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Using the Microsoft Kinect™ to assess 3-D shoulder kinematics during computer use

Xu Xu [a, *], Michelle Robertson [b], Karen B. Chen [a], Jia-hua Lin [c], Raymond W. McGorry [b]

[a] *Edward P. Fitts Department of Industrial and Systems Engineering, North Carolina State University, Raleigh, NC 27695, USA*
[b] *Liberty Mutual Research Institute for Safety, 71 Frankland Road, Hopkinton, MA 01748, USA*
[c] *Safety and Health Assessment and Research for Prevention (SHARP) Program, Washington State Department of Labor and Industries, WA 98504, USA*

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ABSTRACT

Shoulder joint kinematics has been used as a representative indicator to investigate musculoskeletal symptoms among computer users for office ergonomics studies. The traditional measurement of shoulder kinematics normally requires a laboratory-based motion tracking system which limits the field studies. In the current study, a portable, low cost, and marker-less Microsoft Kinect™ sensor was examined for its feasibility on shoulder kinematics measurement during computer tasks. Eleven healthy participants performed a standardized computer task, and their shoulder kinematics data were measured by a Kinect sensor and a motion tracking system concurrently. The results indicated that placing the Kinect sensor in front of the participants would yielded a more accurate shoulder kinematics measurements then placing the Kinect sensor 15° or 30° to one side. The results also showed that the Kinect sensor had a better estimate on shoulder flexion/extension, compared with shoulder adduction/abduction and shoulder axial rotation. The RMSE of front-placed Kinect sensor on shoulder flexion/extension was less than 10° for both the right and the left shoulder. The measurement error of the front-placed Kinect sensor on the shoulder adduction/abduction was approximately 10° to 15°, and the magnitude of error is proportional to the magnitude of that joint angle. After the calibration, the RMSE on shoulder adduction/abduction were less than 10° based on an independent dataset of 5 additional participants. For shoulder axial rotation, the RMSE of front-placed Kinect sensor ranged between approximately 15° to 30°. The results of the study suggest that the Kinect sensor can provide some insight on shoulder kinematics for improving office ergonomics.

1. Introduction

Nowadays, computer use has become an important portion of occupational settings ranging from data entry tasks and call center service operators to knowledge workers using computers for various accounting and analytical tasks. Previous epidemiology studies have revealed that computer use is a potential risk factor for work-related musculoskeletal disorders (WMSD) (Collins and O'Sullivan, 2015; Waersted et al., 2010). It was found the incidence rate of shoulder and neck discomfort ranged between 10% and 60% for extensive computer users (Davis and Kotowski, 2014) where the prevalence of shoulder pain was ranked in the top three of the prevalence rates among various WMSD for computer users (Cho et al., 2012; Oha et al., 2014).

Shoulder discomfort among computer users could be due to the non-neutral posture of shoulder joints (Karlqvist et al., 1998), repetitive movement of the shoulder (Bernard, 1997), as well as little posture variation (Mathiassen, 2006). Since the shoulder joint angles can be representative indicators of those potential reasons for shoulder discomfort during computer use, it is crucial to measure shoulder kinematics during computer use for office ergonomics studies. In a lab setting, such measurement is normally performed by a motion tracking system (Asundi et al., 2010; Onyebeke et al., 2014).

It is, however, challenging to measure shoulder kinematics in field studies because of the difficulty of adopting or the feasibility of mass dissemination of motion tracking systems. One alternative way to estimate shoulder kinematics is through posture observation, either direct or video-based, such as Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 1993). While posture

* Corresponding author.
E-mail address: xxu@ncsu.edu (X. Xu).

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observation can be easily adopted for field studies, perception errors (van Wyk et al., 2009) and inter-rater reliability (Xu et al., 2011) can affect the accuracy of the estimated shoulder joint angles. Specifically, since computer use normally long periods of intense keying and mousing which provides continuous shoulder kinematics, posture observation can be very labor-intensive. To address these issues, a recent study (Bruno et al., 2012) developed a computer graphic algorithm to automatically extract the shoulder, elbow, and wrist joint centers from field survey videos and estimate the 2-D shoulder abduction. Such an algorithm can eliminate inter-rater disagreement and substantially improve the efficiency for posture observations from field survey video. The error can be well controlled within 12°. However, the algorithm cannot provide 3-D shoulder kinematics because field survey videos are essentially a 2-D mapping of 3-D movement. The algorithm also requires placement of high contrast stickers on the joints of the upper extremities for joint recognition from the video clips, which may fall off during the long-term movement.

The Kinect™ sensor was originally developed by Microsoft in 2010 for player interaction with video games using body movements. The most recent generation of the Kinect sensor can identify the 3-D location of 25 body joint centers at 30 Hz using a personal computer. Due to its portability, low cost, and marker-less design, the Kinect sensor can be easily adopted in home, office, clinics, or other built environments for measuring human movements. The validity of the Kinect sensor has been examined for various applications, including fall detection (Parra-Dominguez et al., 2012), gait analysis (Gabel et al., 2012; Pfister et al., 2014), posture control (Clark et al., 2012), functional assessment (Bonnechere et al., 2014), and clinical studies (Galna et al., 2014).

The goal of the current study is to investigate the potential of using the Kinect to estimate 3-D shoulder kinematics during computer use. Specifically, this study is to understand 1) the amount/magnitude of measurement error when using a Kinect sensor to monitor shoulder kinematics during computer tasks; 2) which placement of the Kinect sensor view angle can provide the best estimate of shoulder kinematics; and 3) whether the measurement error of the shoulder kinematics can be calibrated using a regression method.

2. Method

2.1. Participants

Eleven healthy participants (5 females and 6 males, age: 26.5 (9.2) years old, height: 1.71 (0.10) m, mass: 70.3 (10.9) kg) without acute or chronic musculoskeletal disorders were recruited from local communities. All the participants were familiar and comfortable using their right hand to operate a mouse. The experiment protocol was approved by the local Institutional Review Board. All the participants provided written informed consent for participating in this study.

2.2. Experiment setup

A simulated workstation was set up using a 17 inch LCD monitor, a keyboard, and a mouse. The mouse was placed on the right side of the keyboard. The participants sat in front of the workstation and on a stool with a low profile fixed-back support to perform a standardized computer task. This task was similar to the task used in Asundi et al. (2010), which included a combination of text typing, comprehensive reading, icon clicking, and icon dragging and dropping. The interface of the standardized computer task was developed using LabView (ver. 8.5, National Instruments, Austin, TX, USA) (see Fig. 1).

Each participant performed a 10-min computer task three times. A Kinect sensor (v2, Model 1656, Microsoft Corporation, Redmond, WA, U.S.A) was placed, randomly either right behind the monitor with the camera optical axis parallel to participants' sagittal plane (front), 15° to the left side of the participants, or 30° to the left of the participants. The horizontal distance between the Kinect sensor and the participants was approximately 75 cm. The height and the tilt angle of the Kinect sensor were adjusted so that the upper body and upper extremities of a participant could be observed by the Kinect sensor. Customized software using Kinect for Windows SDK 2.0 was used to acquire the raw 3-D locations of major joint centers at 30 Hz (Fig. 2). The raw data were then up-sampled to 60 Hz using the spline interpolation.

A motion tracking system (Optotrak Certus System, Northern Digital, Canada) was used to collect reference 3-D motion data at 60 Hz of the thorax, upper arms, and forearms. The motion tracking system was synchronized with the Kinect sensor. Anatomical landmarks for creating the anatomical coordinate system of each body segment were digitized using a probe (Wu et al., 2005).

2.3. Data processing

The motion tracking system-based anatomical coordinate system of the thorax and right upper arms was created in accordance with International Society of Biomechanics (ISB) recommendations (Wu et al., 2005). To avoid the artefact in the upper arm cluster positioning due to humerus axial rotation (Cutti et al., 2005), the second option for creating the upper arm coordinate system in the ISB recommendations was adopted as well as was used to define the Kinect sensor-based upper arm coordinate. Since the Kinect sensor did not directly provide the 3-D location of the bony landmarks that were used to define the thorax coordinate system in the ISB recommendations, the Kinect sensor-based thorax coordinate system was defined to mimic that in the ISB recommendation. They were as follows: Z-axis was from "*shoulder left*" to "*shoulder right*", X-axis was pointing anteriorly and was perpendicular to Z-axis and "*spine*".

The right shoulder joint angles were calculated from the rotation matrix describing the relative ordination of upper arms with respect to the orientation of the thorax. For the decomposition sequence the first rotation was adduction (X+)/abduction (X-), the second rotation was flexion (Z+)/extension (Z-), and the third rotation was internal axial rotation (Y+)/external axial rotation (Y-) (Bonnefoy-Mazure et al., 2010; Phadke et al., 2011). For the left shoulder joint angles, the motion data was mirrored to the right counterpart before performing the above-mentioned data processing (Wu et al., 2005).

For each view angle of the Kinect sensor placement, the correlation coefficient (r), concordance correlation coefficient (r_c), and root-mean-square error (RMSE) between the Kinect-based and motion tracking system-based shoulder joint angles were calculated. These indices are commonly used for concurrent validity analysis (Pfister et al., 2014). The motion tracking system-based shoulder joint angles were considered as the reference in this study. Freidman nonparametric tests were performed to investigate whether the view angle of the Kinect sensor significantly affected the r and r_c, while one-way repeated measure ANOVAs and post-hoc Tukey test were performed for RMSE of the shoulder joint angles. The statistical tests were performed by SAS 9.2 (SAS, Cary, NC, USA).

2.4. Shoulder kinematic calibration

During the pilot test, it was found that the measurement error of the Kinect sensor on the shoulder adduction/abduction was

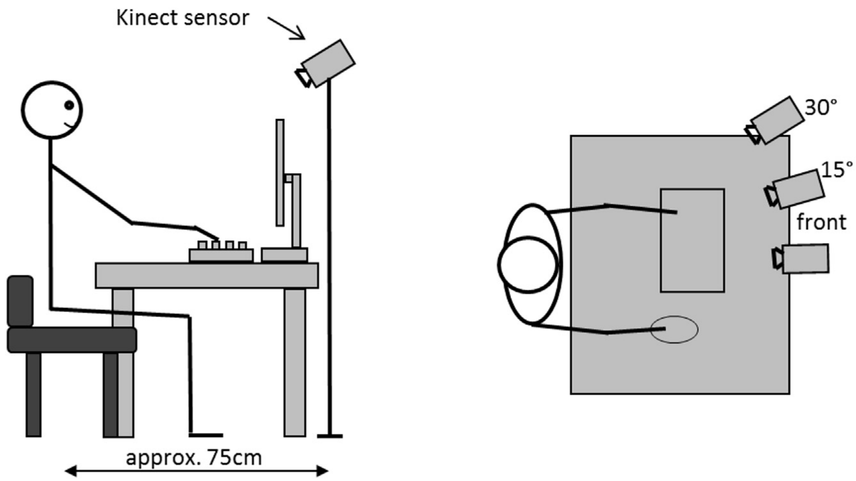

Fig. 1. An illustration of the experiment setup. Left: The Kinect sensor is placed 75 cm away from the center of the keyboard. The stool height is 46 cm, and the work station height is 77 cm. Right: The Kinect sensor is placed at participants' sagittal plane (front), 15° to the left side of the participants, or 30° to the left of the participants.

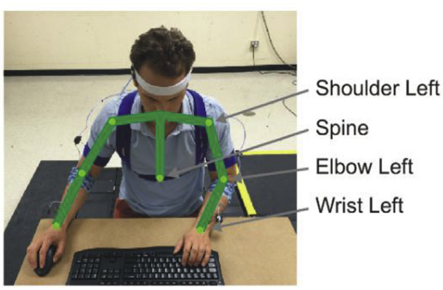

Fig. 2. The Kinect sensor-identified joints on trunk and upper extremities used in the current study. The name of joint is inherent in the Kinect sensor and may not have an anatomical meaning.

approximately proportional to the magnitude of that joint angle. Therefore, once the best view angle of the Kinect sensor was determined, the calibration equations were developed using linear regression for that view angle. The linear regressions were performed between each Kinect sensor-based shoulder joint angle and its motion tracking system-based counterpart. To evaluate the calibration equations, 5 additional participants (2 females and 3 males, age: 21.2 (3.1) years old, height: 1.75 (0.08) m, mass: 71.0 (8.6) kg) were recruited to follow the identical experimental protocol to provide an independent dataset. The root-mean-square error (RMSE) between the calibrated Kinect-based and motion tracking system-based shoulder joint angles were calculated and then compared with the RMSE of the non-calibrated Kinect-based shoulder joint angles using a *t*-test.

3. Results

The results indicate that the Kinect sensor had a better estimate on shoulder flexion/extension, compared with shoulder adduction/abduction and shoulder axial rotation. The RMSE was less than 10° for both the right and the left shoulder when the Kinect sensor was placed right in front of the participants. For adduction/abduction, the right shoulder had a greater error by approximately 5° to 10° than the left shoulder among three view angles (Table 1). The greatest error occurred on shoulder axial rotation, the RMSE, which ranged between approximately 20° to 40°.

Among three difference viewing angles, placing the Kinect sensor in front of the participants yielded a stronger correlation coefficient for right shoulder adduction/abduction, as well as a stronger concordance correlation coefficient for right shoulder flexion/extension. In addition, placing the Kinect sensor at 30° yielded a significantly greater RMSE for right shoulder flexion/extension, right shoulder axial rotation, and left shoulder axial rotation. Therefore, the results suggested that placing the Kinect sensor in front of the participants has a better accuracy level for measuring the shoulder joint angles. Subsequently, the kinematics calibration was based on the data of 0° view angle of the Kinect sensor.

Table 1
Correlation coefficient (r), concordance correlation coefficient (r_c), and root-mean-square error (RMSE), between the Kinect-based and motion tracking system-based shoulder joint angles. Small letters a and b, and Greek letters α and β represent significant differences of correlation coefficient and concordance correlation coefficient from Freidman nonparametric test. Capital letter A and B represent significant differences of RMSE post-hoc Tukey test.

Shoulder joint		Kinect sensor view angle		
		Front	15° to left	30° to left
right adduction/abduction	r	0.84 (0.20)^a	0.62 (0.35)^b	0.53 (0.29)^b
	r_c	0.28 (0.22)	0.19 (0.15)	0.30 (0.28)
	RMSE(°)	14.8 (5.9)	18.9 (6.7)	16.3 (9.0)
right flexion/extension	r	0.68 (0.18)	0.52 (0.21)	0.40 (0.30)
	r_c	0.40 (0.28)$^\alpha$	0.29 (0.18)$^\beta$	0.21 (0.20)$^\beta$
	RMSE(°)	8.7 (5.9)^A	10.6 (5.8)^A	14.0 (4.9)^B
right axial rotation	r	0.57 (0.46)	0.50 (0.46)	0.37 (0.27)
	r_c	0.32 (0.24)	0.27 (0.23)	0.17 (0.14)
	RMSE(°)	26.4 (9.1)^A	31.3 (12.8)^A	38.5 (7.9)^B
left adduction/abduction	r	0.53 (0.22)	0.57 (0.16)	0.53 (0.22)
	r_c	0.17 (0.18)	0.30 (0.21)	0.29 (0.26)
	RMSE(°)	9.9 (4.6)	7.0 (4.2)	8.5 (3.8)
left flexion/extension	r	0.75 (0.17)	0.60 (0.29)	0.49 (0.35)
	r_c	0.40 (0.31)	0.36 (0.26)	0.31 (0.29)
	RMSE(°)	9.1 (6.4)	9.5 (6.9)	12.0 (7.4)
left axial rotation	r	0.16 (0.37)	0.21 (0.41)	0.20 (0.36)
	r_c	0.06 (0.23)	0.12 (0.27)	0.08 (0.14)
	RMSE(°)	17.0 (11.3)^A	20.0 (10.5)^A	28.1 (15.8)^B

For the calibration, the right and left shoulder joint angles were aggregated together for parsimony since data from the front view angle were adopted. The RMSE of right shoulder adduction/abduction, flexion/extension, and axial rotation of those additional participants were 7.5° (4.9°), 8.1° (1.4°), and 27.3° (15.8°), respectively, after applying the calibration equations. For the left shoulder, the values were 6.4° (0.9°), 10.1° (4.5°), and 23.4° (9.1°), respectively. A subsequent *t*-test, however, revealed that only shoulder adduction/abduction were significantly improved in terms of the RMSE for right shoulder ($p = 0.0235$) and left shoulder ($p = 0.0443$) (Fig. 3). Therefore, only the calibration equation for shoulder adduction/abduction was reported here:

$$\theta_x^{Kin_{Cali}} = 0.72 \times \theta_x^{Kin} + 2.3^\circ. \tag{1}$$

where θ_x^{Kin} is the shoulder adduction/abduction angle measured by the Kinect sensor placed in front of the participants, and $\theta_x^{Kin_{Cali}}$ is the calibrated shoulder adduction/abduction angle.

4. Discussion

The goal of the current study was to understand the feasibility of using a Kinect sensor to monitor shoulder postures during computer use. The results indicate a great range of validity among different view angles and different shoulder joint angles. The correlation coefficients ranged from 0.16 to 0.84, and the concordance correlation coefficients ranged from 0.06 to 0.40. Therefore, the Kinect-based shoulder joint angles are positively correlated to those measured by a motion tracking system, and there is a positive agreement between the two systems in general.

The range of the correlation coefficient in the current study is similar to that of joint angles of lower extremities measured between a Kinect sensor and a motion tracking system during slow ground walking (Pfister et al., 2014), which was from −0.04 to 0.77. The range of the concordance correlation coefficients in the current study was, however, narrower than that of the temporal and spatial gait parameters measured by the Kinect sensor (Clark et al., 2013), which was from 0.14 to 0.99. Particularly, the concordance correlation coefficient for the left shoulder axial rotation was only around 0.1 for all view angles. The average RMSE across all the participants ranged from 8.5° to 38.5° for all the joint angles. If the shoulder axial rotation is excluded, the average RMSE is limited to 18.9°, which is similar to the error range for joint angles of lower extremities (Pfister et al., 2014). During the experiments, it was observed that the Kinect sensor tended to identify the lateral edges of the workstations as participants' forearms when the participants moved their hands closer to the edge of the workstation. Because the shoulder axial rotation is determined by the wrist position, this incorrect observation of the forearm resulted in a greater RMSE for shoulder axial rotation. This misidentification was more prominent for the left forearm then the right one in the current workstation setup possibly due to the mouse being positioned on the right side. The left forearm had less movement, making it more challenging for the Kinect sensor to identify. As noted, the left shoulder axial rotation had an even lower concordance correlation coefficient.

The finding of placing the Kinect sensor with the camera optical axis parallel to participants' sagittal angle can provide the best estimate on shoulder joint angles is consistent with the findings of Obdrzalek et al. (2012), where for siting posture the front-placed Kinect sensor had the most stable and reliable position of identified joint enters. This results suggest that the front placement of the Kinect sensor should be adopted, whenever it is possible, for monitoring the shoulder kinematics during computer use. However, it should be noted that the effect of the Kinect sensor placement may depend on what tasks (computer tasks vs. assembly tasks) and measurement are needed to be monitored. A previous study by Pfister et al. (2014) placed the Kinect sensor at 45° on the left side of the participants for monitoring lower extremities movements. Their results indicated a good measurement of gait temporal parameters based on the timing of maximum and minimum degrees of hip and knee flexion. Such results seem to suggest the Kinect sensor has a good validity of frequency domain even if is not placed directly in front of the participants. While computer use is not a highly periodically, cyclical, repetitive task for the shoulder, other tasks, such as light-duty assembly tasks, can be periodically repetitive for the shoulder. Whether placing the Kinect sensor at the side with an angle can have a good measurement on shoulder temporal parameters for these light-duty assembly tasks warrant further investigation.

The coefficients of the calibration equation (Eq. (1)) indicated that the Kinect sensor proportionally overestimated shoulder

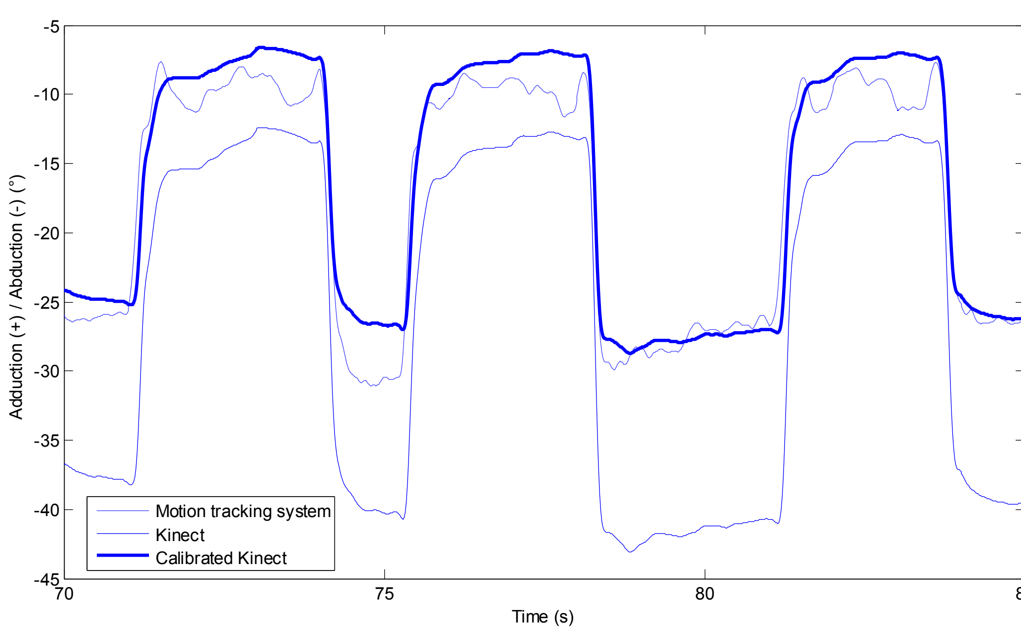

Fig. 3. An example showing the shoulder adduction/abduction measured by the motion tracking system, the Kinect sensor before the calibration, and the Kinect sensor after the calibration.

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adduction/abduction angle by approximately 39%. Such proportional overestimation has not been observed in previous studies of using the Kinect sensors. A plausible reason is that in most scenarios the Kinect sensors are mounted horizontally to the ground level, while in the current study the Kinect sensor was tilted down to capture the trunk and upper extremities of the participants. The shoulder adduction/abduction was based on the upward and downward position of the elbow joints relative to the shoulder joints. Once the Kinect sensor tilts down, such upward and downward position has a component along the optical axis of the Kinect sensor. Dutta (2012) found that the measurement error in the measurement volume of the Kinect sensor was not homogeneous. It was speculated that this proportional error may be related to the different levels of measurement errors along the three different axes of the coordinates of the Kinect sensor. It is of interest to further investigate the translational error of the joint centers measured by the Kinect sensor during computer use requiring an alignment between the motion tracking system and the Kinect sensor.

Although the results of the current study indicate that the shoulder kinematics measured by the Kinect sensor is less accurate than those measured by a motion tracking system, the Kinect sensor may potentially serve as an alternative device for shoulder posture categorization. A previous study (van Wyk et al., 2009) systematically investigated the optimal size for posture categories during video-based posture identification based on the trade-off between the number of misclassifications and the magnitude of error. Their study showed that, for shoulder flexion/extension and shoulder abduction/adduction, the magnitude of error is approximately 30° at their optimal posture category size as determined by human observation. Compared with the human observational error, the current results showed a smaller measurement error from the Kinect sensor. Additionally, the Kinect sensor is more efficient, as it appears, without human observation.

Using the Kinect sensors allows for a better understanding of the placement of the various computer input devices (e.g., keyboard, mouse) and the effects on the body postures. Furthermore, these non-neutral body postures have been correlated with musculoskeletal symptoms among computer users. Forearm support has been shown to be important to reduce the upper body static loads of the trapezius muscle and shoulder region. Given the increase mouse use among computer users, it is essential to examine the impact, as measured by the Kinetic system on the shoulder region to provide further guidelines for reducing upper extremity muscle loads within a range of specific degrees of shoulder flexion/extension and abduction and adduction.

There are a few limitations that need to be recognized regarding this study. First, the current study is based on a lab setup which provides an ideal workstation setup for the Kinect sensor to observe human movement. In reality, other factors such as the nature of the tasks, the placement of the input devices on the workstation, the shape and size of the workstation, the lighting conditions, etc. can also contribute to measurement error of the shoulder kinematics. Second, the sedentary seated postures adopted by the participants were more consistent than in the real-world condition since only a fixed-back support chair was provided for marker placement purpose in the experiment. When the participants can lean back, additional error may be introduced to the trunk orientation and, in turn, affect the shoulder kinematics. Third, because marker clusters needed to be attached to the body segments, only a tank top was worn by the participants during the experiment. Given that the Kinect sensor uses the scanned surface of the human body to identify the joint centers, wearing loose clothing could result in more error. Fourth, it should be noted that the current study only tested the validity of the Kinect sensor during the performing the computer tasks which involved only limited shoulder postures and tasks. Caution should be exercised in applying the Kinect sensor to measure other shoulder postures, such as overhead reaching during assembly tasks.

5. Conclusion

In summary, a large range of validity among the different view angle and different shoulder joint angles have been found when using the Kinect sensor to estimate 3-D shoulder kinematics during computer use. Placing the Kinect sensor in front of the participants can provide less error for the shoulder joint angles than placing the sensor at the side. Although the Kinect sensor is not as precise as a traditional motion tracking system, its accuracy, efficiency, cost-effectiveness, and non-intrusive property could provide a good alternative for shoulder posture categorization, such as RULA (McAtamney and Corlett, 1993), as the angle resolution is 20° to 45° in general. These measures can also provide potential essential information to guide the placement and arrangement of computer input devices and other computer accessories minimizing the shoulder joint angle deviation and shoulder repetitive motion, which are risk factors for shoulder musculoskeletal injuries.

Conflict of interest statement

All authors declare that there is no proprietary, financial, professional or other personal interest of any nature or kind in any product, service or company that could be construed as influencing the position presented in the manuscript entitled, “Using the Microsoft Kinect™ to assess 3-D shoulder kinematics during computer use”.

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