Factors impacting high-level mobility in traumatic brain injury: a scoping review

Syazlin Azmi[1], Nor Azlin Mohd Nordin[2], Alia Alghwiri[3], Haidzir Manaf[4]
[1]Department of Physiotherapy, Hospital Rehabilitasi Cheras, Kuala Lumpur, Malaysia
[2]Physiotherapy Program, Center for Rehabilitation and Special Needs Studies, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia
[3]Department of Physiotherapy, School of Rehabilitation Sciences, University of Jordan, Amman, Jordan
[4]Centre for Physiotherapy Studies, Faculty of Health Sciences, Universiti Teknologi MARA, Selangor, Malaysia

Article Info

Article history:

Received Jun 1, 2024
Revised Jan 29, 2025
Accepted Mar 6, 2025

Keywords:

Brain injuries
Health care
Mobility limitation
Outcome assessment
Predictive factors
Rehabilitation
Traumatic

ABSTRACT

High-level mobility is crucial for improving quality of life and ensuring active participation in daily routines and community engagement. Therefore, this scoping review explored the available evidence on factors impacting high-level mobility among traumatic brain injury (TBI) individuals and the outcome measures used to evaluate high-level mobility. Following the preferred reporting items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines, five databases were searched: Scopus, Web of Science, Cochrane Library, Science Direct, and PubMed, yielding 109 articles, with eight meeting eligibility criteria. The keywords used in the search strategies were: traumatic brain injury, TBI, brain trauma, traumatic encephalopathy, and high-level mobility. This review revealed that the High-Level Mobility Assessment Tool (HiMAT) was identified as the most commonly used outcome measure for assessing high-level mobility. The key factors that may influence the outcome of high-level mobility in people with TBI are age, sex, mechanism of injury, duration of post-traumatic amnesia, and individual endurance. The associations between individuals' factors and outcomes in TBI studies exhibit significant variation. This can be attributed to several factors, including the diverse characteristics of TBI samples, different neurological recovery rates, methodological differences, timing of assessments, interactions between factors, and potential moderators.

Corresponding Author:

Haidzir Manaf
Centre for Physiotherapy Studies, Faculty of Health Sciences, Universiti Teknologi MARA
Puncak Alam Campus, Puncak Alam 42300, Selangor, Malaysia
Email: haidzir5894@uitm.edu.my

1. INTRODUCTION

High-level mobility (HLM) encompasses complex movements such as running, jumping, and stair climbing, which extend beyond basic walking and are crucial for daily activities like crossing streets, managing household chores, childcare, and faster movement during transportation [1]. These skills are also essential for participating in leisure activities, engaging in active sports, and maintaining employability [2], [3]. HLM plays a key role in reintegrating individuals into community life and sustaining physical activity that can prevent long-term health decline. Despite its significance, HLM is frequently overlooked in rehabilitation programs, which often prioritize lower-level mobility skills like bed mobility, transfers, and basic walking [4]. While much of the research and clinical focus has been on improving gait and balance, there is limited attention on how these gains translate into advanced mobility skills [1], leaving a gap in the evidence needed to guide effective rehabilitation for traumatic brain injury (TBI) survivors.

Several studies emphasize the importance of HLM for full participation in life, including work and social reintegration. Spencer *et al.* [1] reviewed HLM training in individuals with neurological impairments, including TBI. They found that while interventions targeting HLM can be beneficial, more well-designed studies with larger sample sizes are needed to confirm these findings. Their work highlights the need for further research to better understand the predictors of HLM and the effectiveness of different rehabilitation strategies. Kersey *et al.* [2] also noted that HLM plays a critical role in community reintegration for individuals with TBI, emphasizing that it is not merely a physical milestone but a vital factor for social and functional recovery. However, the various personal, environmental, and injury-related factors that affect HLM outcomes remain poorly understood, making personalized rehabilitation plans challenging. More recently, Gallow *et al.* [4] explored when individuals with TBI can safely resume HLM activities. Their study revealed the absence of clear guidelines, leaving clinicians uncertain about how and when to incorporate HLM into rehabilitation. This highlights the need for more research to develop a comprehensive understanding of the factors influencing HLM in TBI recovery. This highlights the need for more research to develop a comprehensive understanding of the factors influencing HLM in TBI recovery. Given these gaps, this scoping review addresses the following research question: What are the key factors influencing high-level mobility outcomes in individuals with TBI?

Building on these insights, this scoping review aims to investigate the factors that affect HLM in individuals with TBI. While previous studies have acknowledged the importance of HLM, there remains a lack of clarity on the key factors that influence mobility outcomes. A preliminary search of medical literature analysis and retrieval system online (MEDLINE), the Cochrane database of systematic reviews, and Joanna Briggs Institute (JBI) Evidence Synthesis revealed no current or ongoing scoping reviews on this topic. Therefore, this scoping review seeks to fill these gaps by systematically exploring the factors influencing HLM in individuals with TBI and identifying the outcome measures used to evaluate HLM in rehabilitation settings. This review aims to contribute to the field in two significant ways: first, by illuminating the complex interactions between factors that influence HLM outcomes in TBI, and second, by proposing future research directions and rehabilitation strategies. Ultimately, these findings will assist clinicians and researchers in optimizing rehabilitation approaches for individuals with TBI, advancing the field of neurorehabilitation.

2. METHOD

2.1. Study design

Given the limited research available on HLM in TBI, a scoping review was chosen to explore the existing literature, identify patterns, and highlight areas that need further study. This review followed a structured approach using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist [5]. Additionally, to further ensure transparency and accountability, the review protocol was registered with the open science framework (OSF) (https://osf.io/xmz8j) [6]. The review was conducted in four key stages: i) determine search strategy, ii) specify eligibility criteria, iii) study selection, and iv) data charting and extraction.

2.2. Search strategy

An extensive search was conducted across five major databases: Scopus, Web of Science (WoS), Cochrane Library, Science Direct, and PubMed. This comprehensive approach aimed to capture all relevant studies on HLM in individuals with TBI. No date restrictions were applied, recognizing the limited amount of research specifically addressing HLM in TBI populations and ensuring all pertinent evidence was included. Medical Subject Headings (MeSH) terms from the Cochrane Database were utilized to account for all possible synonyms, and Boolean operators (AND, OR) were used to combine search terms effectively. Quotation marks were applied around specific phrases, and parentheses were used to group similar concepts. The primary search terms included ("traumatic brain injury*" OR "TBI*" OR "brain trauma*" OR "traumatic encephalopathy*") AND ("high-level mobility"). A detailed list of the search queries and the number of articles retrieved from each database is provided in Table 1.

2.3. Eligibility criteria

To ensure the review focused on high-quality research, specific inclusion and exclusion criteria were set. The review included studies involving people with TBI, regardless of the severity, as long as the study looked at factors or predictors affecting HLM and used at least one performance-based outcome measure. Observational studies, like cohort, case-control, and cross-sectional designs, were also considered. Meanwhile, articles without full text, those not in English, intervention studies, and research that only validated outcome measures without reporting actual performance data were excluded. Intervention studies were excluded because the aim was to identify factors impacting HLM, rather than assess the efficacy of specific treatments. Similarly, studies focused on validating outcome measures without performance data were excluded to ensure the review concentrated on real-world performance outcomes. Secondary sources, such as reviews or book chapters, were also left out to focus on original, relevant findings related to HLM.

Table 1. Search queries used in the scoping review of factors impacting HLM among TBI

Database	Concept	Keywords	Articles
Scopus	-	TITLE-ABS-KEY ((“traumatic brain injury*” OR “TBI*” OR “brain trauma*” OR “traumatic encephalopathy*”) AND (“high-level mobility”))	38
Web of Science	-	(AB = (“traumatic brain injury*” OR “TBI*” OR “brain trauma*” OR “traumatic encephalopathy*”)) AND AB = (“high-level mobility”)	27
Cochrane Library	#1	Title Abstract Keyword “traumatic brain injury*” OR “TBI*” OR “brain trauma*” OR “traumatic encephalopathy*”	54
	#2	Title Abstract Keyword “high-level mobility”	25
	(#1) AND (#2)	Title Abstract Keyword ((“traumatic brain injury*” OR “TBI*” OR “brain trauma*” OR “traumatic encephalopathy*”) AND (“high-level mobility”))	5
Science Direct	-	Title, abstract, or author-specified keywords (“traumatic brain injury” OR “TBI” OR “brain trauma” OR “traumatic encephalopathy”) AND (“high-level mobility”)	8
PubMed	#1	“traumatic brain injury*”[Title/Abstract] OR “TBI”[Title/Abstract] OR “brain trauma*”[Title/Abstract] OR “traumatic encephalopathy*”[Title/Abstract]	55,338
	#2	“high-level mobility”[Title/Abstract]	71
	(#1) AND (#2)	(“traumatic brain injury*”[Title/Abstract] OR “TBI”[Title/Abstract] OR “brain trauma*”[Title/Abstract] OR “traumatic encephalopathy*”[Title/Abstract]) AND “high-level mobility”[Title/Abstract]	31
Total			109

2.4. Study selection

Following the PRISMA-ScR guidelines, the search strategy comprised four key stages: identification, screening, eligibility, and inclusion, as depicted in Figure 1. The initial search across five databases yielded a total of 109 articles. After the removal of 68 duplicates, 41 records proceeded to the screening stage. Two independent reviewers assessed the titles and abstracts of these articles to determine their relevance, leading to the exclusion of an additional seven articles. A total of 34 full-text articles were then assessed for eligibility. Following this more thorough review, 26 articles were excluded based on the pre-established criteria. Reasons for exclusion included articles not in English, articles lacking full text (e.g., abstracts or editorials), and studies focused solely on validating outcome measures. Finally, eight studies met the eligibility criteria and were included in the final synthesis for data extraction. Any disagreements between the reviewers during the selection process were resolved through discussion, ensuring a rigorous and unbiased selection of studies for inclusion in the review.

2.5. Data charting and extraction

The step-by-step data extraction ensured consistency in the information collected and minimized the risk of omitting critical details. Data were extracted using a standardized form, which was iteratively refined to ensure accuracy and comprehensiveness. Two reviewers independently charted the data, and any discrepancies were discussed until a consensus was reached. This process ensured the robustness and reliability of the data. The following key information was extracted from each study; i) study characteristics (author(s), publication year, and study design); ii) participant details (population, sample size, age, and gender); iii) predictors/factors (variables analyzed as factors impacting HLM); iv) outcome measures of HLM; v) correlations (statistical relationships between predictors and HLM outcomes if available); and vi) key findings (summary of the main results related to HLM in TBI populations). Table 2 (see in appendix) provides the extracted data from the included study.

2.6. Data analysis

The data were analyzed using both descriptive and thematic methods. Thematic analysis was applied to categorize different predictors and factors affecting HLM, while descriptive analysis summarized the characteristics of the studies and populations involved. Where quantitative data were available, correlations and statistical associations between factors and HLM outcomes were reported.

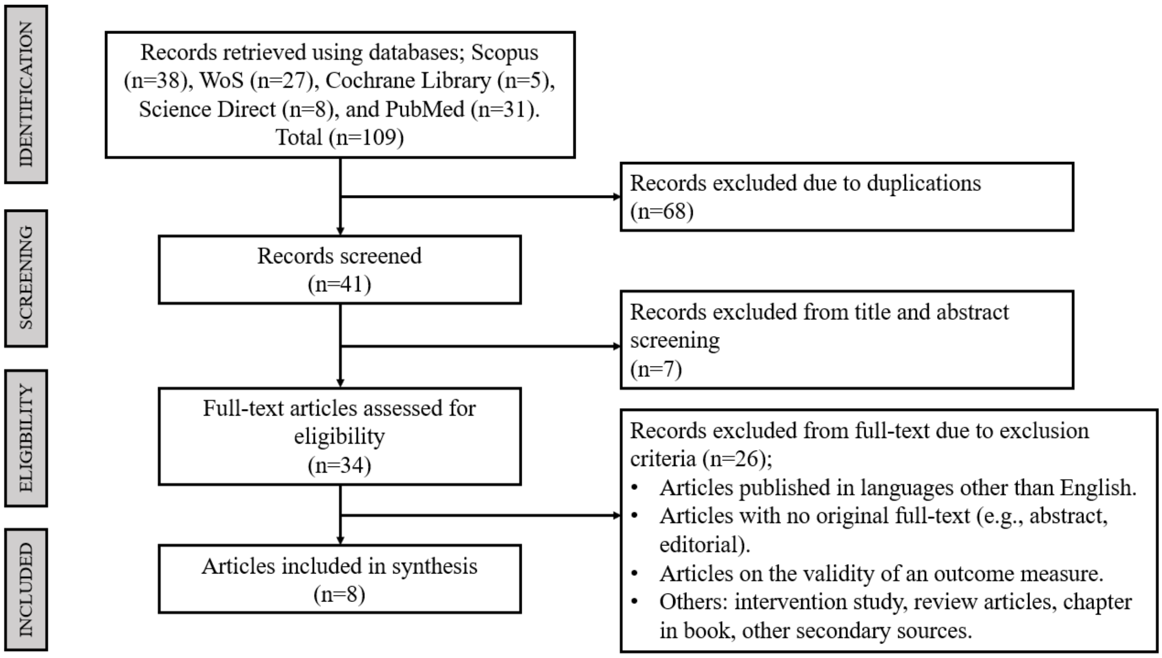

Figure 1. The PRISMA-ScR flow diagram of this review

3. RESULTS AND DISCUSSION

3.1. Characteristics of studies

Of the eight studies included in this review, seven were published between 2010 and 2016, with one more recent study published in 2022. The studies utilized two main observational designs: cross-sectional (n = 2) and cohort (n = 6). Sample sizes varied, ranging from 56 to 136 participants. The studies included individuals with varying levels of traumatic brain injury (TBI) severity: mild TBI (n = 1), moderate TBI (n = 1), and moderate to severe TBI (n = 1). However, five studies did not specify TBI severity, and only four studies measured injury severity using a validated metric, such as post-traumatic amnesia (PTA) duration. Based on demographics, the participants generally reflected the broader TBI population, with a majority being male and predominantly young, with a mean age range between 29 and 32.2 years. Six of the eight studies identified correlations between factors and HLM outcomes.

3.2. Outcome measures of high-level mobility

In this scoping review, four outcome measures were used to assess HLM: the High-Level Mobility Assessment Tool (HiMAT) (n = 8), the Revised HiMAT (HiMAT-R) (n = 2), the modified Illinois Agility Test (mIAT) (n = 2), and the ability to run (n = 1). HiMAT was the most commonly utilized measure originally developed to assess mobility limitations in adolescents and adults with TBI. The tool consists of 13 tasks, including walking backward, running, jumping, skipping, hopping, and climbing stairs [7]. Using standardized outcome measures like HiMAT is essential for setting meaningful and achievable rehabilitation goals. These measures provide a clear baseline, enabling clinicians and patients to track progress and tailor treatment plans based on the individual's abilities and functional deficits [8]. Regular assessment with tools like HiMAT helps guide clinical decision-making, allowing for evidence-based adjustments to rehabilitation programs [9]. Moreover, standardized outcome measures facilitate effective communication between healthcare providers, patients, and other stakeholders, ensuring a shared understanding of the patient's progress [10]. In research, the consistent application of these tools enables data comparison across studies and populations, facilitating the identification of best practices and the evaluation of rehabilitation protocol effectiveness. These measures are essential for optimizing patient care by providing a structured framework to assess treatment outcomes and promote active patient engagement in their recovery process [11].

3.3. Factors impacting high-level mobility

After thorough data extraction, we identified a range of factors that seem to influence HLM in people with TBI. These factors were categorized into three distinct domains: personal factors, injury-related characteristics, and impairments. Each domain sheds light on different aspects that contribute to HLM outcomes. Personal factors include individual characteristics such as age at injury, gender, body composition, and activity levels, all of which can shape someone's recovery and adaptation. Injury-related characteristics cover details specific to the injury itself, such as severity of injury, duration of PTA, and certain findings from neuroimaging. Lastly, impairments include physical or functional challenges such as spasticity, walking speed, endurance, balance, and muscle performance that may limit a person's ability to engage in HLM. Table 3 provides a summary of these domains, listing each factor and relevant studies that highlight its role.

Table 3. Factors impacting HLM

Domain	Predictors/factors	Reference(s)
Personal factors	Age at injury	[12]
	Sex	[12]
	Body mass index (BMI)	[13]
	Sum of 9 skinfold measures	[13]
	Activity level	[13]
Injury-related characteristics	Injury severity	[12]
	Injury mechanism	[12]
	Duration of PTA	[12]
	Cortical contusion	[12]
	Diffuse axonal injury (DAI)	[12]
Impairments	Spasticity	[14]–[16]
	Walking speed	[13], [17]
	Endurance	[12]
	Cardiovascular fitness	[12]
	Vestibular	[18]
	Balance	[17], [19]
	Muscle performance (APG)	[15], [17]

3.3.1. Personal factors

Two studies examined the association between personal factors and HLM outcomes, focusing on age at injury, sex, body mass index (BMI), the sum of nine skinfold measures, and physical activity levels (PALs). According to Moen *et al.* [12], age at injury appeared to have a significant unique contribution to both outcome measures of HLM, which are HiMAT and HiMAT-R, determined by unstandardized regression coefficient (B = 0.33, p<.001; B = 0.237, p<.001), respectively. These findings are consistent with previous studies [20]–[22] which suggest that younger individuals tend to recover mobility more effectively due to enhanced neuroplasticity. Sex also appeared to have a significant unique contribution to HiMAT and HiMAT-R (B = 4.943, p<.05; B = 3.686, p<.05) [12]. According to Han *et al.* [23] and Hamilton *et al.* [24], males often demonstrate better recovery, potentially because of greater muscle mass and higher baseline physical fitness. However, the influence of personal factors may interact with other variables, and inconsistencies in the literature highlight the need for additional research, particularly on hormonal factors and gender differences [25], [26]. The interaction of these personal factors with injury severity and psychosocial factors further complicates the understanding of HLM outcomes [23], [27]. Thus, future research is necessary to investigate these interactions and develop more personalized rehabilitation strategies that account for individual differences in recovery potential.

BMI and the sum of nine skinfold measures demonstrated only a negligible relationship with HLM, while PALs showed a moderate correlation (r = 0.508, p<.05) with HLM [13]. Petkeviciene *et al.* [28] found that individuals with TBI often had PALs well below recommended guidelines, highlighting the need for increased daily physical activity through moderate to vigorous exercise. The recommended guidelines for PALs include 30 minutes of moderate-intensity exercise five days per week or 60-75 minutes per week of vigorous-intensity exercise [24]. The significance of PALs in predicting HLM outcomes aligns with previous research indicating that higher levels of physical activity are associated with better recovery trajectories in individuals with TBI [29]. PALs are an important predictor of HLM, their interaction with other factors suggests that a multidimensional approach is necessary to improve mobility outcomes.

3.3.2. Injury-related characteristics

Moen *et al.* [12] explored the association between injury-related characteristics and HLM outcomes, focusing on injury severity, mechanism of injury, duration of PTA, and magnetic resonance imaging (MRI) findings (cortical contusion and diffuse axonal injury. The role of injury-related factors, such as motor vehicle accidents (MVAs) and PTA duration, adds complexity to mobility recovery. The mechanism of injury, particularly MVAs, had a significant impact on both HiMAT (B = 4.559, p<.05) and HiMAT-R (B = 4.034, p<.05) scores. Interestingly, patients involved in MVAs tended to have better HLM outcomes, possibly due to demographic factors such as younger age and better access to rehabilitation. Likewise, the duration of PTA was a strong predictor of HiMAT outcomes (B = 4.368, p<.05), although it did not affect HiMAT-R scores. PTA duration was also a strong predictor of poorer outcomes, with each additional week of PTA reducing the likelihood of regaining productivity by 14% [30]. Shorter PTA durations were associated with better recovery and a higher chance of returning to pre-injury functioning. As a result, the recovery process for moderate to severe TBI is often prolonged, with outcomes ranging from full recovery to long-term dependence, making it difficult to predict mobility outcomes and plan rehabilitation strategies. Other injury-related factors, such as cortical contusions and diffuse axonal injury, showed no significant association with HLM [12].

3.3.3. Impairments

Impairments had a substantial influence on HLM. Seven studies examined the relationship between impairments and HLM outcomes, with five studies identifying significant correlations. Walking speed and endurance were the most critical factors in this domain. Two studies [13], [17] reported a strong correlation between walking speed and HLM, with one study showing a significant contribution to the ability to run (B = 6.42, p<.001) [17]. Endurance also showed a robust correlation with HLM (r = 0.932) [13], highlighting the need to include gait training, cardiovascular fitness, and endurance exercises in rehabilitation strategies to enhance mobility recovery.

Spasticity was frequently assessed but showed only a weak correlation with HLM (r = 0.13, p = 0.22) [15], suggesting that its impact on mobility recovery may be less significant than motor control and endurance. Although lower limb spasticity was associated with greater mobility limitations (t91 = 2.15, p = 0.03) [16], the lack of specific timelines in the assessments makes it difficult to determine its long-term effects. As the findings showed a weak correlation between spasticity and HLM, this raises the question of whether lower limb spasticity is a primary physical impairment that requires management to improve mobility or whether it is primarily a barrier to effectively treating other physical impairments, such as muscle weakness in people with TBI. Therefore, spasticity may significantly impact mobility outcomes due to additional impairments, such as muscle weakness and reduced power generation [15].

Ankle power generation (APG) demonstrated a moderate correlation with HLM (ranging from 0.48 to 0.63) but did not show a significant unique contribution to mobility outcomes [15], [17]. Other impairments, such as vestibular function and balance, showed moderate correlations with HLM but were not as strongly linked to recovery as walking speed and endurance. Static balance and lateral center of mass (COM) displacement were moderately correlated with HLM (r = 0.57 and r = 0.51, respectively), explaining 32% and 26% of the variance in HiMAT scores [19]. Vestibular function reflected by the Vestibular Ocular Motor Screening (VOMS) and near point convergence (NPC) distance was also found to have a very weak correlation with HLM ranging from 0.02 to 0.06 and 0.14 to 0.21, respectively [18], suggesting that it may not be a primary focus in mobility recovery for TBI patients.

Overall, walking speed and endurance emerged as the most influential factors in the impairment domain. These findings emphasize the importance of targeting these capacities in rehabilitation strategies. While spasticity management is often emphasized, improving motor control and endurance may lead to better mobility outcomes. Additionally, incorporating activity-monitoring tools, such as pedometers, can help patients maintain regular physical activity, supporting long-term mobility recovery. The variability in study results may be attributed to differences in TBI characteristics, the impairments studied, and the extent of neurological recovery. These discrepancies highlight the need for personalized, client-centered rehabilitation approaches to account for diverse recovery patterns among TBI patients. Further research, particularly through interventional trials, is needed to determine the most significant impairments affecting mobility outcomes.

3.4. Implications of study

This study highlights the importance of personalized rehabilitation approaches tailored to individual patient characteristics, including age, sex, duration of PTA, and walking speed. Recognizing the variability in recovery trajectories is crucial for developing effective rehabilitation strategies [31], [32]. Personalized interventions can lead to improved outcomes by addressing the specific needs and goals of each patient, thereby facilitating a more efficient recovery process [33], [34]. The acknowledgment of these factors allows clinicians to design rehabilitation programs that are not only individualized but also more likely to yield positive results in terms of mobility and overall rehabilitation success [35].

Standardized assessment tools, such as the HiMAT, play a pivotal role in evaluating and tracking progress in TBI rehabilitation. The consistent use of HiMAT across various studies demonstrates its effectiveness in establishing realistic and measurable goals for patients recovering from TBI [36], [37]. By employing standardized outcome measures, healthcare providers can better assess improvements in HLM, make informed adjustments to treatment plans, and enhance communication among clinicians, patients, and families [38]. This approach not only aids in monitoring progress but also ensures that rehabilitation efforts are aligned with best practices in the field [39], [40].

The study also lays a foundation for future research by identifying gaps in the current understanding of how personal, environmental, and injury-related factors interact to influence mobility outcomes. Addressing these gaps is essential for refining rehabilitation protocols and enhancing clinical practice [41]. Future investigations could explore the complex interplay of these factors to develop more nuanced rehabilitation strategies that cater to the diverse needs of TBI patients [42], [43]. This research trajectory is vital for optimizing rehabilitation outcomes and ensuring that interventions are both effective and relevant to the patient population.

Lastly, the implications of this study extend to rehabilitation policies and guidelines. The observed variability in HLM outcomes suggests that existing rehabilitation protocols may benefit from incorporating advanced mobility targets. Policymakers and rehabilitation centers should consider revising guidelines to include interventions specifically aimed at enhancing HLM, which could improve the chances of successful community reintegration and long-term recovery for individuals with TBI [44], [45]. By aligning rehabilitation practices with the latest research findings, stakeholders can foster an environment that supports the holistic recovery of TBI patients, ultimately enhancing their quality of life. In summary, the study provides crucial insights into the factors influencing high-level mobility in individuals with TBI. It advocates for personalized rehabilitation strategies, the use of standardized assessment tools, and a stronger focus on HLM training. Additionally, it emphasizes the need for further research and potential policy changes to improve rehabilitation outcomes and the overall quality of life for individuals recovering from TBI.

3.5. Strength and limitation

However, this review has several limitations that must be acknowledged. Many of the included studies had small sample sizes, limiting the generalizability of the findings. Additionally, the observational nature of most studies makes it difficult to establish causality between the identified factors and mobility outcomes. The variability in outcome measures, such as the use of different versions of the HiMAT, also contributed to inconsistencies across studies. Another significant limitation is the lack of consideration for environmental factors, such as access to community resources or social support, which are likely to influence mobility recovery.

Future research should address these limitations by conducting larger, more rigorous studies that use standardized outcome measures, allowing for better comparability across diverse populations. It is also essential to explore the role of environmental factors and their interaction with personal and injury-related characteristics in influencing HLM. Additionally, further investigation into the effectiveness of interventions targeting endurance, balance, and muscle strength will be critical in optimizing rehabilitation strategies and improving outcomes for individuals with TBI. These insights will help guide the development of more tailored rehabilitation programs, ultimately enhancing the quality of life for TBI survivors.

4. CONCLUSION

This study found significant variations in the reported associations among factors in different domains that may predict HLM in people with TBI. Age at injury, sex, motor vehicle accident, duration of PTA, walking speed, and endurance were identified as the most influential factors of HLM outcomes. However, further investigation is needed to better understand those factors' interactions and potential moderators' interactions with HLM in people with TBI. This would help healthcare professionals develop appropriate interventions and effective rehabilitation programs focusing on modifiable factors to improve HLM. Ultimately, those interventions are crucial for enhancing the quality of life for individuals with TBI.

ACKNOWLEDGMENTS

We appreciate the contribution of reviewers whose insights significantly supported this study.

FUNDING INFORMATION

This work was supported by 1) Universiti Teknologi MARA through the Geran Insentif Penyeliaan (600-RMC/GIP 5/3 (058/2022) and 2) the Ministry of Higher Education, Malaysia, through the Fundamental Research Grant Scheme (600-RMC/ FRGS 5/3 (009/2022)).

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Syazlin Azmi	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Nor Azlin Mohd Nordin		✓						✓	✓	✓	✓	✓		
Alia Alghwiri	✓		✓	✓					✓		✓		✓	
Haidzir Manaf	✓								✓	✓		✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable.

DATA AVAILABILITY

The data that supports the findings of this study are available from the corresponding author, [HM], upon reasonable request.

REFERENCES

[1] T. Spencer, S. Aldous, G. Williams, and M. Fahey, "Systematic review of high-level mobility training in people with a neurological impairment," *Brain Injury*, vol. 32, no. 4, pp. 403–415, Mar. 2018, doi: 10.1080/02699052.2018.1429656.

[2] J. Kersey, L. Terhorst, C.-Y. Wu, and E. Skidmore, "A scoping review of predictors of community integration following traumatic brain injury: A search for meaningful associations," *Journal of Head Trauma Rehabilitation*, vol. 34, no. 4, pp. E32–E41, Jul. 2019, doi: 10.1097/HTR.0000000000000442.

[3] R. A. Abdul Rahman, F. Rafi, F. A. Hanapiah, A. W. Nikmat, N. A. Ismail, and H. Manaf, "Effect of dual-task conditions on gait performance during timed up and go test in children with traumatic brain injury," *Rehabilitation Research and Practice*, vol. 2018, pp. 1–7, Oct. 2018, doi: 10.1155/2018/2071726.

[4] S. Gallow, L. Hilet, E. Sutherland, J. McGinley, J. Olver, and G. Williams, "The timeframe for safe resumption of high-level mobility following traumatic brain injury is currently unknown: a systematic review," *Disability and Rehabilitation*, vol. 44, no. 19, pp. 5363–5373, Sep. 2022, doi: 10.1080/09638288.2021.1936220.

[5] M. T. Pham, A. Rajić, J. D. Greig, J. M. Sargeant, A. Papadopoulos, and S. A. McEwen, "A scoping review of scoping reviews: advancing the approach and enhancing the consistency," *Research Synthesis Methods*, vol. 5, no. 4, pp. 371–385, Dec. 2014, doi: 10.1002/jrsm.1123.

[6] M. D. J. Peters *et al.*, "Best practice guidance and reporting items for the development of scoping review protocols," *JBI Evidence Synthesis*, vol. 20, no. 4, pp. 953–968, Apr. 2022, doi: 10.11124/JBIES-21-00242.

[7] G. Williams, J. Pallant, and K. Greenwood, "Further development of the high-level mobility assessment tool (HiMAT)," *Brain Injury*, vol. 24, no. 7–8, pp. 1027–1031, Jul. 2010, doi: 10.3109/02699052.2010.490517.

[8] A. Hertsyk, "Smart goal setting in physical therapy," *Educação física, esporte, saúde e saúde na sociedade moderna: uma coleção de trabalhos científicos*, vol. 2, no. 34, pp. 57–63, 2016.

[9] J. Schmitt *et al.*, "The harmonizing outcome measures for eczema (home) roadmap: A methodological framework to develop core sets of outcome measurements in dermatology," *Journal of Investigative Dermatology*, vol. 135, no. 1, pp. 24–30, Jan. 2015, doi: 10.1038/jid.2014.320.

[10] P. R. Williamson *et al.*, "Developing core outcome sets for clinical trials: issues to consider," *Trials*, vol. 13, no. 1, p. 132, Dec. 2012, doi: 10.1186/1745-6215-13-132.

[11] R. M. Viglialoro *et al.*, "A projected AR serious game for shoulder rehabilitation using hand-finger tracking and performance metrics: A preliminary study on healthy subjects," *Electronics*, vol. 12, no. 11, p. 2516, Jun. 2023, doi: 10.3390/electronics12112516.

[12] K. T. Moen *et al.*, "High-level mobility in chronic traumatic brain injury and its relationship with clinical variables and magnetic resonance imaging findings in the acute phase," *Archives of Physical Medicine and Rehabilitation*, vol. 95, no. 10, pp. 1838–1845, Oct. 2014, doi: 10.1016/j.apmr.2014.04.014.

[13] G. Williams, N. Weragoda, K. Paterson, and R. Clark, "Cardiovascular fitness is unrelated to mobility limitations in ambulant people with traumatic brain injury," *Journal of Head Trauma Rehabilitation*, vol. 28, no. 6, pp. E1–E7, Nov. 2013, doi: 10.1097/HTR.0b013e318279536d.

[14] G. Williams, M. Banky, D. McKenzie, and J. Olver, "Ankle plantarflexor spasticity is not differentially disabling for those who are weak following traumatic brain injury," *Brain Injury*, vol. 31, no. 2, pp. 193–198, Jan. 2017, doi: 10.1080/02699052.2016.1218548.

[15] G. Williams, M. Banky, and J. Olver, "Severity and distribution of spasticity does not limit mobility or influence compensatory strategies following traumatic brain injury," *Brain Injury*, vol. 29, no. 10, pp. 1232–1238, Aug. 2015, doi: 10.3109/02699052.2015.1035328.

[16] G. Williams, M. Banky, and J. Olver, "Distribution of Lower Limb Spasticity Does Not Influence Mobility Outcome Following Traumatic Brain Injury," *Journal of Head Trauma Rehabilitation*, vol. 30, no. 5, pp. E49–E57, Sep. 2015, doi: 10.1097/HTR.0000000000000094.

[17] G. Williams, A. G. Schache, and M. E. Morris, "Self-selected walking speed predicts ability to run following traumatic brain injury," *Journal of Head Trauma Rehabilitation*, vol. 28, no. 5, pp. 379–385, Sep. 2013, doi: 10.1097/HTR.0b013e3182575f80.

[18] L. Parrington *et al.*, "Exploring vestibular ocular motor screening in adults with persistent complaints after mild traumatic brain injury," *Journal of Head Trauma Rehabilitation*, vol. 37, no. 5, pp. E346–E354, Sep. 2022, doi: 10.1097/HTR.0000000000000762.

[19] G. P. Williams and M. E. Morris, "Tests of static balance do not predict mobility performance following traumatic brain injury," *Physiotherapy Canada*, vol. 63, no. 1, pp. 58–64, Jan. 2011, doi: 10.3138/ptc.2009-53.

[20] A. L. Zaninotto *et al.*, "Visuospatial memory improvement in patients with diffuse axonal injury (DAI): a 1-year follow-up study," *Acta Neuropsychiatrica*, vol. 29, no. 1, pp. 35–42, Feb. 2017, doi: 10.1017/neu.2016.29.

[21] C. Wiseman-Hakes *et al.*, "Sleep in the acute phase of severe traumatic brain injury," *Neurorehabilitation and Neural Repair*, vol. 30, no. 8, pp. 713–721, Sep. 2016, doi: 10.1177/1545968315619697.

[22] Y. G. Bodien *et al.*, "Diagnosing level of consciousness: The limits of the glasgow coma scale total score," *Journal of Neurotrauma*, vol. 38, no. 23, pp. 3295–3305, Dec. 2021, doi: 10.1089/neu.2021.0199.

[23] K. Han, R. A. Davis, S. B. Chapman, and D. C. Krawczyk, "Strategy-based reasoning training modulates cortical thickness and resting-state functional connectivity in adults with chronic traumatic brain injury," *Brain and Behavior*, vol. 7, no. 5, May 2017, doi: 10.1002/brb3.687.

[24] M. Hamilton, G. Williams, A. Bryant, R. Clark, and T. Spelman, "Which factors influence the activity levels of individuals with traumatic brain injury when they are first discharged home from hospital?," *Brain Injury*, vol. 29, no. 13–14, pp. 1572–1580, Dec. 2015, doi: 10.3109/02699052.2015.1075145.

[25] E. A. Newell, B. P. Todd, Z. Luo, L. P. Evans, P. J. Ferguson, and A. G. Bassuk, "A mouse model for juvenile, lateral fluid percussion brain injury reveals sex-dependent differences in neuroinflammation and functional recovery," *Journal of Neurotrauma*, vol. 37, no. 4, pp. 635–646, Feb. 2020, doi: 10.1089/neu.2019.6675.

[26] L. Wilson *et al.*, "The chronic and evolving neurological consequences of traumatic brain injury," *The Lancet Neurology*, vol. 16, no. 10, pp. 813–825, Oct. 2017, doi: 10.1016/S1474-4422(17)30279-X.

[27] T. Wang, D. Mantini, and C. R. Gillebert, "The potential of real-time fMRI neurofeedback for stroke rehabilitation: A systematic review," *Cortex*, vol. 107, pp. 148–165, Oct. 2018, doi: 10.1016/j.cortex.2017.09.006.

[28] J. Petkeviciene, J. Klumbiene, V. Kriaucioniene, A. Raskiliene, E. Sakyte, and I. Ceponiene, "Anthropometric measurements in childhood and prediction of cardiovascular risk factors in adulthood: Kaunas cardiovascular risk cohort study," *BMC Public Health*, vol. 15, no. 1, p. 218, Dec. 2015, doi: 10.1186/s12889-015-1528-5.

[29] S. Driver, S. Juengst, E. E. McShan, M. Bennett, K. Bell, and R. Dubiel, "A randomized controlled trial protocol for people with traumatic brain injury enrolled in a healthy lifestyle program (GLB-TBI)," *Contemporary Clinical Trials Communications*, vol. 14, p. 100328, Jun. 2019, doi: 10.1016/j.conctc.2019.100328.

[30] J. Ponsford, S. Carrier, A. Hicks, and A. McKay, "Assessment and management of patients in the acute stages of recovery after traumatic brain injury in adults: A worldwide survey," *Journal of Neurotrauma*, vol. 38, no. 8, pp. 1060–1067, Apr. 2021, doi: 10.1089/neu.2020.7299.

[31] M. Oberholzer and R. M. Müri, "Neurorehabilitation of traumatic brain injury (TBI): A clinical review," *Medical Sciences*, vol. 7, no. 3, p. 47, Mar. 2019, doi: 10.3390/medsci7030047.

[32] A. O. Asemota, B. P. George, C. J. Cumpsty-Fowler, A. H. Haider, and E. B. Schneider, "Race and insurance disparities in discharge to rehabilitation for patients with traumatic brain injury," *Journal of Neurotrauma*, vol. 30, no. 24, pp. 2057–2065, Dec. 2013, doi: 10.1089/neu.2013.3091.

[33] K. O'Donnell *et al.*, "Traumatic brain injury epidemiology and rehabilitation in Ireland: a protocol paper," *HRB Open Research*, vol. 4, p. 66, Jun. 2021, doi: 10.12688/hrbopenres.13209.1.

[34] J. Yu, H. M. K. Tam, and T. M. C. Lee, "Traumatic brain injury rehabilitation in hong kong: A review of practice and research," *Behavioural Neurology*, vol. 2015, pp. 1–8, 2015, doi: 10.1155/2015/274326.

[35] E. Pagan, T. Ownsworth, S. McDonald, J. Fleming, C. Honan, and L. Togher, "A survey of multidisciplinary clinicians working in rehabilitation for people with traumatic brain injury," *Brain Impairment*, vol. 16, no. 3, pp. 173–195, Dec. 2015, doi: 10.1017/BrImp.2015.34.

[36] J. Kingston, J. Katsaros, Y. Vu, and G. L. Goodrich, "Neurological vision rehabilitation: Description and case study," *Journal of Visual Impairment & Blindness*, vol. 104, no. 10, pp. 603–612, Oct. 2010, doi: 10.1177/0145482X1010401006.

[37] G. S. Griesbach, L. A. Kreber, D. Harrington, and M. J. Ashley, "Post-acute traumatic brain injury rehabilitation: Effects on outcome measures and life care costs," *Journal of Neurotrauma*, vol. 32, no. 10, pp. 704–711, May 2015, doi: 10.1089/neu.2014.3754.

[38] S. D. S. Ramos, M. Oddy, J. Liddement, and D. Fortescue, "Brain injury and offending: The development and field testing of a linkworker intervention," *International Journal of Offender Therapy and Comparative Criminology*, vol. 62, no. 7, pp. 1854–1868, May 2018, doi: 10.1177/0306624X17708351.

[39] M. Fitzgerald *et al.*, "AUS-TBI: The Australian health informatics approach to predict outcomes and monitor intervention efficacy after moderate-to-severe traumatic brain injury," *Neurotrauma Reports*, vol. 3, no. 1, pp. 217–223, Jun. 2022, doi: 10.1089/neur.2022.0002.

[40] L. Odgaard, J. Feldbæk Nielsen, I. Poulsen, L. P. Kammersgaard, and S. P. Johnsen, "Surviving severe traumatic brain injury in Denmark: incidence and predictors of highly specialized rehabilitation," *Clinical Epidemiology*, p. 225, Mar. 2015, doi: 10.2147/CLEP.S78141.

[41] H. Kashyap and K. Kumar, "Integrated rehabilitation for a case with traumatic brain injury," *The Indian Journal of Neurotrauma*, vol. 7, no. 1, pp. 89–91, Jun. 2010, doi: 10.1016/S0973-0508(10)80020-6.
[42] T. van der Weijden *et al.*, "How to integrate individual patient values and preferences in clinical practice guidelines? A research protocol," *Implementation Science*, vol. 5, no. 1, p. 10, Dec. 2010, doi: 10.1186/1748-5908-5-10.
[43] Y. Lu, X. Zhou, J. Cheng, and Q. Ma, "Early intensified rehabilitation training with hyperbaric oxygen therapy improves functional disorders and prognosis of patients with traumatic brain injury," *Advances in Wound Care*, vol. 10, no. 12, pp. 663–670, Dec. 2021, doi: 10.1089/wound.2018.0876.
[44] C.-L. Moller, T. Lingah, and S. M. Phehlukwayo, "'We all need employment' - An exploration of the factors which influence the return to work after a severe traumatic brain injury," *South African Journal of Occupational Therapy*, vol. 47, no. 3, pp. 17–24, Dec. 2017, doi: 10.17159/2310-3833/2017/v47n3a4.
[45] K. Reuter-Rice, J. K. Eads, S. Berndt, and K. Doser, "The initiation of rehabilitation therapies and observed outcomes in pediatric traumatic brain injury," *Rehabilitation Nursing*, vol. 43, no. 6, pp. 327–334, Nov. 2018, doi: 10.1097/rnj.0000000000000116.

APENDIX

Table 2. Data extracted from the included study

Study/ study design	Study population/sample size (N)	Mean age (years)/gender (M: F)	Predictor(s)/ factor(s)	Outcome measure (s) on HLM	Finding(s)	Conclusion
[12] LF-UP	Moderate and severe TBI TBI = 65 HC = 71 Total = 136	Mean age TBI = 32.2 HC = 34.4 Gender TBI = 2.8 HC = 3.2	Personal Factors - Age at injury - Sex Injury-related characteristics Clinical variables (HISS, injury mechanism, duration PTA, ISS category) MRI (Cortical contusion, DAI)	- HiMAT - HiMAT-R - mIAT	HiMAT - Age at injury (B = -0.33)*** - Sex (B = -4.943)* - MVA (B = -4.559)* - PTA (B = -4.368)* - model fit (R2 =0.588)*** HiMAT-R - Age at injury (B = 0.237)*** - Sex (B = 3.686)* - MVA (B = 4.034)* - model fit (R2 = 0.599)***	Clinical variables in the acute phase were significantly associated with the HLM performance of TBI in the chronic phase.
[13] CSC	Severe TBI TBI = 28 HC = 28 Total = 56	Mean age TBI = 31.3 HC = 31.1 Gender TBI (20:8) HC (20:8)	Personal Factors - BMI - Sum of 9 skinfold measures - Activity level (steps per day) - Physical activity (HAP, steps per day) Impairments - Mobility (10MWT, 6MWT) - CV fitness (PWC_{130})	HiMAT	HiMAT - 10MWT (r = 0.829) - steps per day (r = 0.300) - HAP-AAS (r = 0.508)* - PWC_{130} (r = 0.073) - 6MWT (r = 0.932)* - BMI (r = 0.286) - skinfold measures (r =0.164)	- 6MWT and average daily activity levels strongly correlate with HLM in ambulant people with TBI. - No relationship was identified between mobility and cardiovascular fitness following TBI.
[17] CSC	TBI N = 97	Mean age 30.2 Gender 72:25	Impairments - Postural stability (lateral COM displacement) - APG push-off - GPS - Self-selected walking speed	- Ability to run - HiMAT	Ability to run - self-selected walking speeds displacement (B = -0.01) - APG push-off (B = -0.21) - GPS (B = -0.25) - model fit: $\chi2$ (4) =53.83***	- Self-selected walking speed is strongly associated with the ability to run following TBI. - Self-selected walking speeds higher than 1.0 m/s are more likely to be able to run following brain injury. - The 1.0 m/s threshold may be an important indicator of the ability to run in this population.

Table 2. Data extracted from the included study (continued)

Study/ study design	Study population/sample size (N)	Mean age (years)/gender (M: F)	Predictor(s)/ factor(s)	Outcome measure (s) on HLM	Finding(s)	Conclusion
						- None of the TBI participants achieved normative HiMAT values, indicating significant HLM limitations.
[14] CSC	TBI G1 (no spasticity) = 34 G2 (Ankle plantar flexor spasticity) = 41 Total = 75	Mean age G1 = 29.1 G2 = 29.9 Gender G1 (22:12) G2 (33:8)	Impairments - Ankle plantar flexor spasticity (Tardieu Scale)	HiMAT	- No significant interaction of HiMAT score between Group and APG. - No significant interaction of HiMAT score between Group and plantar flexor strength.	The presence of ankle plantar flexor spasticity did not lead to greater mobility limitations for those who were weak following TBI.
[15] CS	TBI N = 93	Mean age 29.0 Gender 67:26	Impairments - Lower limb Spasticity (Tardieu Scale) - APG - HPG	HiMAT	HiMAT - Spasticity severity ($r = 0.13$) - APG ($r = 0.63$)**	- No significant relationship between the severity and distribution of lower limb spasticity and mobility limitations. - APG had a strong relationship with mobility outcomes following TBI.
[16] CSC	TBI N = 93	Mean age 29.0 Gender 67:26	Impairments - Lower limb spasticity (Tardieu Scale)	- 10-MWT - HiMAT	HiMAT - with vs without LL spasticity ($t_{91} = 2.15$)* - distal vs proximal/mixed LL spasticity ($t_{57} = 1.02$) - bilateral distal vs unilateral distal spasticity ($t_{39} = -0.47$).	- Participants with spasticity had significantly greater initial mobility limitations than participants without spasticity. - After 6-month follow-up, the presence and distribution of spasticity do not appear to impact mobility outcomes.
[18] CS	Mild TBI mTBI = 53 HC = 57 Total = 110	Mean age mTBI = 32.0 HC = 31.1 Gender mTBI (21:32) HC (28:29)	Impairments - Vestibular (VOMS, NPC distance)	- HiMAT-R - mIAT	HiMAT-R - VOMS ($r = -0.02$) - NPC distance ($r = -0.14$) mIAT - VOMS ($r = 0.06$) - NPC distance ($r = 0.21$)	No significant relationships existed between VOMS measures (including NPC distance) and measures of HLM.
[19] CS	TBI N = 71	Mean age 29.3 Gender 56:15	Impairments - Static balance (SLS) - Lateral COM displacement	HiMAT	HiMAT - Static balance ($r = 0.57$***, $r^2 = 0.32$) - lateral COM displacement ($r = 0.51$***, $r^2 = 0.26$)	- Static balance and lateral COM displacement strongly correlated with HiMAT but are a poor predictor of mobility performance in TBI.

Abbreviations: APFT, Army Physical Fitness Test; APG, Ankle Power Generation; BMI, Body Mass Index; BPPV, Benign Paroxysmal Positional Vertigo; CS, cross-sectional; CSC, Cross-sectional cohort; COM, center of mass; DAI, Diffuse Axonal Injury; GPS, Gait Profile Scores; HAP, Human Activity Profile; HiMAT-R, Revised High-Level Mobility Assessment Tool; HISS, Head Injury Severity Scale; HPG, Hip Power Generation; ISS, Injury Severity Score; LF-UP, Longitudinal follow-up; mIAT, modified Illinois Agility Test; NPC, near point convergence; PTA, Post-Traumatic Amnesia; PWC130, Physical Work Capacity at 130bpm; VOMS, Vestibular Ocular Motor Screening; 6MWT, 6-minute walking tes

BIOGRAPHIES OF AUTHORS

Syazlin Azmi is a dedicated physiotherapist with over ten years of experience in neurological rehabilitation. She works at Hospital Rehabilitasi Cheras, Ministry of Health Malaysia, one of the largest rehabilitation hospitals in Asia, specializing in stroke and traumatic brain injury rehabilitation. An active contributor to her field, she has served as an expert panel member for content validation in rehabilitation tools and has delivered numerous clinical lectures and workshops on neurological rehabilitation and mobility enhancement. Syazlin is the primary investigator of ongoing research on mobility predictors in moderate to severe traumatic brain injury, with her work presented at both local and international conferences and recognized with awards for oral and poster presentations. She can be contacted at email: norsyazlin_azmi@yahoo.com.

Nor Azlin Mohd Nordin is a distinguished physiotherapist and academic with over 30 years of experience in the field of physiotherapy and rehabilitation. She is currently serving as an Associate Professor and researcher at the Physiotherapy Program, Faculty of Health Sciences, Universiti Kebangsaan Malaysia (UKM). She has an impressive portfolio of academic contributions, including numerous peer-reviewed publications, international conference presentations, and research projects. Her research focuses on improving the quality of life for individuals with neurological impairments through innovative rehabilitation strategies. She is also an active consultant, reviewer, and academic advisor for various institutions and journals. Her work has been recognized with numerous awards for excellence in research and teaching. She can be contacted at email: norazlin8@ukm.edu.my.

Alia Alghwiri is a Professor of Neurological Physical Therapy and the Vice Dean of the School of Rehabilitation Sciences at the University of Jordan. She is a board member of the Jordanian Sports Medicine Federation and General Secretary of the Jordanian Athletic Therapy Association. Clinically, she specializes in neurological rehabilitation, particularly in treating concussions and vestibular disorders, achieving significant patient improvements. She earned her Master's and Ph.D. in Neurological Rehabilitation from the University of Pittsburgh, USA, and has over 70 publications in areas such as vestibular disorders, multiple sclerosis, concussion, stroke, and sleep disorders. Her work has garnered over 900 citations, reflecting her notable contributions to the field. She can be contacted at email: alia.alghwiri@gmail.com.

Haidzir Manaf is an Associate Professor and researcher at the Centre of Physiotherapy Studies, Faculty of Health Sciences, Puncak Alam Campus, Universiti Teknologi MARA (UiTM), Malaysia. He also serves as the President of the Malaysian Physiotherapy Association (MPA). His clinical and research interests include neurological rehabilitation, gait analysis, stroke rehabilitation, and movement disorders. He has published several academic works in journals and book chapters related to his field. His research has garnered significant attention, with over 1,000 citations, reflecting his contributions to neurorehabilitation and gait analysis. He can be contacted at email: haidzir5894@uitm.edu.my.