Research Paper

Comparing Microsoft Kinect and Observational Gait Analysis in Assessing Gait Parameters of Apparently Healthy Adults

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ABSTRACT

Objectives: Although the Microsoft Kinect has compelling potential for gait analysis in medicine, data available to compare it with observational gait analysis (OGA) is scarce. This study compared the Microsoft Kinect and the OGA in assessing the gait parameters of apparently healthy adults.

Methods: Ninety-seven apparently healthy young male adults participated in this comparative study. First, the participant's age, height, weight, and body mass index were obtained. Afterward, gait parameters involving the number of steps, cadence, stride length, and step length were assessed concurrently following OGA standard procedures and the Microsoft Kinect during a 6-m walk down the hallway. The obtained data were analyzed using descriptive and inferential statistics. The significance level was set at $P<0.05$.

Results: The Mean±SD walk time, steps, cadence, velocity, and stride length were 8.07±1.39 s, 14.0±2.96 counts, 72.9±11.9 steps/min, 0.8±0.13 m/s, and 0.77±0.13m, respectively. Step length was significantly higher ($P<0.05$) with Microsoft Kinect than OGA, whereas stride length and walk speed values were significantly ($P<0.05$) lower with Microsoft Kinect. A moderate but significant ($P=0.001$) positive correlation existed between Microsoft Kinect and OGA regarding walk speed. In contrast, regarding the step length, a weak but significant ($P<0.05$) positive correlation was found between Microsoft Kinect and OGA.

Discussion: Step length values of Microsoft Kinect were significantly higher than OGA values, whereas stride length and walk speed values of Microsoft Kinect were significantly lower than OGA values. Walk speed and step length measured by Microsoft Kinect and OGA were positively correlated.

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Highlights

• Microsoft Kinect gives significantly higher step length reading than observational gait analysis.

• Microsoft Kinect gives significantly lower stride length and walk speed readings than observational gait analysis.

• Microsoft Kinect and observational gait analysis readings of walk speed were directly but moderately correlated.

Plain Language Summary

Gait parameters (number of steps, cadence, stride length, and step length) were assessed using the observational gait analysis (OGA), which is a traditional approach. The values were compared with readings obtained using the Microsoft Kinect, Microsoft's motion sensor add-on for the Xbox 360 gaming console. Ninety-seven volunteers had their gait parameters measured while they walked on a 6-m hallway following standard procedures. Microsoft Kinect readings of step lengths were higher than OGA, while OGA's stride length and walk speed readings were higher. Only walk speed scores of both assessment methods were moderately correlated.

Introduction

Gait analysis is an important aspect of clinical practice employed among physiotherapists, kinesiologists, prosthetists, physiatrists, and other health team members to get a well-versed diagnosis, enable effective treatment planning, and evaluate the intervention [1-4]. The need for gait analysis and assessment was realized early enough in medical practice; hence, the keen interest in its scientific study shown by early scientists, such as Aristotle and Giovanni Borelli [5, 6].

As a diagnostic and re-assessment tool, gait assessment is required in most physiotherapy interventions, especially among patients with orthopedic and neurological conditions [7-10]. Despite the importance of gait assessment in physiotherapy practice, obtaining accurate measurements is still challenging [11]. There is no universal method of assessment of gait parameters, and most of the available methods have limitations, such as awkwardness, expertise requirements, and other cost-related issues. However, observational gait analysis (OGA) is a traditional method of gait assessment in clinical settings [12, 13]. Even so, the literature is full of OGA limitations, including lack of precision (high subjectivity rather than objectivity), difficulty in recording motions across planes (which requires a great deal of training and practice for proficiency), and the inability to detect subtle deviations with the unaided eye [14, 15].

Consequently, there is a growing interest in using new technologies in gait analysis. Some studies have used such tools as electronic sensors [9, 16, 17]. Doppler radar [18] robotic exoskeletons [19], and 2D or 3D video gait analysis [6, 20]. Also, several imaging techniques have evolved to aid gait analysis and assessment with promising results. However, the challenges with imaging techniques are the awkwardness of the setup, the inability to monitor real-life gait outside the laboratory, skill requirements, and cost-effectiveness [9]. Recently, Kinect, a Microsoft motion sensor add-on for the Xbox 360 gaming console, holds promises for potential use in medicine [21-24]. The Microsoft Kinect innovation, with its image-sensing capability, is reported to be less cumbersome, expensive, and adequately accurate [23-25]. Thus, emerging studies validate the different aspects of the Microsoft Kinect innovation [21, 25-30].

However, studies that compare the different aspects of the Microsoft Kinect compared with traditional methods of gait assessments are sparse [31-33]. Guess et al. argued the need, benefits, and disadvantages of comparing the Microsoft Kinect with instrumented measurement methods in a clinical setting [31]. On the other hand, the OGA tools are reported to be more viable than instrumented measurement scales as they are readily available at low cost and require no specialized devices and choice of location [12, 34] In other words, clinicians are more likely to use OGA tools than instrumented and technological gait assessment tools. Hence, studies seeking to compare the Microsoft Kinect with OGA are warranted, considering that OGA is a firsthand tool in the hands of the clinician for gait assessment. Also, there is a recommendation for using gait analysis from the healthy population to serve as a reference for pathological gait patterns and the indication of considering sex-specific analyses in gait study designs [35, 36]. Therefore, this study compared the Microsoft Kinect with the OGA in assessing the gait parameters of apparently healthy male adults.

Materials and Methods

Ninety-seven apparently healthy individuals participated in this study. The "apparently healthy individuals" asserted their adaptive capacities to provide dynamic and excellent involvement in the study, as noted in a study by Ustinova [37]. Consecutive sampling was used to recruit the study participants. They were exclusively male students from the Obafemi Awolowo University, Ile-Ife, Nigeria, aged between 18 and 30 years. Excluded from the study were those with observable gait deformity, trained athletes, and those with prior experience of OGA or 3-D gait analysis and obvious or reported neurological conditions, such as Parkinson, cerebellar ataxia, and hemiplegia.

A tape measure was used to measure the walkway of 3 m, and an indelible mark was made on the floor with chalk for a starting and end point. Kinect (for Windows console with model No. 1517) was placed facing the marked walkway to capture the participants' movements 0.5 m from the endpoint. We used a laptop computer with Microsoft Kinect software installed, a stopwatch to take total time spent, a weighing scale (inter Ikea B.V. 1999) to measure the body weight, and a height meter to measure the height.

The participants were asked to walk on the pre-measured walkway with markings on the ground to ensure evenness and accurate measurement of the parameters with the OGA. The number of steps, cadence, stride length, and step length were taken and recorded for analysis. The Microsoft Kinect was also used in capturing the same gait parameters concurrently with OGA to ensure intra-subject reliability, considering that gait is affected by many factors, which include psychological, emotional, and physiological [38]. The readings of the Kinect were taken and saved on the computer for analysis. Demographic information of the participants was also taken.

The obtained data were summarized using descriptive statistics of Mean±SD. The independent t-test was used to compare gait parameters. In contrast, the Pearson correlation, Cronbach α, and intra-class correlation were used to find correlations between the two gait analysis methods. The alpha level was set at $P<0.05$. SPSS software, version 16 was used to analyze the data.

Results

The Mean±SD age, weight, height, and body mass index of the participants were 22.4±1.70 y, 64.4±9.01 kg, and 1.70±0.08 m, and 22.1±3.08 kg/m^2, respectively. The general characteristics of the participants are presented in Table 1. The gait parameters readings are shown in Table 2. The Mean±SD walk time, steps, cadence, velocity, and stride length were 8.07±1.39s, 14.0±2.96, 72.9±11.9 steps/min, 0.8±0.13s and 0.77±0.13 m/steps count, respectively. A comparison of Microsoft Kinect and OGA readings for step length, stride length, and walk speed is presented in Table 3. The step length reading obtained from Microsoft Kinect was significantly higher ($P<0.05$) than OGA, whereas stride length and walk speed obtained from Microsoft Kinect were significantly lower ($P<0.05$) (Table 3).

Table 4 shows the result of the Cronbach α and intra-class correlation between Kinect and OGA measures of step length, stride length, and walking speed. The result indicates a significant relationship between Microsoft Kinect and OGA measure of walking speed ($P=0.001$). Pearson product-moment correlation between Microsoft Kinect and OGA measures of step length was significant ($P<0.05$). In contrast, the correlation between Microsoft Kinect and OGA stride length measures was insignificant ($P<0.05$). There was a weak but significant positive

Table 1. General characteristics of the participants

Variables	Mean±SD	Minimum	Maximum
Age (y)	22.3±1.67	19.00	28.00
Weight (kg)	64.4±9.04	6.00	92.00
Height (cm)	1.71±0.08	1.50	1.89
BMI (kg/m^2)	22.1±3.08	15.92	36.11

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BMI: Body mass index; SD: Standard deviation.

Table 2. Gait parameters of the participants during the six meter walk

Variables	Mean±SD	Minimum	Maximum
Walking time (s)	8.07±1.39	5.00	12.00
Number of steps	14.00±2.96	8.00	26.00
Cadence (steps/min)	72.9±11.9	48.00	110.00
Velocity (m/s)	0.77±0.13	0.50	1.20
Actual walking stride length (m)	0.45±0.01	0.23	0.75

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Table 3. Paired t-test comparison of Microsoft KinectTM and OGA in step length, stride length and walking speed of participants

Variables	Mean±SD		t-cal	P
	Microsoft KinectTM	OGA measure		
Step length (m)	0.77±0.23	0.64±0.10	5.77	0.001**
Stride length (m)	0.80±0.31	1.27±0.19	-13.20	0.001**
Walking speed (m/s)	84.8±36.9	132.7±47.6	-12.03	0.001**

OGA: Observational gait analysis; SD: Standard deviation. **Significant.

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Table 4. Cronbach's α and intra class correlation between Microsoft KinectTM and OGA measures of step length, stride length and walking speed of participants

Variables	Cronbach α	ICC	Lower Bound	Upper Bound	P
Step length	0.26	0.15	-0.05	0.34	0.08**
Stride length	0.01	0.01	-0.19	0.21	0.47**
Walking speed	0.65	0.65	0.48	0.77	0.00**

ICC: Intra class correlation. **Significant.

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correlation between the step length of OGA and Microsoft Kinect (Figure 1). Also, the stride length of OGA and Microsoft Kinect showed a weak positive correlation but were not significant (Figure 2). However, the walk speed correlation between OGA and Microsoft Kinect indicated a moderately significant (P<0.05) positive correlation (Figure 3).

Discussion

This study compared the gait parameter readings of Microsoft Kinect, an innovative work built on the Microsoft Kinect Xbox 360, with the traditional OGA. Previous studies have used the Kinect system for physical rehabilitation, postural control, and gait analysis assessment [25-27, 30, 39]. This study found that step length readings of the Microsoft Kinect were significantly higher than that of OGA. In contrast, stride length and walking speed readings from the Microsoft Kinect were significantly lower than that of OGA. The import of the finding of higher step length readings of Microsoft Kinect compared to OGA can be deduced from the report of Lim et al. [40]. They asserted that increased step length during gait demonstrated more involvement of the hip and knee extensors and lesser involvement from gravitational forces [40]. Therefore, it is conclusive that gait assessment with Microsoft Kinect reveals more of the involvement of the hip and knee extensors during gait assessment than with OGA. On the other hand, the finding of this study that strides length and walking speed readings from the Microsoft Kinect was significantly lower than that of OGA is supported by an-

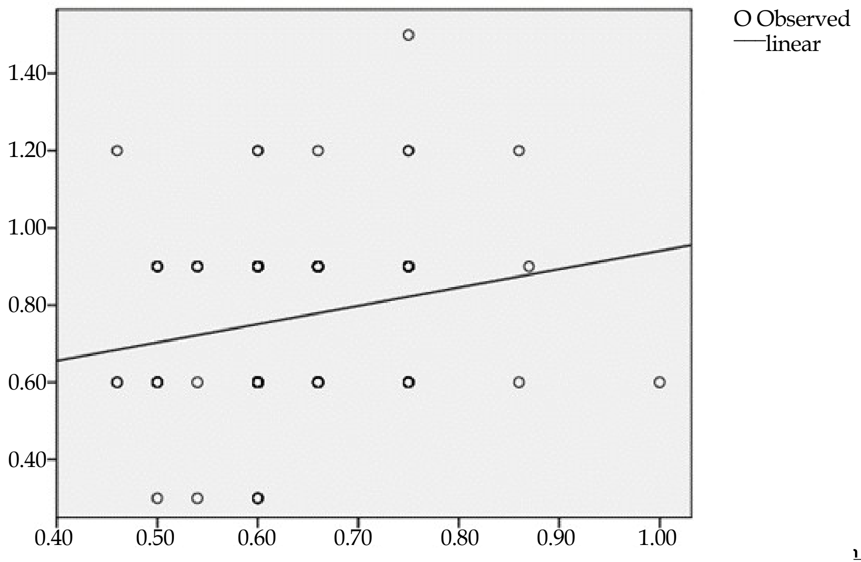

Figure 1. Scatter plot diagram showing the correlation between microsoft kinect and OGA measures of the step length

other study that found a significant association of higher step length with slower speed during gait analysis [41]. Hence, the finding of the present study on lower walking speed from Microsoft Kinect gait assessment compared to OGA is reasonable, given that the step length obtained from the Microsoft Kinect was higher than that obtained from OGA.

Nevertheless, this study found a significant moderate positive correlation between OGA and Microsoft Kinect in walk speed and a significant weak positive correlation in step length. In other words, this study demonstrates that Microsoft Kinect and OGA are similar in assessing gait parameters of step length and walk speed. This finding is consistent with the report of previous studies that found a positive association in walking speed and step length between Microsoft Kinect and other gait assessment tools [27, 42-45]. A recent study found excellent agreement in gait parameters between a 3D kinematic gait analysis and traditional walking [46]. Thus, it is believed that technological tools like the Microsoft Kinect may hold excellent promises for gait assessment in the clinical setting.

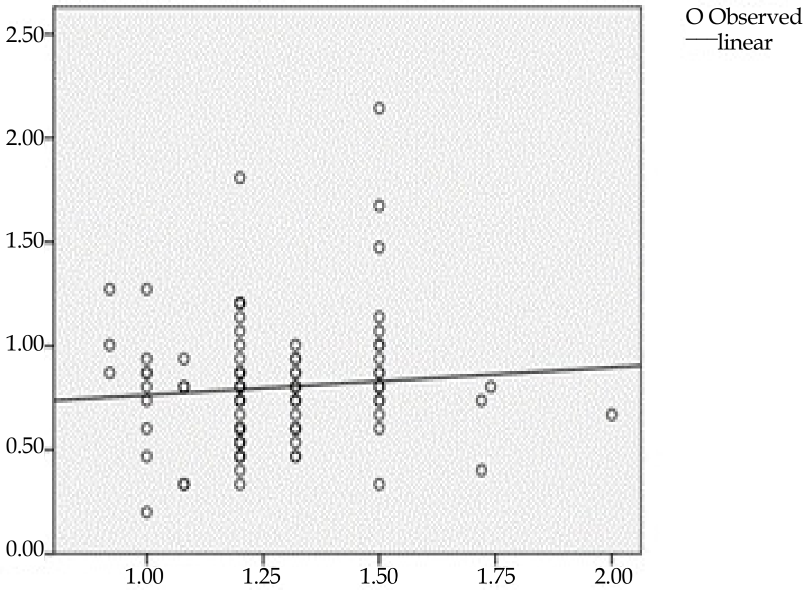

Figure 2. Scatter plot diagram showing the correlation between microsoft kinect and OGA measures of the stride length

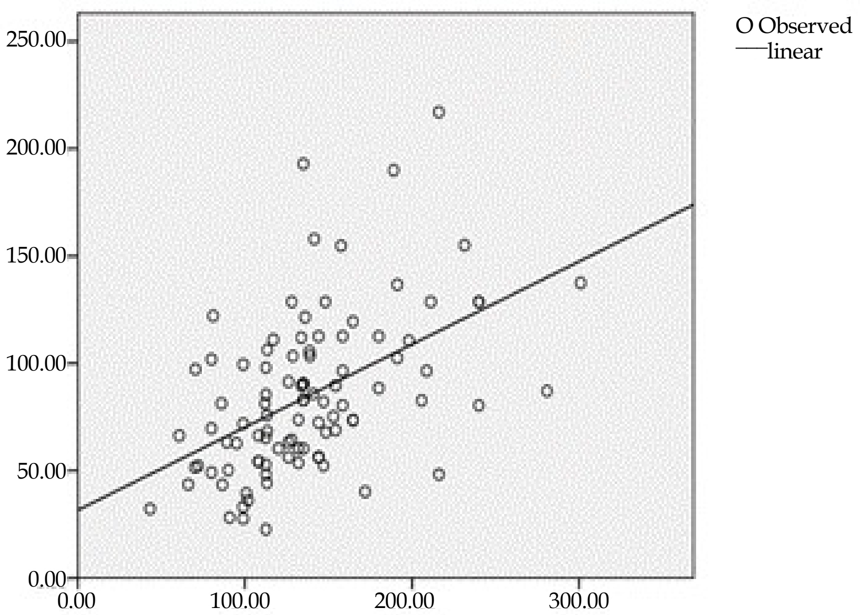

Figure 3. Scatter plot diagram showing the correlation between microsoft kinect and OGA measures of the walking speed

Our observation suggests that Microsoft Kinect does not require high-level skills and experience in 3-D gait analysis as the software is easy to use. Assessment of movements in gait studies is usually recorded and analyzed through 3-D motion analysis technology, capturing the trajectories of the joints and coordinates that requires highly specialized cameras [47-50]. The Microsoft Kinect proffers some advantages due to several reasons. The first is the gaming design, for which no special experience is needed to operate it. Also, it works without external 3-D cameras and markers placed on the skin. Furthermore, setting up the Microsoft Kinect takes no time, even considering the time for booting the system, loading the software, and detecting the participant(s). Finally, the data obtained from the Microsoft Kinect are easily reproducible and objective. However, some previous studies have noted limitations with Kinect Xbox 360 in gait assessment but have also proved it valid and reliable [27, 50-52]. The Kinect Xbox 360 readings may have some slight differences when repeated, resulting from intra-subject variability or instrument error [50].

This study affirms the relevance of OGA and Microsoft Kinect in gait analysis. Therefore, it is recommended that Microsoft Kinect's potential in gait analysis be explored in health and disease as a diagnostic and outcome tool among clinicians involved in managing gait-related conditions, as the device can capture angles of the joints and deformities, such as vara or valga.

Conclusion

The step length value of Microsoft Kinect was significantly higher than the OGA value. In contrast, the stride length and walk speed values of Microsoft Kinect were significantly lower than OGA values. Walk speed and step length measured by Microsoft Kinect and OGA were positively correlated.

Ethical Considerations

Compliance with ethical guidelines

Ethical approval was obtained from the Health Research and Ethics Committee, Institute of Public Health, Obafemi Awolowo University (Code: IPH/OAU/12/387). The purpose of the study was explained to all participants, and their consent was obtained.

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Authors' contributions

Conceptualization, Searching the literature and data analysis: All authors; Editing: Chidozie Emmanuel Mbada, Saturday Nicholas Oghumu and Francis Fatoye; Final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Richards J, Levine D, Whittle M. Whittle's gait analysis. Amsterdam: Elsevier; 2022. [Link]

[2] Benedetti MG, Beghi E, De Tanti A, Cappozzo A, Basaglia N, Cutti AG, et al. SIAMOC position paper on gait analysis in clinical practice: General requirements, methods and appropriateness. Results of an Italian consensus conference. Gait & Posture. 2017; 58:252-60. [DOI:10.1016/j.gaitpost.2017.08.003] [PMID]

[3] Baker R, Esquenazi A, Benedetti MG, Desloovere K. Gait analysis: Clinical facts. European Journal of Physical and Rehabilitation Medicine. 2016; 52(4):560-74. [PMID]

[4] Hodgkinson G. Observation video gait analysis. Manchester: National Health Service. [Link]

[5] Sethi D, Bharti S, Prakash C. A comprehensive survey on gait analysis: History, parameters, approaches, pose estimation, and future work. Artificial Intelligence in Medicine. 2022; 129:102314. [DOI:10.1016/j.artmed.2022.102314] [PMID]

[6] Bakker M, Verstappen CC, Bloem BR, Toni I. Recent advances in functional neuroimaging of gait. Journal of Neural Transmission (Vienna, Austria : 1996). 2007; 114(10):1323-31. [DOI:10.1007/s00702-007-0783-8] [PMID] [PMCID]

[7] Klöpfer-Krämer I, Brand A, Wackerle H, Müßig J, Kröger I, Augat P. Gait analysis - Available platforms for outcome assessment. Injury. 2020; 51 (Suppl 2):S90-6. [DOI:10.1016/j.injury.2019.11.011] [PMID]

[8] Marín J, Blanco T, Marín JJ, Moreno A, Martitegui E, Aragüés JC. Integrating a gait analysis test in hospital rehabilitation: A service design approach. PLoS One. 2019; 14(10):e0224409. [DOI:10.1371/journal.pone.0224409] [PMID] [PMCID]

[9] Muro-de-la-Herran A, Garcia-Zapirain B, Mendez-Zorrilla A. Gait analysis methods: An overview of wearable and non-wearable systems, highlighting clinical applications. Sensors (Basel). 2014; 14(2):3362-94. [DOI:10.3390/s140203362] [PMID] [PMCID]

[10] Armutlu K. Ataxia: physical therapy and rehabilitation applications for ataxic patients. International Encyclopedia of Rehabilitation. 2010; 1-19. [Link]

[11] Rida I, Almaadeed N, Al-ma'adeed S. Robust gait recognition: A comprehensive survey. IET Biometrics. 2019; 8(1):14-28. [DOI:10.1049/iet-bmt.2018.5063]

[12] Ridao-Fernández C, Pinero-Pinto E, Chamorro-Moriana G. Observational gait assessment scales in patients with walking disorders: Systematic review. BioMed Research International. 2019; 2019:2085039. [DOI:10.1155/2019/2085039] [PMID] [PMCID]

[13] Groth HR, Novak SE. Examination of the reliability and validity of rancho los amigos observational gait analysis [PhD dissertation]. Michigan: Grand Valley State University; 1999. [Link]

[14] Guzik A, Wolan-Nieroda A, Drużbicki M. Assessment of agreement between a new application to compute the wisconsin gait score and 3-dimensional gait analysis, and reliability of the application in stroke patients. Frontiers in Human Neuroscience. 2022; 16:775261. [DOI:10.3389/fnhum.2022.775261] [PMID] [PMCID]

[15] McGinley JL,Goldie PA, Greenwood KM, Olney SJ. Accuracy and reliability of observational gait analysis data: Judgments of Push-off in gait after stroke. Physical Therapy. 2003; 83(2):146-60. [DOI:10.1093/ptj/83.2.146]

[16] Díaz S, Stephenson JB, Labrador MA. Use of wearable sensor technology in gait, balance, and range of motion analysis. Applied Sciences. 2020; 10(1):234. [DOI:10.3390/app10010234]

[17] Qiu S, Liu L, Wang Z, Li S, Zhao H, Wang J, et al. Body sensor network-based gait quality assessment for clinical decision-support via multi-sensor fusion. IEEE Access. 2019; 7:59884-94. [DOI:10.1109/ACCESS.2019.2913897]

[18] Seifert AK, Grimmer M, Zoubir AM. Doppler radar for the extraction of biomechanical parameters in gait analysis. IEEE Journal of Biomedical and Health Informatics. 2021; 25(2).547-58. [DOI:10.1109/JBHI.2020.2994471] [PMID]

[19] Swank C, Sikka S, Driver S, Bennett M, Callender L. Feasibility of integrating robotic exoskeleton gait training in inpatient rehabilitation. Disability and Rehabilitation. Assistive Technology. 2020; 15(4):409-17. [DOI:10.1080/17483107.2019.1587014] [PMID]

[20] Michelini A, Eshraghi A, Andrysek J. Two-dimensional video gait analysis: A systematic review of reliability, validity, and best practice considerations. Prosthetics and Orthotics International. 2020; 44(4):245-62. [DOI:10.1177/0309364620921290] [PMID]

[21] Ma Y, Mithraratne K, Wilson NC, Wang X, Ma Y, Zhang Y. The validity and reliability of a kinect v2-based gait analysis system for children with cerebral palsy. Sensors. 2019; 19(7):1660. [DOI:10.3390/s19071660] [PMID] [PMCID]

[22] Bilesan A, Owlia M, Behzadipour S, Ogawa S, Tsujita T, Komizunai S, et al. Marker-based Motion Tracking using Microsoft Kinect. IFAC-PapersOnLine. 2018; 51(22):399-404. [DOI:10.1016/j.ifacol.2018.11.575]

[23] Mousavi Hondori H, Khademi M. A review on technical and clinical impact of microsoft kinect on physical therapy and rehabilitation. Journal of Medical Engineering. 2014; 2014:846514. [DOI:10.1155/2014/846514] [PMID] [PMCID]

[24] Zhang, Z. Microsoft kinect sensor and its effect. IEEE Multimedia. 2012; 19(2):4-10. [DOI:10.1109/MMUL.2012.24]

[25] Antico M, Balletti N, Ciccotelli A, Ciccotelli M, Laudato G, Lazich A, et al. 2Vita-B Physical: An intelligent home rehabilitation system based on microsoft Azure kinect. Frontiers in Human Dynamics. 2021; 3:678529. [DOI:10.3389/fhumd.2021.678529]

[26] Pfister A, West AM, Bronner S, Noah JA. Comparative abilities of microsoft kinect and Vicon 3D motion capture for gait analysis. Journal of Medical Engineering & Technology. 2014; 38(5):274-80. [DOI:10.3109/03091902.2014.909540] [PMID]

[27] Clark RA, Pua YH, Bryant AL, Hunt MA. Validity of the microsoft kinect for providing lateral trunk lean feedback during gait retraining. Gait & Posture. 2013; 38(4):1064-6. [DOI:10.1016/j.gaitpost.2013.03.029] [PMID]

[28] Stone EE, Skubic M. Capturing habitual, in-home gait parameter trends using an inexpensive depth camera. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference. 2012; 2012:5106-9. [DOI:10.1109/EMBC.2012.6347142] [PMID]

[29] Ali A, Sundaraj K, Ahmad B, Ahamed N, Islam A. Gait disorder rehabilitation using vision and non-vision based sensors: A systematic review. Bosnian Journal of Basic Medical Sciences. 2012; 12(3):193-202. [DOI:10.17305/bjbms.2012.2484] [PMID] [PMCID]

[30] Stone EE, Skubic M. Passive in-home measurement of stride-to-stride gait variability comparing vision and Kinect sensing. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference. 2011; 2011:6491-4. [PMID]

[31] Guess TM, Bliss R, Hall JB, Kiselica AM. Comparison of azure kinect overground gait spatiotemporal parameters to marker based optical motion capture. Gait & Posture. 2022; 96:130-6. [DOI:10.1016/j.gaitpost.2022.05.021] [PMID]

[32] Bawa A, Banitsas K, Abbod M. A review on the use of microsoft kinect for gait abnormality and postural disorder assessment. Journal of Healthcare Engineering. 2021; 4360122. [DOI:10.1155/2021/4360122] [PMID] [PMCID]

[33] Guffanti D, Brunete A, Hernando M, Rueda J, Navarro Cabello E. The accuracy of the microsoft kinect v2 sensor for human gait analysis. A different approach for comparison with the ground truth. Sensors. 2020; 20(16):4405. [DOI:10.3390/s20164405] [PMID] [PMCID]

[34] Dolatabadi E, Taati B, Mihailidis A. Concurrent validity of the microsoft kinect for windows v2 for measuring spatiotemporal gait parameters. Medical Engineering & Physics. 2016; 38(9):952-8. [DOI:10.1016/j.medengphy.2016.06.015] [PMID]

[35] Horst F, Slijepcevic D, Simak M, Schöllhorn WI. Gutenberg gait database, a ground reaction force database of level overground walking in healthy individuals. Scientific Data. 2021; 8(1):232. [DOI:10.1038/s41597-021-01014-6] [PMID] [PMCID]

[36] Rowe E, Beauchamp MK, Astephen Wilson J. Age and sex differences in normative gait patterns. Gait & Posture. 2021; 88:109-15. [DOI:10.1016/j.gaitpost.2021.05.014] [PMID]

[37] Ustinova O1. Apparently healthy human being: The necessity to refine the notion. Life Science Journal. 2014; 11(10):524-6. [Link]

[38] Davis RB, Õunpuu S, Tyburski D, Gage JR. A gait analysis collection and reduction technique. Human Movement Science. 1991; 10(5):575-87. [DOI:10.1016/0167-9457(91)90046-Z]

[39] Ma Y, Mithraratne K, Wilson N, Zhang Y, Wang X. Kinect V2-based gait analysis for children with cerebral palsy: validity and reliability of spatial margin of stability and spatiotemporal variables. Sensors (Basel). 2021; 21(6):2104. [DOI:10.3390/s21062104] [PMID] [PMCID]

[40] Lim YP, Lin YC, Pandy MG. Effects of step length and step frequency on lower-limb muscle function in human gait. Journal of Biomechanics. 2017; 57:1-7. [DOI:10.1016/j.jbiomech.2017.03.004] [PMID]

[41] Rosso AL, Olson Hunt MJ, Yang M, Brach JS, Harris TB, Newman AB, et al. Higher step length variability indicates lower gray matter integrity of selected regions in older adults. Gait & Posture. 2014; 40(1):225-30. [DOI:10.1016/j.gaitpost.2014.03.192] [PMID] [PMCID]

[42] Müller B, Ilg W, Giese MA, Ludolph N. Validation of enhanced kinect sensor based motion capturing for gait assessment. PLoS One. 2017; 12(4):e0175813. [DOI:10.1371/journal.pone.0175813] [PMID] [PMCID]

[43] Springer S, Yogev Seligmann G. Validity of the kinect for gait assessment: A focused review. Sensors (Basel). 2016; 16(2):194. [DOI:10.3390/s16020194] [PMID] [PMCID]

[44] Mentiplay BF, Perraton LG, Bower KJ, Pua YH, McGaw R, Heywood S, et al. Gait assessment using the microsoft xbox one kinect: Concurrent validity and inter-day reliability of spatiotemporal and kinematic variables. Journal of Biomechanics. 2015; 48(10):2166-70. [DOI:10.1016/j.jbiomech.2015.05.021] [PMID]

[45] Mihradi S, Henda AI, Dirgantara T, Mahyuddin AI. Development of 3d gait analyzer software based on marker position DATA. ASEAN Engineering Journal. 2013; 3(2):4-14. [Link]

[46] McGuirk TE, Perry ES, Sihanath WB, Riazati S, Patten C. Feasibility of markerless motion capture for three-dimensional gait assessment in community settings. Frontiers in Human Neuroscience. 2022; 16:867485. [DOI:10.3389/fnhum.2022.867485] [PMID] [PMCID]

[47] Salchow-Hömmen C, Skrobot M, Jochner MCE, Schauer T, Kühn AA, Wenger N. Review-emerging portable technologies for gait analysis in neurological disorders. Frontiers in Human Neuroscience. 2022; 16:768575. [DOI:10.3389/fnhum.2022.768575] [PMID] [PMCID]

[48] Stenum J, Rossi C, Roemmich RT. Two-dimensional video-based analysis of human gait using pose estimation. PLoS Computational Biology. 2021; 17(4):e1008935. [DOI:10.1371/journal.pcbi.1008935] [PMID] [PMCID]

[49] Hawi N, Liodakis E, Musolli D, Suero EM, Stuebig T, Claassen L, et al. Range of motion assessment of the shoulder and elbow joints using a motion sensing input device: A pilot study. Technology and Health Care. 2014; 22(2):289-95. [DOI:10.3233/THC-140831] [PM52D]

[50] Larsson-Green P. Kinect's potential in healthcare [MA thesis]. Umeå: Institutionen för datavetenskap; 2014.

[51] Jun S, Zhou X, Ramsey DK, Krovi VN. A comparative study of human motion capture and computational analysis tools. Paper presented at: The 2nd International Digital Human Modelling Symposium. 11-13 June 2013; Michigan, USA.

[52] Clark RA, Pua YH, Fortin K, Ritchie C, Webster KE, Denehy L, et al. Validity of the microsoft kinect for assessment of postural control. Gait & Posture. 2012; 36(3):372-7. [DOI:10.1016/j.gaitpost.2012.03.033] [PMID]