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Concurrent Validity and Test-Retest Reliability of the Walkbot-K System for Robotic Gait Training

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Abstract. BACKGROUND: During the adults' robotic-assisted gait training systems have rapidly gained widespread acceptance among rehabilitation specialists as a promising gait training paradigm in dysfunction, the validity and reliability for the children's robotic-assisted gait training system has not been well established. **OBJECTIVE:** To investigate the validity and test-retest reliability of the innovative exoskeletal Walkbot-K system which is designed to help the active development and learning of fundamental locomotor skills in children with locomotor impairments. **METHODS:** The real-time motion analysis system was used concurrently to compare the sagittal kinematic angular displacement data with that of the Walkbot-K system as a reference standard measure. **RESULTS:** Neuromechanical data obtained from kinematic measurement produced an excellent validity ($R^2=0.889$). The test-retest reliability for kinematic knee angle data showed a remarkable consistency ($r = 0.999 - 1.000$). **CONCLUSIONS:** This study provides the first compelling evidence of the children's robotic gait assisted Walkbot-K system's validity and reliability, indicating that the system is a highly valid, and reliable robotic-assisted gait training system to evaluate and treat locomotor dysfunction in children.

Keywords: Robotic-assisted gait training, locomotor dysfunction, cerebral palsy, validity, reliability

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1. Introduction

Crouched flexed knee gait is an important biomarker for non-progressive locomotor movement impairment in children with cerebral palsy (CP), which is associated with neuromuscular imbalance due to loss of corticospinal modulation, namely cortical disinhibition [1-6]. To improve such locomotor impairment, robotic-assisted gait training systems, including Walkbot and Lokomat, have been recently developed. Robotic-assisted gait training systems were conceptually evolved from the motor control and learning paradigm – a task specific or oriented gait training model that provides enriched joint proprioceptive 자기 수용의 and kinesthetic stimuli during early locomotor training. Subsequently, this system helps preventing the joint contracture associated with spasticity and paralysis and improving functional walking ability in adults with stroke and spinal cord injury [7,8]. Clinically, robotic-assisted locomotor retraining has been recognized as a promising alternative gait training paradigm in children with gait dysfunction because it is cost-effective, less labor intensive and provides a motor re-learning environment essential for locomotor development [9,10]. Clinical studies showed that children with gait dysfunction gained positive functional outcomes when compared to the conventional over-ground gait training [11]. Nevertheless, the validity and reliability of the robotic system have not been reported and the current robotic-assisted system tends to be costly and less portable, thus not readily available in the clinical settings.

More recently, the innovative child-friendly Walkbot-K (Walkbot-Kids, P&S mechanics, Seoul, Korea) was developed. This innovative Walkbot-K has an active real-time biofeedback system that provides relevant clinical information related to locomotion, including data on stiffness (resistance) associated with spasticity or joint contracture, spatiotemporal data, hip, knee, and ankle kinematic and kinetic force data during locomotion training. Additionally, an age-appropriate augmented virtual reality program is integrated into the system to maximize interactive participation and motivation. This present study was to investigate the accuracy and test-retest reliability of Walkbot-K's knee joint kinematics because the knee joint angular displacement control was crucial for the rehabilitating the crouched knee flexed gait in children with spastic CP [1-6]. The knee joint kinematic recorded from the robotic Walkbot-K system was concurrently compared with those kinematic data obtained from an established 2-dimensional motion analysis system (Simi Actysis, Simi Reality Motion Systems GmbH, Unterschleissheim, Germany) as a reference standard. The present hypothesis was that robotic Walkbot-K knee joint kinematics in the sagittal plane would be comparable or equivalent to human joint kinematics, supporting a valid and reproducible system's capability.

2. Materials and methods

2.1. Materials

Walkbot-K's preprogrammed anthropometric and spatiotemporal data for the exoskeletal lower limb are presented in Table 1. As illustrated in Fig. 1, the Walkbot-K system is primarily composed of three actuators (hip, knee, and ankle joint including for the ankle dorsiflexion movement), precise motor control of synchronization between Walkbot-K robotic exoskeletal and treadmill, and body weight supporting. The system has special features: four degrees of freedom, leg length adjustability by 1mm, customized operating control for individual locomotor pattern, encouragement and facilitation of active muscle control by setting target level, and integrated augmented virtual reality (VR). Built-in actuators for the hip, knee and ankle joints are controlled by algorithms and encoders that detect and process the kinematic and kinetic information. All of the sensors are connected to an input/output module board, which is then connected to a computerized system.

Table 1. Walkbot-K's preprogrammed anthropometric and spatiotemporal data for the exoskeletal lower limb

Parameters	
Anthropometric data	
Leg length	0.32m
Thigh length	0.32m
Ankle height	0.06m
Spatiotemporal data	
Step length	1m/2 steps
Walking velocity	0.6km/h

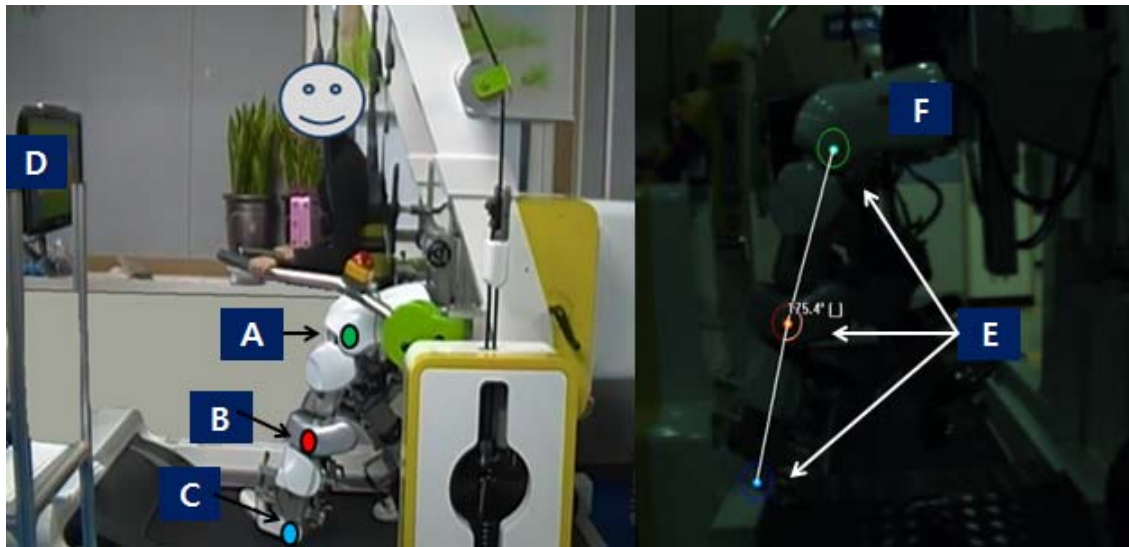


Fig.1 Experimental setup for the robotic Walkbot-K system and Simi motion analysis system. A: hip joint actuator including servomotor, B: knee joint actuator including servomotor, C: ankle joint actuator including servomotor, D: mixed augmented virtual reality (VR), E: active reflective markers of Simi motion system for hip, knee, ankle joint, F: Walkbot-K system's exoskeletal.

2.2. Instrument, kinematic measurement, and data analysis

The real-time motion analysis system (Simi Actysis, Simi Reality Motion Systems GmbH, Unterschleissheim, Germany) was used to concurrently compare the Simi's sagittal knee joint angular kinematics with the Walkbot-K's angular data. As depicted in Fig. 1, three actively reflective markers of Simi motion system were vertically placed on the hip, knee, and ankle joint axis of Walkbot-K's exoskeletal to capture knee joint angle data. The kinematic data were acquired at a sampling rate of 60Hz during the predetermined walking velocity of 0.6m/s on the treadmill built in the Walkbot system. For the validity test, the concurrent Walkbot and Simi knee angle data were collected for four consecutive trials (each trial comprising 200 gait cycles) with a resting interval of 1-2 minutes between the trials. The average knee joint angles obtained from both measurements were used to compute the linear regression R^2 . For the test-retest reliability, the Walkbot's knee joint angle data were repeatedly recorded for 9 consecutive trials (each trial comprising 14 gait cycles) with a resting interval of 5-minutes.

For data analysis, mean knee joint angle kinematic data obtained from three consecutive gait cycles within each trial over repeated measures or trials were, however, used because the collected kinematic data were consistent over the repeated trials.

2.3. Statistical Analysis

Linear regression analysis was computed to determine the validity between the Simi's sagittal knee joint angular kinematics and the Walkbot-K's angular displacement data. The Pearson correlation statistics was used to determine test-retest reliability. Significance was assigned on SPSS version 20.0 (SPSS, Chicago, IL, U.S.A.) for Windows at $p < 0.01$.

3. Results

3.1. Validity of the Walkbot-K system

To determine the validity of the Walkbot-K system, we compared mean knee joint angle data obtained from both the Walkbot-K and 2-dimensional motion analysis measurements at four consecutive trials. Linear regression analysis showed an good to excellent relationship between both measurements the knee joint kinematics ($R^2=0.889$), thus confirming the validity and accuracy of the Walkbot-K system (Fig. 2).

3.2. Reliability of the Walkbot-K system

To determine the Walkbot-K's test-retest reliability, correlational analysis showed an excellent reliability ($r = 0.999 - 1.000$) over the nine repeated measures, thereby supporting the consistency of reproducibility of the Walkbot-K system (Fig. 3).

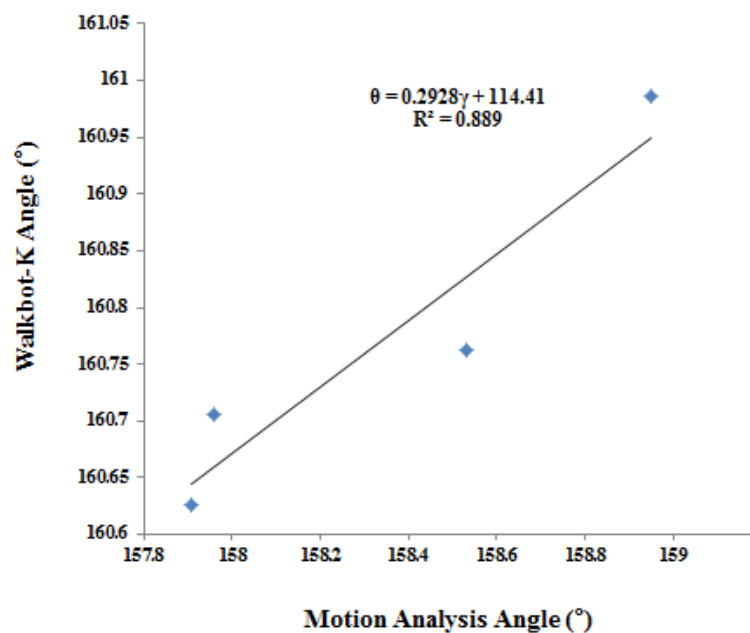


Fig. 2 Representative illustration of linear regression for concurrent validity of the average knee joint angular displacement data between the 2-dimensional motion analysis and Walkbot-K measurements

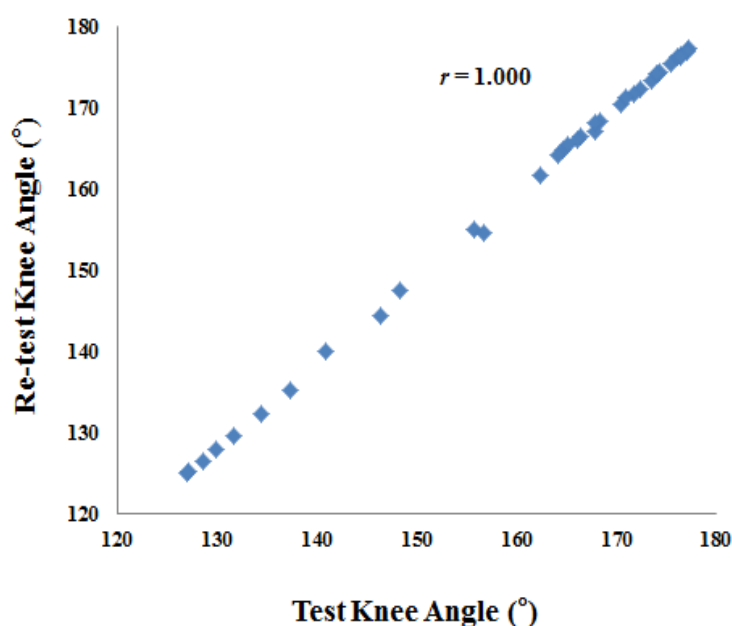


Fig. 3 Representative illustration of correlation between the test and re-test knee joint angle data during one gait cycle in the Walkbot-K system.

4. Discussion

This present investigation highlights that the children's robotic gait-assisted Walkbot-K system was highly valid and reliable when compared to the conventional motion analysis. Most importantly, the Walkbot-K robotic gait system can provide real-time biofeedback information about spatiotemporal 시공간 gait parameters, joint angles, moment, force and clinical stiffness as well as resistance data for successful locomotor training [12]. These invaluable clinical and quantitative gait data are useful for clinicians in designing the optimal gait training protocol and monitoring each child's progress in locomotor control and performance associated with locomotor training. The real-time visual biofeedback about strength and stiffness can allow children to appreciate the baseline force generation of the agonist muscle group and reciprocal inhibition of the antagonist group (estimated by stiffness measurement data) [12]. Based on this information, the target range of motion can be interfaced with the augmented virtual reality mode to facilitate the agonist 길항근 force production. Simultaneously, it can inhibit or dampen the antagonist stiffness reciprocally so that the child can produce a normalized locomotor pattern while engaging the fun and motivated VR game [13]. This effect was consistent with other advanced robotic gait training systems [14,15], which showed improved gait function in children with cerebral palsy [14]. Pajaro-Blazques et al. examined the effects of robotic assisted gait training in 51 children with CP following a 69 session and found that enhanced locomotor velocity and walking endurance [14]. Similarly, another study showed increased step length and decreased in the double support phase in adult with CP following a 6 week of the robotic assisted gait training [15].

Certainly, this makes Walkbot-K the first child-friendly, active lower extremity mechatronics system for locomotor rehabilitation. Additionally, the adjustable leg length and ankle joint control enables Walkbot-K accurately to approximate human kinematics and kinetics, to approximate human kinetics.

The system's detachability feature, whereby it can be used as a single joint robotic orthosis or as a whole unit, allows children with gait impairment to improve along with the hierarchy of normal locomotor development. Moreover, unlike other current robotic assisted gait systems, the Walkbot system has a built-in ankle actuator which provides an optimal ankle motion trajectory during ambulation [12]. This study invites future clinical research to validate the effectiveness of the robotic Walkbot-K system individuals with gait dysfunction due to CP.

5. Conclusion

The present study showed that the children's robotic gait-assisted Walkbot-K system is accurate and reliable in the knee joint kinematics measurement. This established validity and test-retest reliability of the innovative exoskeletal Walkbot-K system will help further development and learning of fundamental locomotor skills in children with cerebral palsy who suffers from the crouched or flexed knee gait impairment.

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Both Lee and Shin have equally contributed as the first co-author.

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