Can the Kinect detect differences between proper and improper wheelchair transfer techniques?

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ABSTRACT

Improper transfer technique predisposes wheelchair users to upper limb joint pain and injuries. The purpose of the current study is to investigate if the Kinect can distinguish between proper and improper transfer techniques. Nine full time wheelchair users performed sitting pivot transfers and the quality of their transfer was scored using the Transfer Assessment Instrument (TAI). Seven unimpaired subjects were also asked to perform four different types of improper transfer techniques that were compared to a proper TAI-based technique. Upper extremities and trunk motion during the transfer trials were measured in both groups using the Kinect. Larger angles of trunk flexion ($p = 0.02$), shoulder elevation ($p < 0.06$), and larger head-hip relative velocity ($p = 0.02$) and acceleration ($p = 0.06$) were detected when the subjects performed head-hip relationships correctly. The Kinect was also able to delineate between correct and incorrect arm positions (p ranges from 0.02 to 0.09). The results suggest the Kinect may be used as a tool to help wheelchair users and therapists assess and train proper transfer techniques.

INTRODUCTION

In the United States, there were approximately 276,000 persons with spinal cord injury (SCI) in 2013 and 12,500 new cases occur each year ("Annual Statistical Report - Facts and Figures at a Glance," 2015). Persons with lower limb paralysis rely on their upper extremities to lift and transfer their body for the completion of activities of daily living (ADLs) (Fliess-Douer, Vanlandewijck, & Van der Woude, 2012). A full-time wheelchair user will perform on average 14 to 18 transfers per day (Finley, McQuade, & Rodgers, 2005). During the performance of transfers, the wheelchair user often applies excessive loads on their arms. Using incorrect transfer skills may further predispose wheelchair users to developing upper limb pain and overuse related injuries, such as rotator cuff tears and carpal tunnel syndrome (Dalyan, Cardenas, & Gerard, 1999) (Paralyzed Veterans of America Consortium for Spinal Cord, 2005) (van Drongelen et al., 2006) that greatly reduce quality of life, independence and societal participation (Gerhart, Bergstrom, Charlifue, Menter, & Whiteneck, 1993; Lundqvist, Siosteen, Blomstrand, Lind, & Sullivan, 1991) (Rintala, Loubser, Castro, Hart, & Fuhrer, 1998) .

The Transfer Assessment Instrument (TAI) was developed to evaluate the quality of sitting-pivot wheelchair transfer techniques and identify any deficits in component skills (McClure, Boninger, Ozawa, & Koontz, 2011) (Tsai, Rice, Hoelmer, Boninger, & Koontz, 2013). Higher scores on the TAI (e.g. using better hand/arm and trunk positions to perform transfers) translate to less mechanical loading on the upper extremities joints (Tsai, Hogaboom, Boninger, & Koontz, 2014). The TAI measures many different components of a transfer including proper setup of the wheelchair and body positioning during transfers. The two components selected for this study (Items 9 and 12) were chosen because they are two of most common deficiencies observed in wheelchair transfer technique and they are directly related to the movement patterns observed during the transfer (Koontz, Kankipati, Lin, Cooper, & Boninger, 2011). Item 9 on the TAI, which checks if a handgrip is utilized correctly by the leading arm, can be given a 'no' score if no handgrip is outside of the base of support or if the hand is fisted or placed with fingers fully extended on the surface. Reaching for a handgrip that is outside of one's base of support will result in undesirable arm positions (e.g. highly elevated and/or overextended shoulder). The second set of criteria ensures that the hand is placed properly on the surface (e.g. fingers are gripping the surface).

The Kinect, released by Microsoft in 2010, is a low-cost, portable, and marker-less video gaming sensor and an accessory for the Xbox gaming system to track the movement of a player. Recently it has been used to track upper and lower body motions in several rehabilitation applications (R. A. Clark, Pua, Bryant, & Hunt, 2013) (Ross A. Clark et al., 2015) (Kiselev, Haesner, Govercin, & Steinhagen-Thiessen, 2015). It consists of an infrared (IR) light projector, an IR camera, a RGB video camera, and microphones. The Kinect sensor v1.8 detects and records the body surface with depth and RGB data recorded from the cameras then applies an algorithm of triangulation to automatically identify the location of joint centers of the body in the 3-D space. In 2014, Microsoft released a new version of Kinect for Xbox One with wide-angle time-of-flight camera and improved resolution for the traditional camera. Compared to Kinect v1.8, the Kinect for Xbox One can identify 25 joint centers (compared to 20 from the v1.8) and Kinect has faster processor and 60% wider field of vision.

The purpose of this study is to determine if Microsoft Kinect can distinguish between proper and improper transfer techniques in unimpaired subjects (UIs) who were trained to perform proper and certain improper techniques and a SCI cohort who performed transfers using their natural methods. For the wheelchair users (WCUs) with SCI, we hypothesized that smaller peak angles of the plane of elevation in shoulder (POE), shoulder elevation, elbow flexion, and wrist extension would be detected by the Kinect for WCUs who put their leading arm in proper positions during transfer as determined by the TAI score. We also hypothesized that smaller angles trunk and thigh (subjects flexed more) and larger velocities and accelerations of the head relative to the hips would be detected when the WCUs used a head-hip relationship to transfer in accordance with the TAI principles. For the UIs, we hypothesized that Kinect could detect differences in these same motion variables between a proper TAI transfer and four different improper transfer motions. The findings will be used to guide the development of a transfer technique assessment and coaching system that can be used in a clinical setting.

METHODS

Participation

The study was approved by the Department of Veterans Affairs Institutional Review Board. All testing occurred at the Human Engineering Research Laboratories in Pittsburgh, PA. For the WCUs, each subject met the following inclusion criteria: (1) older than 18 years old, (2) one year after injury or diagnosis, (3) use a wheelchair for at least 40 hours/week, and (4) unable to stand up without support. The exclusion criteria were (1) pressure sores within the past year, (2) history of angina or seizures. For the UIs, the inclusion criteria were: (1) older than 18 years old, and (2) able to perform transfers independently without assistance.

Testing Protocol – WCUs

Subjects were asked to naturally position themselves next to a bench, and perform up to five trials of level-height bench transfer in their natural way. They were provided an opportunity to adjust their wheelchair position and familiarize themselves with the setup prior to data collection. Subjects had time to rest in between trials and additional rest was provided as needed. During each transfer, up to two study clinicians independently observed and scored each subject's transfer skills using the TAI. The same two clinicians evaluated all of the participants in the study. Both were physical therapists who were trained to use the TAI before the study started. The trials were recorded using the Kinect v1.8 because the current version of Kinect for Xbox One was not available yet during the testing period.

Table 1. Joint centers defined by two Kinect sensors to calculate the body segment vectors.
https://msdn.microsoft.com/en-us/library/jj131025.aspx
https://msdn.microsoft.com/en-us/library/microsoft.kinect.jointtype.aspx

Body Segment Vectors	Kinect v1.8	Kinect for Xbox One
Trunk	Shoulder_Center Hip_Center	Spine_Shoulder Spine_Base
Shoulder	Shoulder_Center Shoulder_Left	Spine_ Shoulder Shoulder_Left
Upper Arm	Shoulder_Left Elbow_Left	
Forearm	Elbow_Left Wrist_Left	
Hand	Hand_Left Wrist_Left	
Thigh	Knee_Left Hip_Left	

Testing Protocol – UIs

Before the trials, the subjects were trained how to perform proper transfer techniques in accordance with TAI principles (Rice et al., 2013). After the training and practice period, the subjects performed proper transfers to a level-height bench (ST). Then the subjects were asked to perform four types of improper transfer motions: placing leading arm behind (posterior to) the trunk (BAK), placing the leading arm outside the base of support (FAR), using a clenched fist on the leading hand (FIST), and keeping trunk upright (TU) during transfer. Each proper and improper transfer was performed five times for one subject. These trials were recorded using the latest Kinect sensor for Xbox One with a Windows adaptor.

Microsoft Kinect Motion Sensor

The Kinect sensor was mounted on a tripod and placed 2 m in front of the subjects, 70 cm above the floor and centered between the transfer surface and where the subjects placed their wheelchairs. A graphical user interface was programed in C# using Visual Studio 2012, .NET Framework 4.0, and the Kinect for Windows SDK to collect the 3D joint center position data in a Cartesian coordinate system from the Kinect system. The joint motions of the leading arm and trunk were calculated based on the approaches defined by the Standardization and Terminology Committee (STC) of the ISB (Wu et al., 2005). Body segment vectors were defined using the joint centers from the Kinect. Different joint centers were available to use for each Kinect system (Table 1). These joint center positions were acquired at 30 Hz sampling frequency for both Kinect systems. The joint motion angles were defined as the angles between the two body segment vectors (Table 2).

The head-hip relationship is a technique that can make the transfer easier to perform. This technique involves leaning the trunk forward towards the target and then lifting the body and "twisting" the buttocks to the target. Ideally the head and hips are moving in opposite directions (the hip is moving towards the target and the head is slightly moving away from the targert). Thus we hypothesized that the Kinect can determine if a subject is not using the head-hip relationship by using a larger angle between the thighs and shoulders and a lower head-hip relative velocity/acceleration compared to those who performed the relationship. The head-hip relative velocity and acceleration

Table 2. Vectors for the joint motion angle calculation.
* The POE is defined as a angle between the vectors of trunk_anterior and upper arm projected on the transverse plane
** The trunk anterior vector is normal to the coronal plane in anterior direction calculated by the cross product between the truck and shoulder vector.

Joint Motion Angle	Vectors for Angle Calculation	
Shoulder POE*	Trunk_Anterior **	Upper Arm
Shoulder Elevation	Trunk	Upper Arm
Elbow Flexion	Upper Arm	Forearm
Wrist Extension	Forearm	Wrist
Trunk	Trunk	Thigh

Table 3, Average (Avg), range of motion (ROM), maximum (Max), and minimum (Min) degrees of each joint motions, and head-hip relative velocity/acceleration (Head-Hip Vr/Ar) in WCUs and UIs in each trials associated to the leading arm position. ST, proper transfers; BAK, placing leading arm behind (posterior to) the trunk; FAR, placing the leading arm outside the base of support; FIST, using a clenched fist on the leading hand during transfers.

		WCUs				UIs										
		proper (n=5)		improper (n=4)		ST (n=7)		BAK (n=7)			FAR (n=7)			FIST (n=7)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-value	Mean	SD	p-value	Mean	SD	p-value
Shoulder POE (Deg.)	Avg	81.99	9.30	81.59	2.18	111.07	14.83	133.93	20.68	**0.02**	112.95	17.20	0.61	111.75	10.38	0.87
	ROM	62.79	29.63	82.01	11.41	80.93	24.76	76.15	33.54	0.74	87.01	30.64	0.40	77.46	22.48	0.87
	Max	109.48	19.44	112.31	2.22	144.24	10.83	165.49	10.66	**0.02**	150.87	9.80	**0.03**	147.57	15.06	0.40
	Min	46.70	12.66	30.30	10.70	63.31	28.15	89.34	40.41	**0.09**	63.86	30.87	1.00	70.11	19.12	0.40
Shoulder Elevation (Deg.)	Avg	49.97	6.19	53.34	17.62	53.71	13.80	47.76	14.75	0.13	64.15	13.57	**0.06**	56.44	10.58	0.61
	ROM	63.58	23.64	56.38	14.34	67.05	36.03	56.56	24.31	0.31	68.95	24.27	0.87	63.59	20.63	0.87
	Max	90.80	20.02	82.92	22.24	91.73	35.32	76.56	29.57	**0.09**	98.42	24.25	0.74	92.44	23.56	0.74
	Min	27.21	9.59	26.54	15.74	24.68	3.27	20.00	6.50	0.24	29.47	5.63	**0.06**	28.85	5.95	0.18
Elbow Flexion (Deg.)	Avg	33.52	2.66	45.21	7.58	34.63	9.81	40.93	24.31	1.00	32.71	14.12	0.87	47.16	7.46	**0.02**
	ROM	43.88	20.44	53.95	18.53	48.04	22.82	71.26	37.90	**0.06**	54.76	22.80	0.24	54.70	17.28	0.31
	Max	60.05	16.58	75.47	16.34	62.38	25.04	83.14	43.00	0.24	65.03	25.06	0.31	77.83	13.26	**0.06**
	Min	16.17	5.52	21.52	4.01	14.34	6.86	11.88	8.42	0.31	10.27	5.22	0.18	23.13	9.22	**0.02**
Wrist Extension (Deg.)	Avg	22.33	7.70	18.87	2.88	35.29	13.66	38.63	11.39	0.74	32.33	9.93	0.50	32.26	13.82	0.24
	ROM	58.36	24.91	62.50	13.12	78.16	13.87	85.98	22.50	0.87	68.00	32.37	0.50	67.86	28.66	0.31
	Max	61.71	23.50	64.18	13.34	85.33	17.21	92.94	22.04	0.61	75.75	29.90	0.61	74.97	27.97	0.31
	Min	3.35	1.70	1.68	0.33	7.17	5.67	6.95	4.63	0.87	7.76	3.72	0.40	7.11	6.25	0.74
Trunk (Deg.)	Avg	70.33	6.29	71.49	7.81	76.48	21.09	75.02	14.59	0.50	75.78	23.95	0.50	81.52	12.97	0.31
	ROM	55.21	10.17	60.58	8.11	50.80	18.87	52.29	24.78	0.74	64.10	30.00	0.24	56.89	28.78	0.87
	Max	86.60	3.35	85.86	5.46	104.14	26.08	103.15	21.40	0.24	110.20	29.42	0.61	110.36	22.55	0.87
	Min	51.82	9.53	56.44	9.89	53.35	20.63	50.86	14.24	0.61	46.10	19.78	**0.06**	53.47	15.40	0.61
Head-Hip Vr (m/s)	Avg	0.56	0.22	0.44	0.07	0.76	0.28	0.82	0.31	0.61	0.95	0.38	**0.04**	0.73	0.27	0.61
	Max	2.94	1.98	1.79	0.48	3.41	1.24	3.70	0.62	0.45	4.04	1.28	0.18	3.33	1.01	0.87
	Min	0.05	0.02	0.05	0.01	0.11	0.05	0.10	0.09	0.67	0.12	0.05	0.80	0.11	0.06	0.93
Head-Hip Ar (m/s^2)	Avg	1.90	2.81	1.10	1.78	2.60	1.28	3.10	1.11	0.31	4.66	1.99	**0.09**	2.58	1.32	0.87
	Max	104.43	57.98	75.59	56.54	125.17	66.75	134.79	38.05	0.50	147.00	47.30	0.24	125.71	52.73	0.87
	Min	-65.52	54.93	-39.78	19.54	-59.95	31.96	-56.57	20.73	0.87	-53.50	25.88	0.31	-49.32	23.01	0.24

was defined as the velocity/acceleration of the head relative to the hip. The velocity vector was calculated by the joint centers of “Head” and “Hip_Center” in Kinect v1.8 as well as “Head” and “Spine_Base” in Kinect for Xbox One.

Data analysis

Descriptive statistics (means and standard deviations (SD)) were calculated for each variable. Average, maximum, minimum, and ranges of motion (ROM) for angles of shoulder POE, shoulder elevation, elbow flexion, wrist extension, and trunk, as well as maximum head-hip relative velocity and acceleration were computed for each transfer trial. These kinematic variables were averaged over the five transfer trials performed within each transfer condition. All the statistical analyses were performed in SPSS 21 (IBM Inc., Chicago, IL).

WCUs group: Subjects were sorted into a proper and improper group based on the yes/no response on the TAI items. For the leading arm position, TAI part 1, item 9 (TAI 1-9), “if no handgrip is available or outside the individual’s base of support, the hand should be placed flat on the transfer surface” was applied. For the head-hip relationship, TAI part 1, item 12 (TAI 1-12), “head-hip relationship is used” was applied. Mann-Whitney test was used to compare the kinematic variables between the proper and improper transfer groups on TAI items 1-9 and TAI 1-12.

UIs group: A paired t-test was used to compare the kinematic variables between each improper type of transfers (BAK, FAR, FIST, and TU) to the proper ST transfer. The level of significance was set to 0.1.

RESULTS

Participants

Nine male WCUs participated in this study. Five subjects had a SCI, one had double above-knee amputation; one had muscular dystrophy, one had osteogenesis imperfecta, and one had myelopathy.

Leading Arm Position

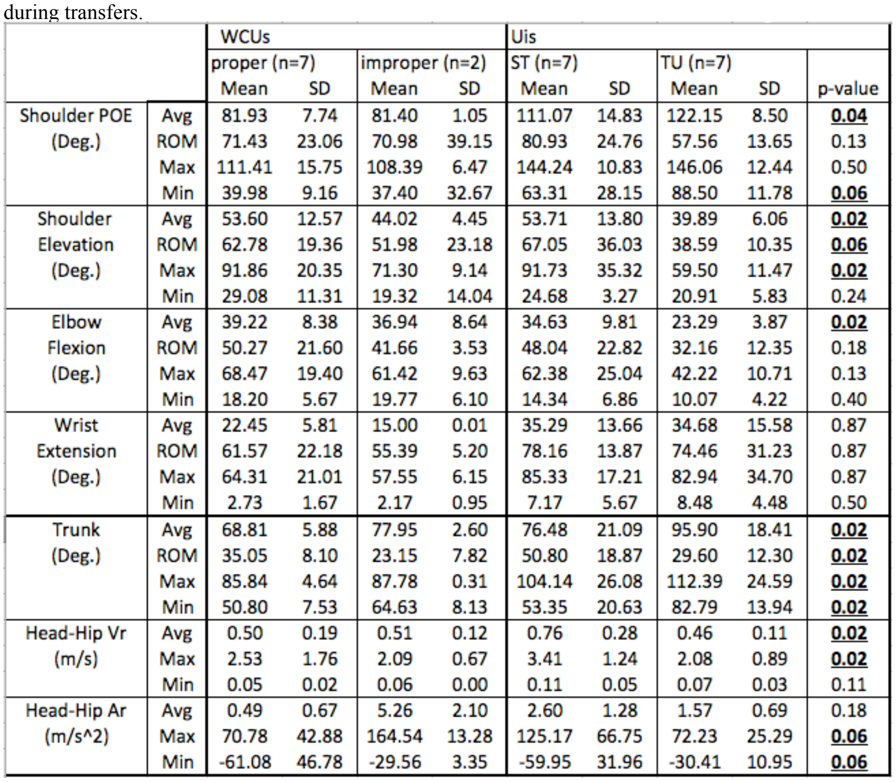
WCUs who did not position their leading arm properly (n=4) applied larger average and minimum elbow flexion angles, and smaller average and minimum wrist extension angles compared to those who positioned their leading arm properly (n=5; table 3).

For the UIs, the Kinect detected larger average, maximum, and minimum angles of shoulder POE ($p < 0.09$) in BAK, larger average and minimum angle of shoulder elevation in FAR, and larger average, maximum, and minimum elbow flexion angle in FIST when compared to using the proper TAI technique (ST).

Head-Hip Relationship

WCUs who properly applied the head-hip relationship (n=7) had larger average, maximum, and minimum angles of shoulder elevation, and smaller average and minimum trunk angles (subject flexed more) compared to those who did not use the head-hip relationship (n=2). (Table 4).

Table 4, Average (Avg), range of motion (ROM), maximum (Max), and minimum (Min) degrees of each joint motions, and head-hip relative velocity/acceleration (Head-Hip Vr/Ar) in WCUs and UIs in each trials associated to the head-hip relationship. ST, proper transfer skill; TU, keeping trunk upright during transfers.



		WCUs				Uis				
		proper (n=7)		improper (n=2)		ST (n=7)		TU (n=7)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-value
Shoulder POE (Deg.)	Avg	81.93	7.74	81.40	1.05	111.07	14.83	122.15	8.50	**0.04**
	ROM	71.43	23.06	70.98	39.15	80.93	24.76	57.56	13.65	0.13
	Max	111.41	15.75	108.39	6.47	144.24	10.83	146.06	12.44	0.50
	Min	39.98	9.16	37.40	32.67	63.31	28.15	88.50	11.78	**0.06**
Shoulder Elevation (Deg.)	Avg	53.60	12.57	44.02	4.45	53.71	13.80	39.89	6.06	**0.02**
	ROM	62.78	19.36	51.98	23.18	67.05	36.03	38.59	10.35	**0.06**
	Max	91.86	20.35	71.30	9.14	91.73	35.32	59.50	11.47	**0.02**
	Min	29.08	11.31	19.32	14.04	24.68	3.27	20.91	5.83	0.24
Elbow Flexion (Deg.)	Avg	39.22	8.38	36.94	8.64	34.63	9.81	23.29	3.87	**0.02**
	ROM	50.27	21.60	41.66	3.53	48.04	22.82	32.16	12.35	0.18
	Max	68.47	19.40	61.42	9.63	62.38	25.04	42.22	10.71	0.13
	Min	18.20	5.67	19.77	6.10	14.34	6.86	10.07	4.22	0.40
Wrist Extension (Deg.)	Avg	22.45	5.81	15.00	0.01	35.29	13.66	34.68	15.58	0.87
	ROM	61.57	22.18	55.39	5.20	78.16	13.87	74.46	31.23	0.87
	Max	64.31	21.01	57.55	6.15	85.33	17.21	82.94	34.70	0.87
	Min	2.73	1.67	2.17	0.95	7.17	5.67	8.48	4.48	0.50
Trunk (Deg.)	Avg	68.81	5.88	77.95	2.60	76.48	21.09	95.90	18.41	**0.02**
	ROM	35.05	8.10	23.15	7.82	50.80	18.87	29.60	12.30	**0.02**
	Max	85.84	4.64	87.78	0.31	104.14	26.08	112.39	24.59	**0.02**
	Min	50.80	7.53	64.63	8.13	53.35	20.63	82.79	13.94	**0.02**
Head-Hip Vr (m/s)	Avg	0.50	0.19	0.51	0.12	0.76	0.28	0.46	0.11	**0.02**
	Max	2.53	1.76	2.09	0.67	3.41	1.24	2.08	0.89	**0.02**
	Min	0.05	0.02	0.06	0.00	0.11	0.05	0.07	0.03	0.11
Head-Hip Ar (m/s^2)	Avg	0.49	0.67	5.26	2.10	2.60	1.28	1.57	0.69	0.18
	Max	70.78	42.88	164.54	13.28	125.17	66.75	72.23	25.29	**0.06**
	Min	-61.08	46.78	-29.56	3.35	-59.95	31.96	-30.41	10.95	**0.06**

For the UIs, the Kinect detected larger average ($p = 0.02$), ROM ($p = 0.06$), and maximum angles ($p = 0.02$) of shoulder elevation smaller average, maximum, minimum, and larger ROM of the trunk angle ($p = 0.02$) (subject flexed more), higher average and maximum head-hip relative velocity, and higher average and minimum acceleration for the proper TAI technique (e.g. which incorporates the head-hips relationship) compared to their TU transfer.

DISCUSSION

Our study shows that the earlier Kinect v1.8 demonstrated the ability to distinguish proper from improper transfer technique in a SCI cohort. The results showed that the WCUs who scored a 'no' on Item 9 applied larger average and minimum of elbow flexion, and smaller average and minimum wrist extension compared to WCUs who scored a 'yes'. These results are promising and suggest that the Kinect can provide some general indication that handgrip used is appropriate or inappropriate. As a next step we further examined the sensitivity of the Kinect for detecting different lead arm positions and handgrips by training a group of UIs to specifically perform improper techniques that are commonly observed in practice: placing leading hand posterior to the trunk (BAK), placing leading hand far away from the trunk (FAR), and using a clenched fist on the leading hand (FIST). In this analysis Kinect detected larger angles of shoulder POE ($p < 0.09$) in BAK, shoulder elevation angles in FAR, and elbow angles in FIST compared to the proper TAI transfer. These results demonstrate that the Kinect for Xbox One has the ability to measure differences between proper and improper techniques in the shoulder and the elbow joint motions. The wrist angle measured by the Kinect for Xbox One showed no significant difference. One possible reason could be that the Kinect sensor has difficulty to identify the joint centers when the subject’s hand is in contact with an object or surface. These results suggest that it might be possible for Kinect to delineate quality of shoulder and elbow motions distinctively for transfer assessment and be used to support a future coaching tool.

The WCUs who performed the head-hips technique correctly showed the expected decreases in the trunk angles that indicate that the subject flexed their trunk more than those who did not perform the head-hips relationship. They also showed increases in shoulder elevation angles, implying that shoulder elevation motion could also be a factor in detecting the head-hip relationship. However a larger relative acceleration was measured in the improper group. It may be due to small sample size and the lower reliability of sensor in detecting the lower body section of Kinect v1.8 for a seated individual (Xu & McGorry, 2015).

The result shows that the new Kinect measured significant differences ($p<0.06$) between ST (proper) and TU (improper) head-hips relationship for the shoulder elevation angle, trunk flexion angle, and head-hip relative velocity/acceleration. These variables could be factors to evaluate the quality of trunk motion during transfer skills. The greater differences found for the UI group for the head-hips relationship may be due to a greater distinction between the ST and TU transfers motions or that the new Kinect is better at measuring these differences. This finding supports the need for future studies with the new Kinect and a WCU cohort.

CONCLUSIONS

The results demonstrate that Microsoft Kinect demonstrates the ability to distinguish between proper and improper transfer techniques by the joint motions measured for the upper extremities and trunk. The results provide evidence to support the potential feasibility of the Kinect to be used in a coaching system that assesses, trains and provides corrective feedback to improve the quality of transfer technique.

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