1 – L2	2 (9.5)	...	2 (20)
Spinal cord disease	1 (4.8)	...	1 (10)

Abbreviation: MWC, manual wheelchair; WUSPI, Wheelchair User's Shoulder Pain Index.

^{*} Seat dump angle was recorded for only 19 participants; 1 not recorded, 1 participant had a natural chair setup equal to a 0° test condition.

[†] WUSPI score corrected for corrected for 4 participants; 3 did not answer 1 question (tub/shower transfer or loading wheelchair into car) and 1 did not answer 3 questions (transferring from wheelchair to car, tub/shower transfer, and loading wheelchair into car).

Table 2Changes in Lordosis Spinal Curvature During Propulsion, Stratified by Seat Dump Angle^{*}

	Spinal Curvature, median (IQR),°		Difference in Spinal Curvature, median (IQR),°	P Value†
Event	Seat Dump Angle, 0°	Seat Dump Angle, 14°		
All Participants				
Start of push	9.9 (2.4 to 20.6)	5.4 (0.5 to 12.1)	3.2 (0 to 9.8)	.01
Mid push	11.7 (4.0 to 18.8)	4.7 (0.6 to 12.7)	2.0 (0 to 10.6)	.02
End of push	18.2 (8.5 to 26.7)	10.1 (1.6 to 17.3)	4.6 (0 to 13.5)	.02
Mid recovery	11.5 (4.4 to 21.4)	5.3 (0.3 to 14.6)	3.5 (−0.5 to 11.2)	.03
Low-Level SCI‡				
Start of push	15.6 (6.8 to 27.5)	8.4 (5.4 to 18.2)	5.7 (0.3 to 13.8)	.02
Mid push	14.3 (7.5 to 30.3)	10.8 (5.3 to 17.2)	4.2 (−0.2 to 13.7)	.049
End of push	23.2 (15.6 to 38.9)	16.8 (12.2 to 20.9)	9.0 (−0.2 to 14.1)	.02
Mid recovery	19.2 (11.2 to 32.4)	13.0 (7.7 to 19.3)	7.6 (−0.8 to 13.4)	.049

Abbreviations: IQR, interquartile range; SCI, spinal cord injury.

^{*} Kyphosis was not significantly changed by seat dump angle. (See Supplemental Table 1.)[†] Wilcoxon signed-rank test.[‡] Low-level SCI was defined as T10 and below.

Table 3Changes in Scapulothoracic Internal Rotation During Propulsion, Stratified by Seat Dump Angle^{*}

	ST Internal Rotation (+), mean (95% CI),°		Difference in ST Internal Rotation, mean (95% CI),°	P Value [‡]
Event	Seat Dump Angle, 0°	Seat Dump Angle, 14°		
All Participants				
Start of push	22.2 (17.0 to 27.4)	24.2 (19.0 to 29.3)	2.5 (0.4 to 4.6)	.02
Mid push	23.7 (18.1 to 29.3)	25.8 (20.2 to 31.4)	2.7 (1.0 to 4.5)	.004
End of push	35.6 (30.5 to 40.6)	37.0 (31.6 to 42.4)	1.8 (−0.3 to 4.0)	.09
Mid recovery	28.2 (22.9 to 33.4)	29.5 (24.2 to 34.8)	2.0 (−0.2 to 4.1)	.07
High-Level SCI [‡]				
Start of push	17.0 (8.3 to 25.7)	20.9 (11.9 to 30.0)	4.6 (1.0 to 8.2)	.02
Mid push	18.9 (9.8 to 28.1)	22.1 (12.7 to 31.5)	4.1 (0.9 to 7.2)	.02
End of push	31.0 (22.5 to 39.6)	33.6 (24.1 to 43.1)	3.0 (−0.2 to 6.2)	.06
Mid recovery	23.6 (15.0 to 32.3)	26.5 (17.2 to 35.8)	3.9 (0.4 to 7.3)	.03

Abbreviations: ST, scapulothoracic; SCI, spinal cord injury.

^{*} No significant differences in scapulothoracic internal rotation were observed for the low-level SCI group.[‡] Paired *t* test.[‡] High-level SCI was defined as T9 and above.

Table 4Changes in Scapulothoracic Upward/Downward Rotation During Propulsion, Stratified by Seat Dump Angle ^{*}

	ST Upward/Downward Rotation (-/+), mean (95% CI), [°]		Difference in ST Upward/Downward Rotation, mean (95% CI), [•]	P Value [†]
Event	Seat Dump Angle, 0 [°]	Seat Dump Angle, 14 [°]		
All Participants				
Start of push	-2.6 (-7.7 to 2.6)	-0.4 (-4.6 to 3.8)	2.4 (0.2 to 4.5)	.03
Mid push	-6.4 (-11.2 to -1.6)	-4.7 (-8.7 to -0.6)	2.1 (0.01 to 4.2)	.049
End of push	-1.4 (-5.5 to 2.7)	-0.6 (-4.4 to 3.1)	0.9 (-1.2 to 3.0)	.38
Mid recovery	-2.7 (-7.0 to 1.7)	-1.3 (-5.0 to 2.3)	1.6 (-0.2 to 3.6)	.09
High-Level SCI [‡]				
Start of push	-6.0 (-13.7 to 1.7)	-1.8 (-9.1 to 5.5)	4.4 (2.0 to 6.9)	.003
Mid push	-8.8 (-16.2 to -1.3)	-5.6 (-12.8 to 1.6)	3.8 (0.8 to 6.8)	.02
End of push	-3.4 (-10.7 to 4.0)	-0.9 (-7.8 to 5.9)	2.6 (-0.6 to 5.8)	.10
Mid recovery	-5.2 (-12.5 to 2.1)	-2.1 (-8.8 to 4.5)	3.6 (1.3 to 6.0)	.006

Abbreviation: ST, scapulothoracic; SCI, spinal cord injury.

^{*} No significant differences in scapulothoracic upward/downward rotation were observed for the low-level SCI group.[†] Paired *t* test.[‡] High-level SCI was defined as T9 and above.