Journal of Physical Education and Sport ® (JPES), Vol. 25 (issue 4), Art 98, pp. 903 - 911, April 2025
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Application of intelligent digital infrastructure into the L-test implementation in the physical education of students with lower limb ambulance

OKSANA BLAVT[1], GENNADII IEDYNAK[2], LESIA GALAMANZHUK[3], IGOR VOVK[4], VOLODYMYR NAUMCHUK[5], VOLODYMYR KOVALCHUK[6], VOLODYMYR FAIDEVYCH[7], VASYLIV VOLODYMYR[8]

[1] Department of Physical Education, Lviv Polytechnic National University, UKRAINE
[2]Department of Theory & Methodology of Physical Education, Kamianets-Podilskyi National Ivan Ohiienko University, UKRAINE
[3]Department of Methodology Elementary School Education Kamianets-Podilskyi National Ivan Ohiienko University, UKRAINE
[4]Department of Military Training and Physical Activity. Lviv National Stepan Gzhytsky University of Veterinary Medicine and Biotechnology
[5]Department of Theoretical Foundations and Methods of Physical Education Ternopil Volodymyr Hnatiuk National Pedagogical University, UKRAINE
[6]Department of Department of Physical Education, Sports and Health-Lutsk National Technical University, UKRAINE
[7]Department of Department of Physical Education, Sports and Health Lutsk National Technical University, UKRAINE
[8]Department of Department of theoretical and biological foundations of physical education Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy, UKRAINE

Published online: April 30, 2025
Accepted for publication: April 15, 2025
DOI:10.7752/jpes.2025.04098

Abstract:
The purpose of the study was to determine the psychometric properties of the L-test for students with lower limb amputation implemented by intelligent digital infrastructure. Material and Methods. The experiment involved first-year students (males) with amputation of the lower left limb in the absence of acute conditions, open wounds, or complications. The theoretical and empirical research used the following methods: analysis, synthesis, systematization, generalization, measurement and mathematical statistics. Measurement was implemented using the L-test. Results. The result of our scientific search was the development of an intelligent digital infrastructure designed for the implementation of the L-test, which involved solving tasks in collecting and analyzing testing data such as test execution time, gait trajectory, maintaining balance during gait and accuracy of turning. The intelligent digital infrastructure included: Radiofrequency Identification (RFID) microcontroller with an Arduino Mega 2560 board and PC with OLED display. The development used RFID components: RFID tags located at key points of the L-test trajectory, RFID reader - which is located on the student and RFID - data processing system that accumulates and analyzes information, linking RFID elements into a single system. The signal received and processed by RFID when a student performs a test task is transmitted via radiofrequency communication to the Arduino Mega 2560 microcontroller board. The board provides the ability to process signals from RFID to calculate gait parameters when performing the L-test. To increase the efficiency of the intelligent digital infrastructure, Machine Learning algorithms and cloud data storage were implemented. Analysis of the results of the experimental study showed a «high» level of psychometric properties of the L-test for students with lower limb amputations implemented by the intelligent digital infrastructure in contrast to the results recorded by a stopwatch. Conclusions. The use of the intelligent digital infrastructure in the implementation of the L-test for students with lower limb amputations provides a high level of reliability and objectivity of the control results in real-time. The use of modern artificial intelligence technologies in the developed infrastructure allows analyzing large volumes of collected data and creating models capable of assessing the quality of test performance and identifying gait pathologies in students when performing the L-test.
Key Words*:* **students, limb amputation, physical education, inclusion, control, gait.**

Introduction

Problem statement. For ten years in a row, Ukraine has been tirelessly fighting for its independence and territorial integrity. Tens of thousands of people have lost their limbs during this time, and since the beginning of russia's full-scale invasion of Ukraine (Holovanova et al., 2025). According to information (van Dongen et al., 2017; Laferrier et al., 2010; Pursela et al., 2024), lower limb injuries account for the majority of combat injuries.

Corresponding Author: OKSANA BLAVT, E-mail: oksanablavt@ukr.net

Compared to recent armed conflicts in the West, the number of amputation victims in 17 months of full-scale war is significantly higher and amounts to about 50 thousand (Texty.org.ua).

At the beginning of the russian-ukrainian war the main causes of amputations were artillery and rocket attacks, and these were mostly military. At the moment, amputations have largely spread among the civilian population and are caused by mine-blast injuries. At the same time, amputations are also regularly suffered by people with certain diseases. Despite numerous studies on this issue, several remain unresolved (Collins et al., 2006; Penn-Barwell, 2011; Fiedler et al., 2014). In the context of a prolonged war, the number of students from among the military, veterans and civilians with amputations has increased significantly. Therefore, the current challenges for higher education institutions, along with the provision of educational services, in the rehabilitation of Ukrainian students with lower limb amputation are large-scale. Given the duration of the war and the continuation of hostilities, the issue of the effectiveness of the rehabilitation process of students with lower limb amputation in the learning process is particularly relevant.

Analysis of recent research and publications. There is no doubt that after amputation, there is a need to restore and rehabilitate vital body functions (Godwin, Ahmed, & Shaat, 2022; van Dongen et al., 2017; Fitzgerald et al., 2007). Nowadays, this task is organically implanted in the educational process of inclusive physical education, which in higher education institutions provides the rehabilitation of students with disabilities (Barber et al., 2024). As it has been researched (Karamani et al., 2024; Lieberman, Houston-Wilson, & Grenier, 2024), it is an effective tool in terms of positive impact on the quality of life and functional state of the body of students with disabilities. It has been determined (Dillingham, & Pezzin, 2008; Ladlow et al., 2017; Soares et al., 2009) that the loss of a lower limb has serious consequences for human mobility and activities of daily living. Therefore, as argued by (De Pauw et al., 2020; Lathouwers et al., 2023; Michael, & Bowker, 2004), living with a prosthetic leg is primarily about learning new walking skills.

Scientists are unanimous in their opinion (Thibault, 2019; Demeco et al., 2023; Koenig et al., 2024) that achieving independent mobility after amputation requires the ability to walk freely. The goal of rehabilitation after lower limb amputation is to help gain independence with the most efficient gait possible (Demeco et al., 2023; Rivera, & Pasquina, 2016; Esquenazi, 2014). Accordingly, the control of gait recovery is recognized (Sansam et al., 2009; Farrokhi et al., 2019; Rau, Bonvin, & de Bie, 2007) as a correlate of the entire rehabilitation process.

It has been proven that the indicator of test control of gait parameters provides detection of changes that occur after appropriate rehabilitation measures (Rau, Bonvin, & de Bie, 2007) and provision of prosthesis. Reliability of test control results, according to which the assessment, interpretation of results and correction of inclusive physical education program are realized, are determined by psychometric properties of the test (reliability and validity), which, as it was investigated (Kirshner, & Guyatt, 1985), should be relevant to the population for which it is used.At the same time, eliminating the influence of the human factor in the implementation of test control is recognized (Blavt et al., 2024; Ladlow et al., 2019; Mykytyuk et al., 2022) as a leading factor in ensuring a high level of psychometric properties. At the current level of scientific research, this can be realized by introducing modern technologies (McCreath Frangakis, Lemaire, & Baddour, 2023; Juneau et al., 2021; Dejaco et al., 2023), including artificial intelligence technologies (Davenport, & Kalakota, 2019; Juneau et al., 2022; Chaplin et al., 2023; Zhang et al., 2024) into the testing process.

The purpose of the study is to determine the psychometric properties of the L-test for students with lower limb amputation implemented by intelligent digital infrastructure.

Materials and methods

Research methods

The choice of research methods is justified by the theoretical and empirical nature of our experimental scientific research and the projected purpose of the study. A set of procedures at the theoretical and empirical levels ensured the receipt of objective research data and their processing.

At the theoretical level, general scientific methods (analysis of literary sources, synthesis, generalization) were used to obtain information on the identified research problem. As an applied (specific scientific) method, the method of measurement was used to obtain current information on the defined research problem. The measurement is realized using the L-test. The L-test was originally developed for people after lower limb amputation and is a modified version of the timed up and go test (TUG) (Death, & Miller, 2005). The L-test is a more comprehensive test because it includes a longer walking distance: the walking distance is increased from 6 to 20 meters than the TUG and also requires participants to make four turns in both (right/left) directions (Yuksel et al., 2021), both clockwise and counterclockwise (Eldemir et al., 2025).

The conclusions and description of the study results are based on the results of statistical processing of the measurement results.

Procedure of the test.

The student sits in a chair with his/her back to the chair, hands resting on the arms of the chair, and, if possible, has an assistive device at hand. After the word «go», get out of the chair, walk to the first line, turn 90 degrees, and walk to the second line, then turn 180 degrees, and return to sit in the chair. The student walks at a comfortable speed (The L Test).

Study participants.

The experiment involved 26 first-year students (males) from Lviv Polytechnic National University, Kamianets-Podilskyi National Ivan Ohiienko University, Lviv National Stepan Gzhytsky University of Veterinary Medicine and Biotechnology, Ternopil Volodymyr Hnatiuk National Pedagogical University, Lutsk National Technical University and Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy with lower limb amputation in the absence of acute conditions, open wounds, or complications. Given that the left leg prosthesis creates a higher degree of mobility, all students in the study sample had an amputated left lower limb. The students in the study sample were able to maintain balance on the prosthesis and crutches, walk using crutches, and get up and down without assistance.

The study was conducted on a voluntary and anonymous basis. All students underwent a medical examination before the experiment and received a doctor's permission to participate in the experiment.

The study was planned and carried out following the principles of bioethics set forth by the World Medical Association (WMA-2013) in the Helsinki Declaration «Ethical Principles of Medical Research Involving Humans» and UNESCO in the «General Declaration on Bioethics and Human Rights».

Research organization

Before the test was implemented, students in the study sample received step-by-step instructions on how to complete the test, a demonstration, and an explanation of how to record the results. Students were given two attempts to complete the test with an interval of 2 minutes. The test was administered twice with an interval of seven days. To ensure student safety, chairs were placed near the testing site. Student insurance in the process of performing test tasks was ensured by the teacher's accompaniment along the course. The average time of the two tests was used in the final data analysis. The experiment was implemented as part of a university course on inclusive physical education. Information about the test results was obtained in two ways. The method of obtaining test results was used as an experimental factor. The results of the test control were recorded in two ways: by intelligent digital infrastructure and by the teacher using a stopwatch.

Statistical analysis

When choosing from a variety of available methods of outcome assessment to analyze and summarize the measurement data obtained from the experimental study to determine the psychometric properties of the L-test, we opted for correlation analysis (Prion, & Haerling, 2014).

The psychometric properties of an outcome measure are the characteristics that express its adequacy in terms of reliability and validity.

Psychometric properties are usually measured by Intra-class correlation coefficients and are presented as a number between 0 (no consistency) and 1 (complete consistency) (Shrout, & Fleiss, 1979). The psychometric properties of an outcome measure are the characteristics that express its adequacy in terms of reliability and validity (Outcome Measures for Patients with Lower Limb Amputation).

Reliability – the extent to which results can be reproduced when the study is repeated under the same conditions. Validity – this is the degree to which the content of an outcome measure is an adequate reflection of the concept to be measured (Mokkink et al., 2010)

All statistical analyses were performed using SPSS Version 22.0 (IBM Corporation).

Results

It has been determined (Gait abnormalities in patients with amputations), that in the process of controlling gait with amputated limbs, it is important to know how amputation affects normal gait (De Pauw et al., 2020; Yildirim Şahan, & Erbahçeci, 2023). Therefore, we will use the term «normal gait» to define a model that has been generalized across many variables, including age and gender (Fish, & Nielsen, 1993).

Gait as a complex process involves the coordination of motor and sensory systems (Frengopoulos et al., 2018). Our empirical experiment was based on the fact that lower limb amputation significantly disrupts body statics (Demeco et al., 2023). Accordingly, the center of gravity shifts toward the preserved limb. Walking with a prosthesis after lower limb amputation complicates these processes (Demeco et al., 2023; Farrokhi et al., 2019). As a result, it is possible to walk freely in the 3-4th month of training. At the same time, walking on the right hip prosthesis requires more skill. This is also required for walking on uneven surfaces, climbing slopes, etc. (Raya et al., 2013). In addition, it was taken into account that there may be deviations in gait with amputated limbs that arise as compensation for the prosthesis, muscle weakness or tension, balance disorders, and fear. Such deviations cause a change in gait pattern (Ewins, & Collins, 2014). In the rehabilitation process, these changes must be recognized in time to make corrective decisions.

Therefore, the first stage of our research resulted in the development of an intelligent digital infrastructure designed to implement the L-test. The complexity of developing such an infrastructure involved solving problems in collecting and analyzing test data, including test execution time, gait trajectory, balance during gait, and accuracy of turns.

To meet these requirements, we used the Radiofrequency Identification (RFID) system, a modern automatic identification technology that automates the process of collecting and processing information in a contactless manner (Politanskyi et al., 2024). RFID is an important element of the digital infrastructure that can be easily integrated into it and provides a comprehensive solution to the tasks at hand. In particular, in our development, RFID ensured the recognition and registration of the necessary parameters (Mykytyuk et al., 2023), when a student performs the L-test online and tracked the student's movement using radiofrequency radiation.

The developed infrastructure uses RFID components:

– RFID tags are located at key points in the L-test trajectory. An RFID tag is a miniature storage device with a microchip and an antenna. The microchip is designed to store information, and the antenna transmits and receives data.

An RFID tag does not require power. The «memory» of the tags contains the identification code and has the function of memory overwriting. In addition, it provides storage of unique information data: when it enters the RFID tag's registration area, the information is read. The RFID tag stores up to 10 thousand bytes of up-to-date information, has an increased level of invulnerability and resistance to the environment, has no limitations on its service life and has the potential to save energy.

– An RFID reader is a special microdevice with an antenna that is worn by a student. Its function is to obtain accurate information about the passage of a certain point of the L-test distance and the spatial position of the student during the L-test by reading data from the tags and storing them. RFID readers read information quickly and accurately, approaching 100% identification. The RFID reader communicates with the RFID data processing system via radiofrequency.

– An RFID data processing system that accumulates and analyzes information, linking the elements into a complete system. The RFID system can overwrite RFID tags. An RFID reader does not require direct visibility of the tag to «read» the data. RFID tags are perceived by the packaging, which guarantees «hidden» placement. To read the data, the RFID tag is brought into the registration area, including by moving the RFID system at high speed.

The signal that is received and processed by the RFID when the student performs the test task is transmitted to a microcontroller with an Arduino Mega 2560 board with 256 KB of flash memory. The voltage in the Arduino Mega 2560 is supplied directly from an external power source, not related to 5V from USB or another source of stable voltage, or an external adapter. The board provides the ability to process signals from RFID while the data obtained is used to calculate gait parameters during the L-test, recording the moments when the student crosses the RFID reader zone and determine the time required to complete each segment of the trajectory. The collected data is transmitted by the RFID system to a PC via a wireless module for easy further analysis. In our development, the results are displayed using an OLED display, which is characterized by the lowest power consumption. Such a display provides the ability to present an innovative graphical test scheme with detailed images. The data can be presented in the form of graphs, tables, or 3D models of the student's movement during the L-test. Additionally, the system is expanded with cloud storage, which provides a simple and secure connection to cloud applications using an IoT gateway. Cloud storage is used to track students' progress on the L-test over the long term. Interactive interfaces, such as game scenarios, motivate students to perform tasks more accurately and ensure the effect of the innovations used.

Testing with the use of intelligent digital infrastructure is carried out as follows (Fig. 1). A student of the study sample assumes a sitting position. An RFID reader is placed on the student at certain points. From the beginning of the test task, the information from the RFID tags is transmitted to the RFID reader and then to the RFID data processing system. RFID, information about the student's spatial position during the test is transmitted to the microcontroller and then to the PC. On the OLED display, the information is presented in digital and graphical form.

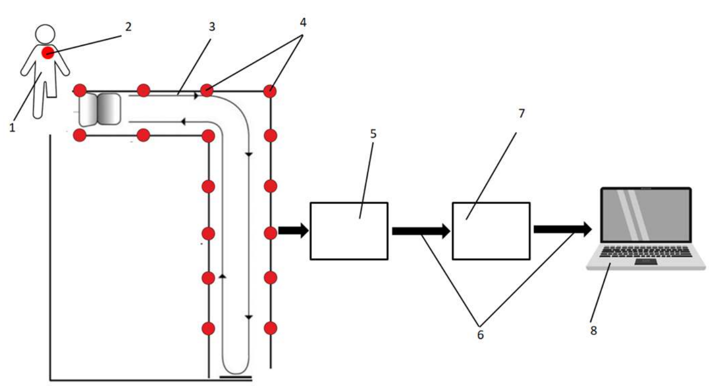

Fig. 1. Scheme of L-test implementation use of intelligent digital infrastructure:

1 – student, 2 – RFID tags, 3 – direction of movement, 4 – RFID reader, 5 – RFID data processing system;

6 – infrared lines; 7 –microcontroller, 8 – PC

Machine learning algorithms are used to improve the efficiency of the smart digital infrastructure. Machine Learning is a branch of artificial intelligence that develops algorithms and statistical models based on test data to make predictions or decisions. They allow us to analyze large amounts of collected data and create models that can assess the quality of test performance and identify pathologies in students' movements during the L-test. In the second stage of the study, the students of the studied sample were tested to determine the level of test reliability and validity of the L-test (Table 1).

Table 1

Psychometric properties of the L-test for students with lower limb amputation (n – 26)

Psychometric properties	Rtt							
	ST	IDI	ST	IDI	ST	IDI	ST	IDI
reliability	0,618	0,901	0,591	0,889	0,672	0,902	0,622	0,889
validity	0,255	0,511	0,248	0,608	0,284	0,587	0,306	0,614

*Note: ST – stopwatch, IDI – intelligent digital infrastructure

The results of the test control and determination of the psychometric properties of the L-test for students with lower limb amputation showed a significantly higher level of reliability and validity of the L-test when the results are recorded by intelligent digital infrastructure. According to the digital data, the level of psychometric properties of the L-test was within the «high» range. Instead, when the results were recorded by a stopwatch, the level of psychometric properties of the L-test reached the «medium» limit.

Dicussion

The relevance of scientific research is due to the fact that the loss of a limb has serious consequences for human mobility and gait (Demeco et al, 2023; Lathouwers et al., 2023; Farrokhi, et al., 2019) and active daily living (Dillingham, & Pezzin, 2008; Ladlow et al., 2017; Sinha et al., 2011). Therefore, we align our research with the findings (Herasymenko et al., 2018; Soares et al., 2009; Laferrier et al., 2010), that appropriate evidence-based rehabilitation after amputation is important to prevent severe mobility and self-care limitations, postural disorders, decreased body endurance, and inability to tolerate physical activity (Esquenazi, & DiGiacomo, 2001; Fiedler et al., 2014; Murray, & McGinty, 2023).

The need to obtain objective test control data is driven by the need to develop best practices for rehabilitation after lower limb amputation (Esquenazi, 2014; Murray, & McGinty, 2023). We support the scientific approaches that test results should be reliable and valid (Alvurdu et al., 2024; de Valle et al., 2021; Ladlow et al., 2019) to ensure the reliability of interpretation of the meaning of changes and appropriate correction of the inclusive physical education program for students after lower limb amputation (Balk et al., 2019; Abraham Correa, Arevalo Osorio, & Maqueira Caraballo, 2024).

We join the idea (Kim, Chu, & Jeon, 2015; Death, & Miller, 2005; Resnik, & Borgia, 2011) about the feasibility and necessity of using the L-test in monitoring the recovery process of people with lower limb amputation, as it covers most functional measures. At the same time, our study extends the findings of previous studies (Ladlow et al., 2017; Ladlow et al., 2019; Wentink et al., 2014) on the use of electronic devices and computer-controlled components (Fiedler et al., 2014; Yildirim Şahan, & Erbahçeci, 2023) in the control of walking in traumatic lower limb amputees.

The study expands the data (McCreath Frangakis, Lemaire, & Baddour, 2023; McCreath Frangakis, 2024) on the use of automated electronic means in the implementation of the L-test. At the same time, the information (Beyea, 2017) confirmed that the use of a stopwatch in recording L-test results is a factor in obtaining unreliable test control results.

It is confirmed (Ladlow al., 2017; Koryahin et al., 2024; Zhang et al., 2024) that the effectiveness of control depends on the tool used: real-time monitoring and feedback mechanisms are a factor in obtaining reliable results, and the use of technological tools for testing has a sufficient level of evidence of their work (Beyea, 2017; Blavt al., 2023; Mykytyuk et al., 2022)

So far, the L-test has been used to control gait in people: with chronic stroke (Kim, Chu, & Jeon, 2015); in stroke patients (Sinha, & Hamdani, 2015) with multiple sclerosis (Eldemir et al, 2025); with Parkinson's diseases (Haas et al., 2019); with total knee arthroplasty (Yuksel al., 2021); in hospitalized elderly (Nguyen al., 2007); in children with cerebral palsy (Cetin, & Erel, 2022); in pediatric lower limb prosthetics (Koenig et al, 2024); with multiple sclerosis (Kader et al., 2024)

However, to date, no studies have been conducted on the applicability of the L-test as a tool for assessing basic gait skills in situations more similar to real-life situations (Eldemir et al., 2025) in a population of students with lower limb amputation. For the first time, we have determined the psychometric properties of the L-test for students with lower limb amputation implemented by intelligent digital infrastructure.

Conclusions

At the moment, the duration of the armed aggression has crossed the ten-year mark. The longer the russian aggression lasts, the more military and civilians suffer amputations as a result of war injuries. The number of students in higher education institutions with amputations is growing from year to year.

Slowly, higher education institutions are beginning to overcome stereotypes and listen to the «special» needs of students with amputations in the process of obtaining education. The core of the university environment is inclusive physical education, which is the basis of the fundamental changes that are taking place in the global educational space by the realities of today.

The paper presents the developed intellectual digital infrastructure designed to implement the L-test to monitor the rehabilitation process in the course of inclusive physical education. The intellectual digital infrastructure includes: RFID, a microcontroller with an Arduino Mega 2560 board, PC with an OLED display. Radiofrequency communication is used for data transmission. To improve the efficiency of the smart digital infrastructure, Machine Learning algorithms and cloud storage were implemented.

The results of the analysis of the results of the experimental study showed a «high» level of psychometric properties of the L-test for students with lower limb amputation implemented by the intelligent digital infrastructure as opposed to recording the results with a stopwatch.

Thus, the use of intelligent digital infrastructure in the implementation of the L-test for students with lower limb amputation provides a high level of reliability and objectivity of the control results in real-time. The use of modern artificial intelligence technologies in our development allows us to analyze large amounts of collected data and create models that can assess the quality of the test and identify pathologies in the course of students.

Conflicts of interest. No conflicts of interest exist.

References

Holovanova, I., Havlovsky, O., Wang, S., Korneta, O., Khorosh, M., Kaydashev, I., Robinsonc, R.·& Haque, U. (2025). Doctors’ satisfaction with the rehabilitation system for anti-terrorist operation participants: A factor analysis. *Heliyon, 11*(1), e40667. https://doi.org/10.1016/j.heliyon.2024.e40667

Van Dongen, T.T., Huizinga, E.P., de Kruijff, L.G, Van der Krans, A.C., Hoogendoorn, J.M., Leenen, L.P., & Hoencamp, R. (2017). Amputation: Not a failure for severe lower extremity combat injury. *Injury, 48*(2), 371-377. https://doi.org/10.1016/j.injury.2016.12.001

Laferrier, J.Z., McFarland, L.V., Boninger, M.L., Cooper, R.A., & Reiber, G.E. (2010). Wheeled mobility: factors influencing mobility and assistive technology in veterans and servicemembers with major traumatic limb loss from Vietnam war and OIF/OEF conflicts. *J Rehabil Res Dev, 47*(4), 349-60.

Pursela, A., Nicholsa, R., & Lindquista, K. (2024). Combat amputee care for Global War on Terror Veterans: A systematic review. Journal of Military, *Veteran and Family Health, 10*(05). https://doi.org/10.3138/jmvfh-2023-0106

Texty.org.ua. Retrieved from: https://texty.org.ua/

Collins, D. M., Karmarkar, A., Relich, R., Pasquina, P.F., & Cooper, R.A. (2006). Review of research on prosthetic devices for lower extremity amputation. *Critical Reviews in Biomedical Engineering, 34*(5), 379-438. https://doi.org/10.1615/CritRevBiomedEng.v34.i5.20

Penn-Barwell, J.G. (2011). Outcomes in lower limb amputation following trauma: a systematic review and meta-analysis. *Injury, 42*(12), 1474-9. https://doi.org/10.1016/j.injury.2011.07.005

Fiedler, G., Akins, J., Cooper, R., Munoz, S. & Rory A. (2014). CooperRehabilitation of People with Lower-Limb Amputations. *Curr Phys Med Rehabil Rep, 2*, 263-272. https://doi.org/10.1007/s40141-014-0068-8

Godwin, Y., Ahmed, A., & Shaat, H.Y. (2022). A review of the first wave of lower limb amputees from the Great March of Return in Gaza: Taking stock and preparing for the task ahead. *Injury, 53*(7), 2541-2549. https://doi.org/10.1016/j.injury.2022.05.031

Fitzgerald, S.G., Cooper, R., Dicianno, B., Collins, D., Teodorski, E., Karmarkar, A., Sporner, M., Pasquina, P., Wichman, T., & Franklin, A. (2007). Impact of physical activity on participation and quality of life in individuals who use prostheses and other assistive technology/lower extremity prostheses versus wheelchair for functional performance and participation of military and veteran personnel: DTIC Document 2007. *Veterans research foundation of Pittsburgh pa human engineering research LABS.*

Barber, W., Walters, W., Girginov, V., & Misener, L. (2024). *Breaking Barriers: A New Model of Inclusive Physical Education.* Routledge.

Karamani, M., Makopoulou, K., Mansfield, S., & Herold, F. (2024). The complex journey towards the enactment of inclusion in physical education: a scoping review of the literature on teachers’ perceptions and practices. *Physical Education and Sport Pedagogy,* 1-23. https://doi.org/10.1080/17408989.2024.2374263

Lieberman, L.J., Houston-Wilson, C., & Grenier, M. (2024). *Strategies for inclusion: Physical education for everyone.* Human Kinetics.

Dillingham, T.R, & Pezzin, L.E. (2008). Rehabilitation setting and associated mortality and medical stability among persons with amputations. *Archives of physical medicine and rehabilitation, 1*, 89(6), 1038-45.

Ladlow, P., Nightingale, T.E., McGuigan, M.P., Bennett, A.N., Phillip, R., & Bilzon, J.L.J. (2017). Impact of anatomical placement of an accelerometer on prediction of physical activity energy expenditure in lower-limb amputees. *PLoS One, 5,* 12(10), e0185731. https://doi.org/10.1371/journal.pone.0185731

Soares, A.S., Yamaguti, E.Y., Mochizuki, L., Amadio, A.C., & Serrão, J.C. (2009). Biomechanical parameters of gait among transtibial amputees: a review. *Sao Paulo Med J, 127*(5), 302-309. https://doi.org/10.1590/s1516-31802009000500010

De Pauw, K., Serrien, B., Baeyens, J.P., Cherelle, P., De Bock, S., Ghillebert, J., Bailey, S.P., Lefeber, D., Roelands, B., Vanderborght, B., & Meeusen, R. (2020). Prosthetic gait of unilateral lower-limb amputees with current and novel prostheses: A pilot study. *Clin Biomech (Bristol), 71*, 59-67. https://doi.org/10.1016/j.clinbiomech.2019.10.028

Lathouwers, E., Baeyens, J.P., Tassignon, B., Gomez, F., Cherelle, P., Meeusen, R., Vanderborght, B., & De Pauw, K. (2013). Continuous relative phases of walking with an articulated passive ankle-foot prosthesis in individuals with a unilateral transfemoral and transtibial amputation: an explorative case-control study. *Biomed Eng Online, 15,* 22(1), 14. https://doi.org/10.1186/s12938-023-01074-2

Michael, J.W., & Bowker, J.H. (Eds.). (2004). *Atlas of amputations and limb deficiencies: surgical, prosthetic, and rehabilitation principles*. Rosemont, IL: American Academy of Orthopaedic Surgeons.

Thibault, G. (2019). *Amputee FS Identification Accuracy from 6 Minute Walk Test Raw Data. Dept. Mechanical Engineering*, Univ. of Ottawa, Ottawa, ON, Canada.

Demeco, A., Frizziero, A., Nuresi, C., Buccino, G., Pisani, F., Martini, C., Foresti, R., & Costantino, C. (2013). Gait Alteration in Individual with Limb Loss: The Role of Inertial Sensors. *Sensors (Basel), 7*, 23(4), 1880. https://doi.org/10.3390/s23041880

Koenig, K.D., Hall, M.J., Gormley, C., Kaleta, M., Munger, M., Laine, J., & Morgan, S.J. (2024). Clinical outcomes measurement in pediatric lower limb prosthetics: A scoping review. *J Pediatr Rehabil Med, 17*(2), 147-165. https://doi.org/10.3233/PRM-230014

Rivera, J.C., & Pasquina, P.F. (2016). Comprehensive rehabilitation following combat extremity trauma: evolution and its impact on outcomes. *Journal of Orthopaedic Trauma, 30,* S31-S33.

Esquenazi, A. (2014). Gait Analysis in Lower-Limb Amputation and Prosthetic Rehabilitation. *Physical medicine and rehabilitation clinics of North America, 25*, 153-67. https://doi.org/10.1016/j.pmr.2013.09.006

Sansam, K., Neumann, V., O'Connor, R., & Bhakta, B. (2009). Predicting walking ability following lower limb amputation: a systematic review of the literature. *J Rehabil Med, 41*(8), 593-603.

Farrokhi, S., Mazzone, B., Moore, J.L., Shannon, K., & Eskridge, S. (2019). Physical Therapy Practice Patterns for Military Service Members with Lower Limb Loss. *Military Medicine, 184*(11-12), e907-e913. https://doi.org/10.1093/milmed/usz107

Rau, B., Bonvin, F., & de Bie, R. (2007). Short-term effect of physiotherapy rehabilitation on functional performance of lower limb amputees. *Prosthetics and Orthotics International, 31*(3), 258-270. https://doi.org/10.1080/03093640600994615

Kirshner, B., & Guyatt, G. (1985). Methodological framework for assessing health indicators. *J Chronic Dis, 38*(1), 27-36.

Blavt, O., Galamanzhuk, L., Huska, M., Iedynak, G., Pityn, M., Kachurak, Y., Faidevych, V., & Turka, R. (2024). Using Programmable Device Installations to Control Students with Disabilities after Blast Traumatic Brain Injury in 10 Meter Walking Test. *Physical Education Theory and Methodology, 24*(3), 433-441. https://doi.org/10.17309/tmfv.2024.3.12

Ladlow, P., Nightingale, T.E., McGuigan, M.P., Bennett, A.N., Phillip, R.D., & Bilzon, J.L.J. (2019). Predicting ambulatory energy expenditure in lower limb amputees using multi-sensor methods. *PLoS One, 31,* 14(1), e0209249. https://doi.org/10.1371/journal.pone.0209249

Mykytyuk, Z., Blavt, O., Hnatchuk, Ya., Stechkevych, O., & Helzhynska, T. (2022). Intensification of Back Muscle Strength Testing in Physical Education of Students by Applying Information and Communication Technologies. *Teorìâ ta Metodika Fìzičnogo Vihovannâ, 22*(2), 216-222. https://doi.org/10.17309/tmfv.2022.2.10

McCreath Frangakis, A.L., Lemaire, E.D., & Baddour, N. (2023). Subtask Segmentation Methods of the Timed Up and Go Test and L Test Using Inertial Measurement Units – A Scoping Review. *Information, 14*(2), 127. https://doi.org/10.3390/info14020127

Juneau, P., Baddour, N., Burger, H., Bavec, A., & Lemaire, E.D. (2021). Comparison of decision tree and long short-term memory approaches for automated foot strike detection in lower extremity amputee populations. *Sensors, 21*(21), 6974.

Dejaco, B., de Jong, L.D., van Goor, H., Staal, J.B., Stolwijk, N., & Lewis, J. (2023). The concurrent validity and reliability of virtual reality to measure shoulder flexion and scaption range of motion. *Physiotherapy, 120*, 95-102. https://doi.org/10.1016/j.physio.2023.06.005

Davenport, T., & Kalakota, R. (2019). The potential for artificial intelligence in healthcare. *Future healthcare journal, 6*(2), 94.

Juneau, P., Baddour, N., Burger, H., Bavec, A., & Lemaire, E. D. (2022). Amputee fall risk classification using machine learning and smartphone sensor data from 2-minute and 6-minute walk tests. *Sensors, 22*(5), 1749.

Chaplin E, Karatzios C, & Benaim C. (2023). Clinical Applications of Virtual Reality in Musculoskeletal Rehabilitation: A Scoping Review. *Healthcare (Basel), 11*(24), 3178. https://doi.org/10.3390/healthcare11243178

Zhang, H., Liao, Y., Zhu, C., Meng, W., Liu, Q., & Xie, S.Q. (2024). VR-Aided Ankle Rehabilitation Decision-Making Based on Convolutional Gated Recurrent Neural Network. *Sensors (Basel), 30,* 24(21), 6998. https://doi.org/10.3390/s24216998

Deathe, A.B., & Miller, W.C. (2005). The L test of functional mobility: measurement properties of a modified version of the timed up and go test designed for people with lower-limb amputations. *Phys Ther, 85*(7), 626-35.

Yuksel, E., Eymir, M., Unver, B., & Karatosun, V. (2021). Reliability, concurrent validity and minimal detectable change of the L test in patients with total knee arthroplasty. *Disability and Rehabilitation, 44*(14), 3714-3718. https://doi.org/10.1080/09638288.2021.1871670

Eldemir, K., Eldemir, S., Ozkul, C., Irkec, C., & Guclu-Gunduz, A. (2025). Reliability and validity of the L test in people with multiple sclerosis. *Physiotherapy, 126,* 101429. https://doi.org/10.1016/j.physio.2024.101429

The L Test. Retrieved from: https://www.physio-pedia.com/The_L_test#cite_note-1

Prion, S., & Haerling, K.A. (2014). Making Sense of Methods and Measurement: Pearson Product-Moment Correlation Coefficient. *Clinical Simulation in Nursing, 10*(11), 587-588. https://doi.org/10.1016/j.ecns.2014.07.010

Shrout, P.E., & Fleiss, J.L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin. Psychol Bull, 86*(2), 420-428.

Outcome Measures for Patients with Lower Limb Amputation. Retrieved from: https://www.physio-pedia.com/Outcome_Measures_for_Patients_with_Lower_Limb_Amputation

Mokkink, L.B., Terwee, C.B., Patrick, D.L., Alonso, J., Stratford, P.W., & Knol, D.L., et al. (2010) The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. *J Clin Epidemiol, 63*(7), 737-745.

Gait abnormalities in patients with amputations. Retrieved from: https://langs.physio-pedia.com/uk/gait-deviations-in-amputees-uk/

Yildirim Şahan, T., & Erbahçeci, F. (2023). Effects of Virtual Reality on Transtibial Amputation Rehabilitation Outcomes: A Randomized Study. *Games for Health Journal, 12*(6), 459-467.

Fish, D.J., & Nielsen, C.P. (1993). Clinical Assessment of Human Gait. *Journal of Prosthetics and Orthotics, 2*(39).

Frengopoulos , C., Payne, M.W.C., Holmes, J.D., Viana, R., & Hunter, S.W. (2018). Comparing the Effects of Dual-Task Gait Testing in New and Established Ambulators With Lower Extremity Amputations. *PMR, 10*(10), 1012-1019. https://doi.org/10.1016/j.pmrj.2018.03.018

Raya, M.A., Gailey, R.S., Gaunaurd, I.A., Ganyard, H., KnappWood, J., McDonough, K., & Palmisano, T. (2013). Amputee Mobility Predictor-Bilateral: A performance-based measure of mobility for people with bilateral lower-limb loss. *J Rehabil Res, 50*(7), 961-68. http://dx.doi.org/10.1682/JRRD.2012.05.0097

Ewins, D., & Collins, T. (2014). Chapter 25 - Clinical Gait Analysis. Editor(s): A. Taktak, P. Ganney, D. Long, P. White, Clinical Engineering. *Academic Press*, 389-406, https://doi.org/10.1016/B978-0-12-396961-3.00025-1

Politanskyi, R., Kogut, I., Vistak, M., Mykytyuk, Z., Shymchyshyn, O., & Diskovskyi, I. (2024). Modelling of a multilayer high-tech film for an infrared photodetector (3.5-5.0 μm). *Physics and Chemistry of Solid State,* 25(4), 757-763. https://doi.org/10.15330/pcss.25.4.757-763

Mykytyuk, Z.M., Barylo, H.I., Kremer, I.P., Kachurak, Y.M., & Shymchyshyn, O.Y. (2023). Sensitive liquid crystal composites for optical sensors. *Molecular Crystals and Liquid Crystals, 768*(2), 1-8. https://doi.org/10.1080/15421406.2023.2235865

Sinha, R., van den Heuvel, W.J., & Arokiasamy, P. (2011). Factors affecting quality of life in lower limb amputees. *Prosthet Orthot Int, 35*(1), 90-96. https://doi.org/10.1177/0309364610397087

Herasymenko, O., Pityn, M., Kozibroda, L., Mukhin, V., Dotsyuk, L., & Galan, Y. (2018). Effectiveness of physical therapy interventions for young adults after lower limb transtibial amputation. *Journal of Physical Education and Sport, 1*(18), 1084-91. https://doi.org/10.7752/jpes.2018.s2162

Esquenazi, A., & DiGiacomo, R. (2001). Rehabilitation After Amputation. *Journal of the American Podiatric Medical Association, 91,* 13-22. https://doi.org/10.7547/87507315-91-1-13

Murray, L., & McGinty, G. (2023). Use of Physical Activity Measures in Rehabilitation Interventions Following Lower Extremity Amputation. *Curr Phys Med Rehabil Rep, 11*, 25-34. https://doi.org/10.1007/s40141-023-00383-w

Alvurdu, S., Akarçeşme, C., Altundağ, E., & Montalvo, S. (2024). Concurrent validity and reliability of iVMES portable force plate for measuring vertical jump height. *Journal of Physical Education and Sport, 24*(4), 117, 1024-1031. https://doi.org/10.7752/jpes.2024.04117

de Valle, K., Dobson, F., Woodcock, I., Carroll, K., Ryan, M.M., Heatwole, C., Eichinger, K., McGinley, J.L. (2021). Reliability and validity of the FSHD-composite outcome measure in childhood facioscapulohumeral dystrophy. *Neuromuscular Disorders, 31*(8), 706-715. https://doi.org/10.1016/j.nmd.2021.05.011

Balk, E.M., Gazula, A., Markozannes, G., Kimmel, H.J., Saldanha, I.J., Trikalinos, T.A., & Resnik, L.J. (2019). Psychometric Properties of Functional, Ambulatory, and Quality of Life Instruments in Lower Limb Amputees: A Systematic Review. *Arch Phys Med Rehabil, 100*(12), 2354-2370. https://doi.org/10.1016/j.apmr.2019.02.015

Abraham Correa, P. F., Arevalo Osorio, M. I., & Maqueira Caraballo, G. de la C. (2024). Leisure activities adapted for the inclusion of students with lower limb prostheses in physical education. *ConcienciaDigital, 7*(4), 120-144. https://doi.org/10.33262/concienciadigital.v7i4.3238

Kim, J.S., Chu, D.Y., & Jeon, H.S. (2015) Reliability and validity of the L test in participants with chronic stroke. Physiotherapy, 101,161-165.

Resnik, L., & Borgia, M. (2011). Reliability of Outcome Measures for People with Lower-Limb Amputations: Distinguishing True Change from Statistical Error. *Phys Ther, 91*, 555-565.

Wentink, E.C., Schut, V.G., Prinsen, E.C., Rietman, J.S., & Veltink, P.H. (2014). Detection of the onset of gait initiation using kinematic sensors and EMG in transfemoral amputees. *Gait Posture, 39*(1), 391-396. https://doi.org/10.1016/j.gaitpost.2013.08.008

McCreath Frangakis, A. L., Lemaire, E. D., Burger, H., & Baddour, N. (2024). L Test Subtask Segmentation for Lower-Limb Amputees Using a Random Forest Algorithm. *Sensors, 24*(15), 4953.

Beyea, J.B.A. (2017). *Automating the Timed Up and Go Test (Tug Test) with Wearable Sensors*. Master's Thesis, University of New Brunswick, Fredericton, NB, Canada.

Koryahin, V., Iedynak, G., Blavt, O., Galamanzhuk, L., Prozar,, M., Zaikin, A., Veselovska, T., Golub, V., Kucher, T., & Gurtova, T. (2020). Introduction of electronic devices in the test of flexibility. *Journal of Physical Education and Sport, 20*(4), 1855–1860. https://doi.org/10.7752/jpes.2020.04251

Blavt, O., Bodnar, A., Mykhalskyi, A., Gurtova, T., & Tsovkh, L. (2023). Application of Electronic Means in Endurance Coordination Testing of Students with Disabilities Who are War Veterans. *Physical Education Theory and Methodology, 23*(3), 397-403. https://doi.org/10.17309/tmfv.2023.3.12

Sinha, M., & Hamdani, N. (2015). Measurement Properties of L Test for Functional Mobility in Stroke Patient. *International Journal of Scientific Research, 4*(7), 188-190.

Haas, B., Clarke, E., Elver, L., Gowman, E., Mortimer, E., & Byrd, E. (2019). The reliability and validity of the L-test in people with Parkinson's disease. *Physiotherapy, 105*(1), 84-89. https://doi.org/10.1016/j.physio.2017.11.218

Nguyen, V.C., Miller, W.C., Asano, M., & Wong, R.Y: (2007). Measurement properties of the l test for gait in hospitalized elderly. *Am J Phys Med Rehabil, 86*, 463-468.

Cetin, S.Y., & Erel, S. (2022). Investigation of the validity and reliability of the L test in children with cerebral palsy. *Physiother Theory Pract, 38*(1), 182-188. https://doi.org/10.1080/09593985.2020.1731894

Kader, E., Eldemirb, S., Ozkulc, C., Irkecd, C., & Guclu-Gunduzc, A. (2024). Reliability and validity of the L test in people with multiple sclerosis. *Physiotherapy, 126*, 101429. https://doi.org/10.1016/j.physio.2024.101429