DEVELOPMENT OF AN ASSESSMENT TOOL FOR OUTDOOR GAIT ANALYSIS (ATOGA)

by

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COMMUNITY PHYSIOTHERAPY

Under the guidance of

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DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation entitled **"Development of an Assessment Tool for Outdoor Gait Analysis (ATOGA)"** is a bona fide and a genuine research work carried out by me under the guidance of **Vijay Samuel Raj V, MPT,** Assistant Professor of JSS College of Physiotherapy, Mysuru.

Date: **Eluri Mani Sandhya Devi**

Place: Mysuru

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This is to certify that the dissertation entitled "**Development of an Assessment Tool for Outdoor Gait Analysis (ATOGA)"** is a bona fide research work done by **Eluri Mani Sandhya Devi** in partial fulfilment of the requirement for the degree of **Master of physiotherapy.**

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ENDORSEMENT BY THE HEAD OF THE INSTITUTION

This is to certify that the dissertation entitled **"Development of an Assessment Tool for Outdoor Gait Analysis (ATOGA)"** is a bona fide research work done by **Eluri Mani Sandhya Devi** under the guidance of **Vijay Samuel Raj V, MPT,** Assistant Professor, JSS College of Physiotherapy, Mysuru.

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Eluri Mani Sandhya Devi

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ABSTRACT

Background: Complex measurement tools such as motion analysis marker-based systems routinely perform objective gait analyses. However, these systems are associated with high costs and dependent on a laboratory restricting their use in the clinical setup. In even terrains where footholds are unconstrained, individuals show a habitual instinct to select a preferred gait cycle comprising an ideal combination of step length, step width, and step duration that minimizes the energy cost of walking by utilizing the passive physical dynamics of bipedal gait. However, walking over rough, unpredictable and uneven Indian terrain requires augmentation of both the inner structural characteristic of the walker and the exterior structure of the environment to be traversed. Studies on gait analysis in an unpredictable uneven outdoor environment and the kinematic variables minimally required to walk in uneven terrain for community ambulation is limited. Therefore, there exists a need to develop a tool to quantify gait in an outdoor environment.

Objectives of the study: To develop a tool for outdoor gait analysis.

Methodology: The study is a cross-sectional observational study done at JSS College of Physiotherapy. Ten (10) participants were recruited based on the inclusion and exclusion criteria and their walking was observed on the unpredictable uneven terrain selected based on feedback from a cross-sectional population living at Mysuru. The video analysis recorded was analyzed with kinovea biomechanical software for the kinematic variables and then analyzed statistically. The development of the outdoor ambulation tool was based on the data analysis derived from the kinematic components of the outdoor gait tool.

Results: On uneven terrain, healthy adults demonstrate numerous gait modifications including peak hip and knee flexion and increased ankle plantar flexion. Maximal ankle dorsiflexion required to walk in the uneven terrain designed was (10.61 ±3.60) during the terminal stance and plantar flexion was (19.4 ± 7) during the initial swing. The maximal inward rotation (inversion) was 21.6 ± 1.6 and outward rotation was 1.3 ± 0.3. Similarly, the maximal varus position adopted in the uneven terrain was 8 ± 3.9 and the valgus position was 11 ± 4.1. On analysis of the joint angles, the peak knee flexion required to walk in the uneven terrain was 62.67 ± 9.75 during the initial swing. The peak extension moment was seen during the mid-stance and the mean value was found to be between 11.7 ± 3.9 and 14.63 ± 5.22. During the terminal swing, the mean value of knee flexion was between 23.90 ± 3.28 and 19.21 ± 6.5. The results of the descriptive data indicate that the peak hip flexion obtained was 38.64 ± 4.5 during mid-swing and the peak hip extension moment was during terminal stance 9.97 ± 4.15.

Conclusion: The study was concluded by developing ATOGA. The mean angles of the components of the ATOGA were measured without taking into context the angle of inclination and declination. Hence the mean angles observed cannot be taken as the reference angles for uneven terrain.

Keywords: Gait, uneven terrain, outdoor, tool.

LIST OF ABBREVIATIONS

ATOGA	Assessment Tool for Outdoor Gait Analysis
BBS	Berg Balance Scale
CASP	Critical Appraisal Skill Programme
CEBM	Centre for Evidence-Based Management
CP	Cerebral palsy
EMG	Electromyography
EVGS	Edinburgh Visual Gait Cycle
IRC	Institutional Research Committee
JROM	Joint range of motion
MeSH	Medical subject headings
OGS	Observation Gait Scale
OGA	Observational Gait Analysis
PRS	Physician Rating Scale
ROM	Range of motion
RVGA	Rivermead Visual Gait Assessment
SGT	Salford Gait Tool
TUG	Timed up and go test
VGAS	Visual Gait Assessment Scale
VGS	Visual Gait Score

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Background

Human locomotion, or gait, is the translatory progression of the body as a whole, produced by coordinated, rotatory movements of body segments.[1] Human walking is the body's innate action of maneuvering from one point to another. Walking is the most common form of physical activity for any individual. The extent to which an individual successfully moves in an environment is a result of the balance between the influences exerted by the outdoor environment and the physical capacity of the individual. Human gait is a result of definite and multiple interactions of the kinetics and kinematics of the gait and it represents a profoundly skillful form of movement. However, any impairment will result in an abnormal gait.[2]

Studies suggest that 'clinical gait analysis' is usually related and associated with the gait laboratories and does not reflect the assessment done in the clinical setup or in the patient's home environment or an outdoor environment. Gait analysis in the lab includes the evaluation of kinetic, kinematic, and Electromyography [EMG] variables and accompanied by slow-motion video recording to give an overall interpretation of the quality of the patient’s gait.[3] Kinematics is the study of movement, requiring the recording of time and distance data, joint angles, and accelerations over time. Kinetics is predominantly concerned with the forces and moments between the foot and the ground and can also interpret the position of the ground reaction force vector relative to each joint.[4] Any human being’s walking pattern is a representation of his or her definite solution to the problem of getting from one place to other. It is achieved through the definite and complex interaction of the different components of the locomotor system, and under normal circumstances serves a highly efficient form of movement with minimal expenditure of energy.[3] Most of the studies had assessed gait indoors, i.e. in specialized gait labs or on an even indoor surface. Some studies have attempted to evaluate gait on irregular surfaces, on a poorly illuminated pathway, obstacle pathway and on uneven terrain. Even in these studies, the variables studied have been specific kinematic variables in a simulated environment gait lab.[5] Clinical evidence suggests that musculoskeletal and neurological disorders can have a considerable impact on the quality of gait. Hence, quantification of gait is essential to determine the severity of impairment and to evaluate therapeutic interventions.[6]

The first reported studies of human walking were conducted in the year 1940 and 1950 in California by (Inman et al. 1981). The studies were done using cine film to capture the moving figure.[5] The development of computerized systems with infra-red or video based cameras, the process of recording and analysis was made much quicker and easier.[7] However, these systems are dependent on a laboratory and associated with high costs, restricting their use in the clinical setting. Objective gait analyses are commonly achieved by complex electronic gadgets and measurement tools such as marker-based motion analysis systems. Instrumented gait analysis (IGA), uses electronic technology that enables objective analysis of patient's mobility in the laboratory. Instrumented gait analysis technology detects gait abnormality by evaluation of slow-motion video recordings, clinical gait parameters, EMG activity and 3D joint kinematic and kinetic variables. In clinical practice Physiotherapist, require a simple and cost-effective tool to analyze the parameters of gait. A structured OGA can be recommended as an alternative to the IGA and are widely used as an essential tool for an assessment of gait. In observational gait analysis, the examiner visually assesses the gait pattern with the aid of video recordings using various scales that describe gait abnormalities in different joints and planes. Video recording of gait in the clinical setting is relatively easy and a preferred method of examination for clinicians.[8]

Gait analysis done indoors, on an even, and essentially flat, pre-determined specific walking path is not an appropriate model of the natural life situation of a patient. Activities in daily life require moving in challenging environments and walking on uneven surfaces. Going outdoors is a prerequisite for taking care of daily activities, meeting friends and relatives, leisure activities, taking a walk for physical exercise or attending different events and fulfilling the social commitment of the individual and even the ICF model of rehabilitation stresses on the participation level of the patient. Moreover, in developing countries, basic ADL's often requires outdoor ambulation. Falls result from a multiple exchanges of various influencing and triggering causes in an individual's environment. Studies revealed that the fall rate was 65.7% among old (74–84 years), 26.3% in young old (65–74 years) and 20.0% in very old (80+years), outdoor falls constituted 57.2%, and indoor falls 42.8%.[9]

1.2 Need for the study

In a developing country like India, many activities of daily living are performed on varied surfaces hence outdoor ambulation becomes a basic requirement of mobility. Studies have suggested that to walk on an unpredictable uneven terrain the kinematic gait variables requires modification, for example, the degree of toe off, the amount of knee flexion required for ground clearance and the degree of trunk rotation required for maintaining the balance. There is no Observational Gait Analysis tool for gait in uneven terrain to our knowledge. Therefore, there exists a need to develop a tool to quantify gait in an outdoor environment. Hence gait analysis should be observed in an outdoor uneven terrain environment to correctly interpret the constraints individuals face in walking in an outdoor environment and plan appropriate management strategies.

1.3 Clinical Significance

The development of a tool for gait analysis on uneven terrain is expected to help rehabilitation professionals to an objective measure to plan interventions. Gait assessment assists in determining the level of impairment while walking and gait assessment tool that can evaluate and predict the risk of falls in the outdoor environment will be helpful in intervention for outdoor ambulation. By studying the kinematic gait variables in uneven terrain, it may be possible to introduce effective strategies to reduce the incidence of falls in the community.

1.4 Assumption of the study

The kinematic variables are the primary factors that are responsible for gait differences between indoor and outdoor surfaces.

1.5 Objective of the study

To develop a tool for outdoor gait analysis.

CHAPTER 2

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1. A methodology of review of the literature

The article search was conducted individually with each keyword under the relevant section. A literature search was conducted from electronic database search engine viz PubMed, Proquest, and Google Scholar. The database and the search engine were searched for articles with no time limit. Mesh terms and keywords included were selected for an individual section with and without Boolean operators- AND, IN, NOT.

2.2. Search strategy

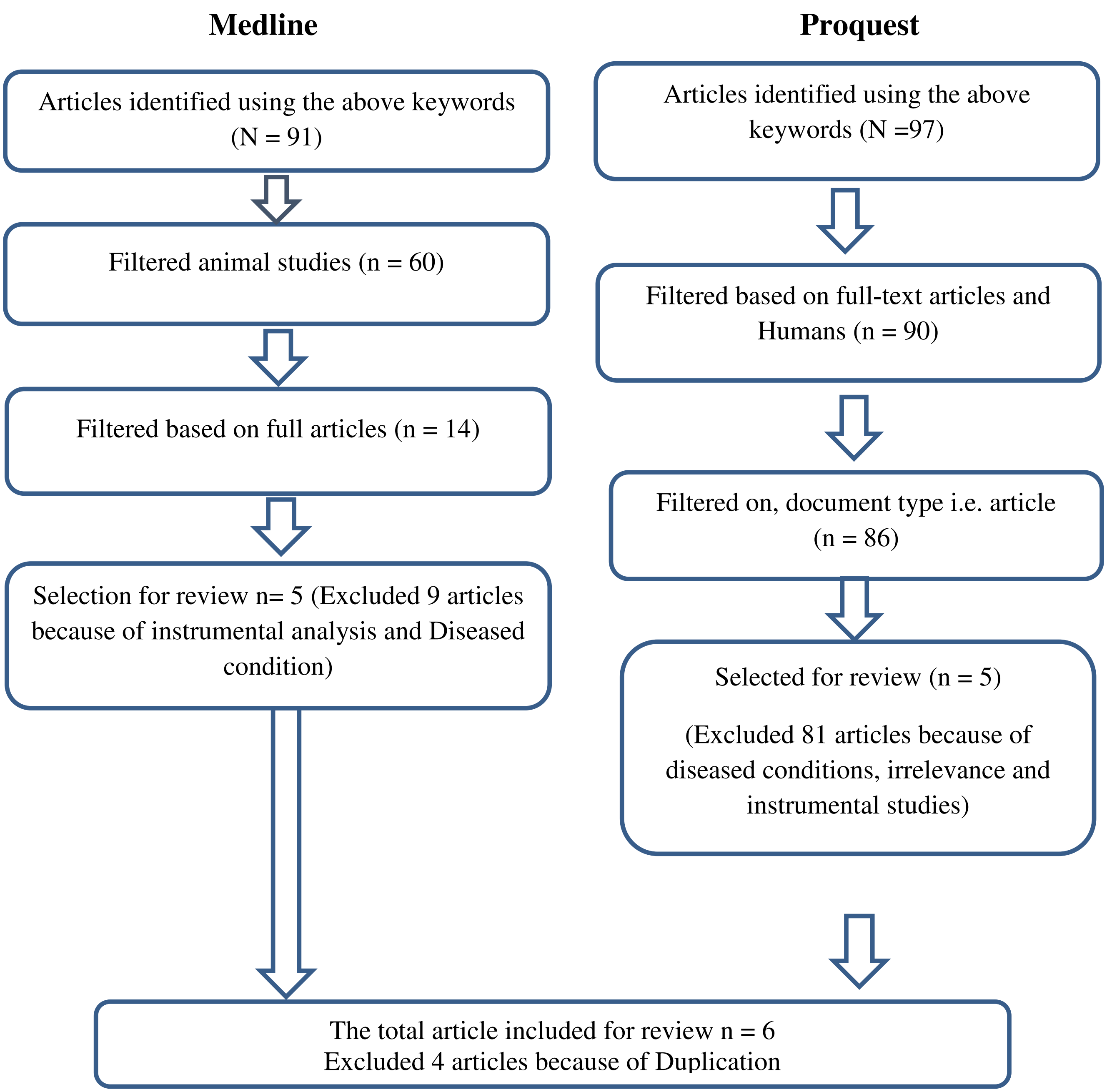
Databases Medline, Proquest and Google scholar were used. The search was narrowed by specifying the English language. Inclusion criteria for this review were gait analysis done in humans, observational gait analyses tools and the quality of articles was more than 60% of Critical Appraisal Skills Programme (CASP). Articles excluded on the basis of duplication and irrelevance and the studies done in disease conditions and the instrumental gait analyses. A quality search of keywords was selected for each section. The results of the review section are described in the following pages under relevant sections.

2.3. Section 1: Types of Gait analysis and Gait tools

Objective: To find out different types of gait analysis tools

Keywords- Gait, Gait analysis, Gait analysis tools

Figure 1: Flow of studies in literature review with keywords Mesh words Gait, Gait Analysis, and Observational Gait Analysis



In section 1, the literature reviews suggest that Gait analysis is one of the important aspects of the overall assessment of any patient with a movement disorder. Loss of walking ability is often a major issue in physical impairment. A healthy gait pattern requires a multitude of biomechanical and kinesiological features, coordinated by the central nervous system for mobility and stability. Injuries and other impairments can change these features and result in serious gait deficits, often with adverse consequences for energy expenditure and balance.[10] Observational Gait Analysis (OGA) is the clinical tool most commonly used to assess gait quality. OGA requires observing an individual walk and to analyze their gait pattern in terms of kinematic and spatiotemporal parameters. OGA can be performed in a clinical setting, during a standardized assessment of gait. OGA can be used to resolve the mechanisms underlying gait dysfunction and thus help in deciding treatment strategies to minimize walking dysfunction in patients.[11] Observation and subjective recording of gait are the important steps of gait assessment in the therapeutic environment and for analyzing the gait pattern in terms of kinematic and spatiotemporal parameters. Observation can provide the Physiotherapist with an existing impression of the quality of movement and help to assess the overall functional walking ability of the patient. Most of the studies in the clinical settings have a basic motion capture system, force plate and electromyography conducted in a gait lab.[2]

Several researchers have developed clinical assessments of gait in an attempt to quantify gait analysis and some clinicians have used the videotaped recording to increase reliability. Video recording allows repeated viewing without the necessity for repetition and patient fatigue and permits the rater to control the pace of the movement analysis, all of which presumably reduces measurement error. SE Lord et al. suggested that the

RVGA is both a valid and sensitive measure of gait impairment in patients with neurological diseases. The RVGA thus could be a useful tool for practicing Physiotherapists, allowing them to document gait impairments in the clinic without expensive equipment, and allowing them to demonstrate clinically relevant changes.[1]

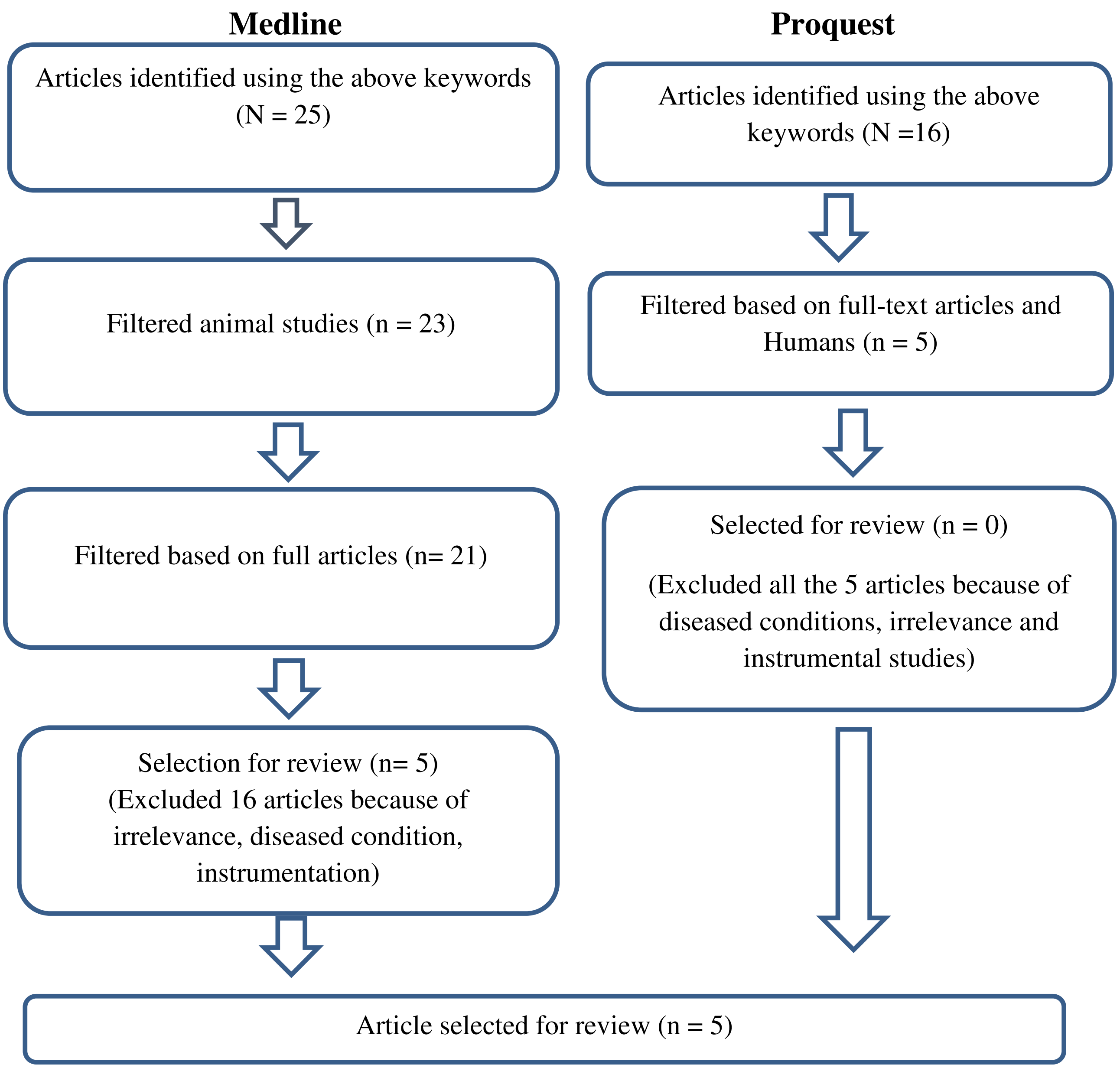
Level of evidence: IV

2.4. Section 2: Kinematics of Gait and Uneven terrain

Objective: To find out kinematic variables of gait in even terrain and uneven terrain

Keywords- kinematics, gait, walking, uneven terrain, outdoor terrain

Figure 2: Flow of studies in literature review with keywords kinematics, gait, walking, uneven terrain, outdoor terrain



The majorities of adult falls occur during walking and are usually caused by extrinsic factors such as uneven terrain. During walking, an individual should not only guarantee forward propulsion of the body in accordance with dynamic equilibrium but is also required to continuously adjust with perturbations—such as postural variation, terrain unevenness, obstacles, etc. in an expectant pattern through coordinated action between different body segments.[8]

One of the most common measures of gait stability is step width variance, which suggests that higher step width variance is associated with less stability. Another kinematic variable used to analyze gait stability is the distance between the center of mass (COM) and the boundary of an individual's base of support. Smaller distance is associated with less stability. Inclination angles are used to evaluate stability in gait in which a maximum inclination angle is associated with reduced stability. It was found that lateral stability was most effectively controlled by lateral foot placement (stepping strategy), followed by ankle inversion/eversion (ankle strategy), and hip abduction/ adduction (hip strategy). [4]

Walking on uneven terrain resulted in a variety of adjustments to gait parameters compared with walking on even terrain. Walking in uneven terrain significantly reduced speed and cadence, increased outward foot rotation, knee, and hip flexion as well as anterior pelvic tilt and relatively minor adaptations in stepping strategy. [6]

Soran Aminiaghdam et al. concluded that negotiating variation in even level walking require a step-specific compensatory kinematic mechanism in lower limbs to maintain dynamic stability regardless of the adjustments of the trunk.[13]

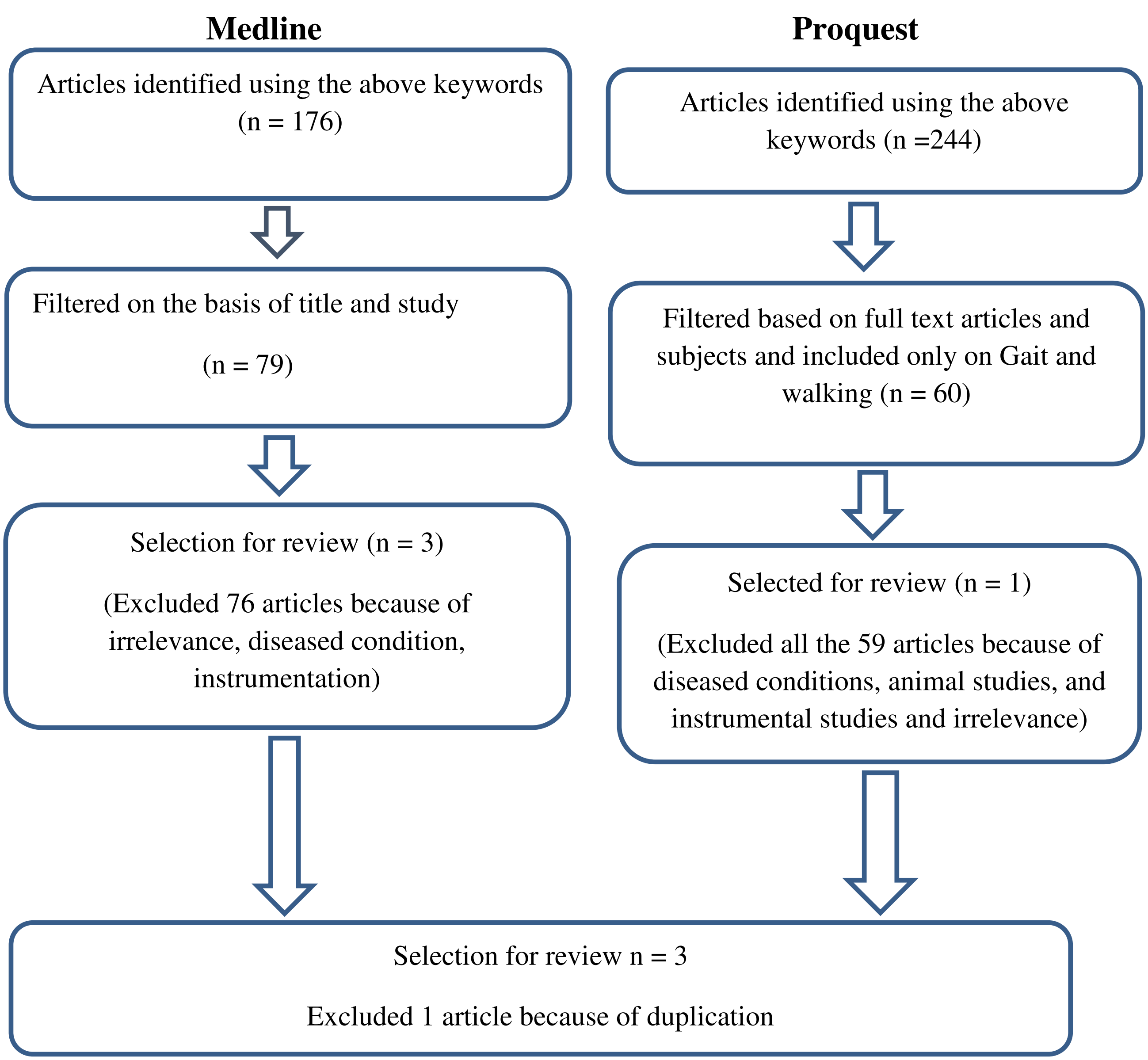
Level of evidence: III

2.5. Section 3: Gait analysis tools in different terrain

Objective: To find out tools for kinematic analysis of gait while walking in different terrain

Keywords- Gait, Kinematics, Tools, Walking, terrain

Figure 3: The flow of studies in literature review with MeSH words gait AND kinematics AND tool AND walking AND terrain



Community ambulation requires not only the ability to walk at a minimum gait speed but also the ability to adapt gait to diverse and complex task demand.[14] Dynamic gait index tool measures the person-environment model of mobility disability in which environmental demands are categorized into 8 dimensions: distance, temporal, ambient, terrain, physical load, attention, postural transitions, and density, representing the external demands required for an individual to be mobile within a particular environment.

The influence of the outdoor environment in the evaluation of specific parameters of gait affects variability indices, whereas the environment does not influence the stability components. The studies have concluded that the differences in stability are more related to the frailty of the elderly individual, which resulted in motor instability. This motor instability are augmented in elderly or during pathological condition, which increases the risk of falls in the community.[12]

Most of the applied clinical gait analysis are impairment-oriented and employed straight level walking as the prime task. The data showed a discrepancy between the need for a valid disability-oriented assessment of gait and the type of gait analysis practiced.

Level of evidence: III

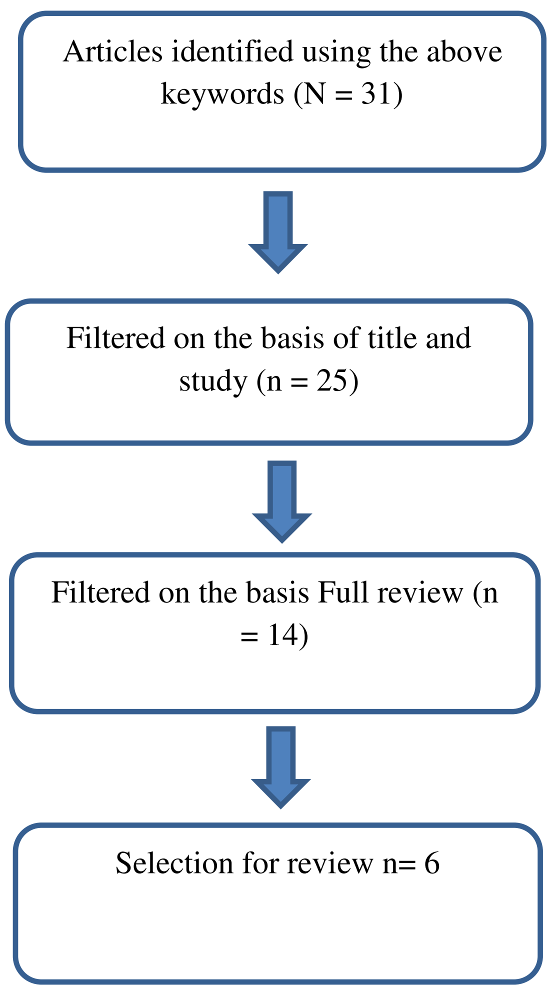
2.6. Section 4: Tool development and reliability

Objective: To review the methodology of tool development for physical function

Keywords-Tool development, scale development, physical function, reliability

Figure 4: Flow of studies in literature review with MeSH words tool development AND scale development AND physical function AND reliability

Medline



The most important and first step in tool development is exploration, identification, definition and literature review of the contents of preliminary items of the tool. Dimensionality and definition of the construct (contents of the tool) should be precise as it is the foundation and building blocks for developing any measurement tool. The first step towards item generation during tool development requires extensive pilot work to refine the content and wording. In addition, the most important strategy in item generation is to employ the research questions repeatedly to ensure that the items reflect the research question being investigated and are relevant to the investigation.[21] Definition of the construct can be by the either inductive or deductive approach. Formulating the scale design, which includes scaling, item tool and instruction, is the next step. Initial item tool should be developed for the construct[22]. This item pool could be developed based on literature, expert opinion and items from existing scales can be used. After subject verifies the initial generation of the item pool, the adequacy of the contents requires experts to review. During the review of items generated the definition of each construct items are provided to the experts. The experts are required then to correlate their opinion with the conceptualization of the scale developer. Instructions for tool administration and scoring should be clear[21, 22]. Next step is content validation. A tool can be given to experts or students. Opinions of the populations for which the tool is applicable can also be considered. Based on content validation the items should be revised and first pilot study should be conducted. On the basis of the pilot study, necessary modification should be done. A revised tool should be administered and item analysis should be done. Item analysis can be done by internal consistency[22]. Based on this analysis item selection should be done. After this reliability and validity studies should be conducted, this is an ongoing process and need multiple studies. Normative values for the targeted population must be collected as a final step[21, 22].

Level of evidence: IV

2.7. Summary of literature review

Table 1: Summary table of literature review

1	
S. No	1
Author	SE Lord, PW Halligan and DT Wade
Journal	Clinical Rehabilitation 1998; 12: 107–119
Study design	Preliminary reliability, validity and sensitivity testing of the tool
Sample size	65
Result	The results of the study concluded that the Rivermead visual gait analysis tool had a high inter-rater reliability. There was a significant correlation between the overall score of the RVGA and the contents score of each item.
Conclusion & Limitation	The RVGA provides the clinician with a clinical assessment of the quality of gait which may be used in conjunction with other measures to inform and monitor the value of physiotherapy treatment for people with MS and stroke, and possibly other neurological deficits. LIMITATIONS Complex gait measures were not used
Quality Of Article	CASP 8 / 10 80%
2	
S. No	2
Author	F. Coutts
Journal	Manual Therapy (1999) 4(1), 2-10
Study design	Master class

Sample size	-
Result	-
Conclusion & Limitation	Gait analysis is one form overall assessment of any patient with a movement disorder. Inability to is a major problem to the patient, thus justifying the period of time that should be spent in evaluating gait impairments and planning re-education of gait. Gait parameters like kinematics, kinetics and electromyographical activity are essential to give a complete description of the specific gait characteristics. The study concluded that the observational gait analysis is the most commonly used tool in the therapeutic environment.
3	
S. No	3
Author	Lara Allet et al
Journal	Gait & Posture 29 (2009) 488–493
Study design	clinical observation study
Sample size	Forty-five
Result	The gait parameters of the diabetic patients significantly differed from those of healthy individuals. Analysis of the post-experimental measure revealed a significant difference in the gait parameters between healthy individuals and patients with diabetic neuropathy, and between healthy individuals and patients without neuropathy. The greatest effect of the surface on walking was exhibited in patients with diabetic neuropathy, followed by patients without neuropathy and healthy individuals.
Conclusion & Limitation	Patients with diabetes without clinically detected neuropathy reported difficulty while walking in outdoor terrain. Risk of falls in a diabetic during walking increases even at an initial period of diabetes
Quality Of Article	CASP 8 / 11 73 %

4	
S.No	4
Author	L. Allet et al.,
Journal	Gait & Posture 32 (2010) 185–190
Study design	randomized controlled trial
Sample size	71
Result	All outcomes except stance time on the tarred terrain remained significant at the six-month follow-up. No significant effect was observed for stride length and the coefficient of variation of gait cycle time on different surfaces
Conclusion & Limitation	A specific training program can improve diabetic patients' gait in a real-life environment. A challenging environment highlights treatment effects on patients' gait better than an evenly tarred surface.
Quality Of Article	CASP 7 / 9 78 %

5	
S. No	5
Author	Tishya A.L. Wren et al.,
Journal	J Pediatr Orthop 2007;27:765Y768)
Study design	Validity study
No. of Subject	25
Result	The results of the study concluded that the inter-rater was fair (k = 0.11 – 0.25 and intra-rater reliability of GGI was moderate (k = 0.49 – 0.65). The result also concluded that the mean values of the items of GGI had consistency among the testers.

Conclusion & Limitation	The results of the study concluded that GGI can be used as a valid tool for evaluating gait.
Quality Of Article	CASP 7 / 10 70%
	6
S.No	6
Author	Alexandra S. Voloshina et all
Journal	The Journal of Experimental Biology (2013) 216, 3963-3970
Study design	Observational study
Sample size	11
Result	Walking on uneven terrain resulted in a variety of changes to gait compared with walking on smooth terrain. Subjects walked with slightly shorter step lengths and substantially increased step variability. Gait kinematics remained similar overall, but knee and hip mechanical work increased on uneven terrain.
Conclusion & Limitation	The study concluded by identifying some of the adaptive mechanisms adopted by individuals while walking in uneven terrain. The study concluded by identifying changes in the stepping and distance parameters, muscle activity and joint angles measured. The limitation of the study was that the participants walked at a set walking speed and the set-up of the force plate was at a specific distance and specific height. Participants were also given limited time to adapt to the uneven terrain.
Quality Of Article	CASP 7 / 10 70 %

7	
S.No	7
Author	Chandrasekhar Rathinam et al
Journal	Gait & Posture (2014)
Study design	A systematic review and meta-analysis based on PRISMA guidelines
Sample size	9 studies
Result	Observational gait evaluation is considered as a low-cost alternative gait tool for IGA in regular clinical practice. Five observational gait tools were identified for children with Cerebral Palsy (CP) and Down's Syndrome. Nine studies related to children with CP were selected for this review and the tools selected did not accomplish the level of IGA's consistency.
Conclusion & Limitation	The reliability and the validity of EVGS was better than the other tools selected for the review. The availability of limited studies pertaining to the gait assessment tools decreased the clinical validity of these tools. The concurrent validity and reliability of the EVGS was found to be high and could be considered for gait analysis of CP.
Quality Of Article	CASP 6 / 10 60 %
8	
S.No	8
Author	Harald Bohm et al.,
Journal	Gait & Posture 39 (2014) 1028–1033
Study design	Observational study
Sample size	16

Result	Gait analysis including EMG was performed under even and uneven surface conditions. Similar strategies to improve leg clearance were found in patients as well as in controls. Both adapted with significantly reduced speed and cadence, increased outward foot rotation, knee, and hip flexion as well as anterior pelvic tilt.
Conclusion & Limitation	On the uneven surface, increased knee flexion was observed in patients with BSCP, although rectus femoris activity was increased. Walking on an uneven surface has the potential to improve knee flexion in stiff-knee gait
Quality Of Article	CASP 7 / 10 70 %
9	
S.No	9
Author	Theo Mulder, Bart Nienhuis, and John Pauwels
Journal	Clinical Rehabilitation 1998; 12: 99–106
Study design	Review
Sample size	
Result	The study reviewed article concerned with the different type of task employed during walking. 96 studies were reviewed. The tasks were based on the type of terrain, manipulative task while walking, walking speed, use of walking aids. The results of the study concluded that most of the study employed a flat terrain with motor tasks to investigate the deviations of the gait. Very few studies investigated gait variation at different level terrains.
Conclusion & Limitation	This review of the literature shows that most of the studies of applied clinical gait analysis are based on the level of impairment and on a straight level walking as the prime task. The systematic review revealed that most of the studies have not tested all the components (motor, perceptual, cognitive, visual, auditory, type of terrain, perturbation, and speed) of walking while evaluating the gait variation during a task.

10	
S.No	10
Author	Gerald F. Harris, Ph.D. PE, Jacqueline J. Wertsch, MD
Journal	Arch Phys Med Rehabil Vol75, February 1994
Study design	Review
Sample size	-
Result	Videotape slow-motion replay and freeze-frame observational gait analysis offer significant improvement over unaided visual observation in the clinical setup. However, observational gait analysis has limited precision and is more descriptive than quantitative.
Conclusion & Limitation	This article reviews gait analysis procedures. The advancement from manual digitization, electrogoniometry, and video technology to sophisticated automated tracking systems in the gait analyzing system has improved the gait analysis procedure. When these advancements are used in combination with biomechanical models, these systems allow quantitative analysis of many specific gait characteristics such as joint moments and powers (kinetic analysis), angular velocities, angular accelerations, and joint angles (kinematic analysis). Analysis of dynamic EMG activity and energy consumption adds useful clinical information to gait analysis.

11	
S.No	11
Author	P Bowker and N Messenger
Journal	Clinical Rehabilitation 1988; 2: 89-97
Study design	Review
Sample size	-
Result	The review article critically examines the different methods available for the measurement of the gait parameters. The article summarizes the available literature on gait assessments into four sections according to the

	type of temporal and spatial parameters; kinetic and kinematic parameters and EMG and energy expenditure.
Conclusion & Limitation	The study concluded by summarizing the different parameters evaluated during clinical gait analysis and the requirements during gait assessment. The requirements are based on the gait parameter being investigated and include the logistical, financial and technology.
12	
S.No	12
Author	Arthur D. Kuo, J. Maxwell Donelan
Journal	Physical Therapy, Volume 90 Number 2, February 2010
Study design	Review of article
No. of Subject	-
Result	The Article investigates the basic principles of gait with respect to dynamic walking. The article reviews the determinants of the gait and the phases of gait cycle and the biomechanics involved in the dynamic stability of locomotion. The review article identifies the correlation between dynamic walking and biomechanics of impaired gait. The article also reviews the various parameters required for dynamic walking.
Conclusion & Limitation	The article reviewed the principles of gait, basic principles of gait with respect to dynamic walking. The article reviews the importance of motor inputs in providing power and stability during dynamic walking. Limitation The article reviews only the dynamic motor behavior of the limbs as the only aspect of the overall walking pattern without taking into account the interlinked behavior of the central nervous system and the musculoskeletal system.
13	
S.No	13
Author	Soran Aminiaghdam
Journal	Journal of Public Library of Science

Study design	Observation study design
No. of Subject	12
Result	The results of the study indicate a degree of compensation, lower limb kinematic changes and trunk movements that negotiate alterations in ground level during walking in uneven terrain. The study specifically measures the changes during the step and step down phase of walking in the uneven terrain.
Conclusion & Limitation	The study concludes that step-specific compensatory adaptations exist in lower limbs kinematics to maintain dynamic without taking into account the trunk orientation. The study concluded that backward rotation of the trunk during step-down occurs as a preventive strategy to control forward horizontal and angular momentum of the body. This mechanism helps to offset changes in the center of mass trajectory in patients with trunk-flexed gait.
Quality Of Article	7/10 70%
14	
S.No	14
Author	Savita S. Patil1et al
Journal	JKIMSU, Vol. 4, No. 4, Oct-Dec 2015
Study design	Cross-sectional study
No. of Subject	416
Result	The study shows that the prevalence of falls was 65.7% among old (74–84 years), 26.3% in young old (65–74 years) and 20.0% in very old (80+years), outdoor falls rate was 57.2%, and indoor falls 42.8%. The incidence of recurrent falls in a year was 17.7%. and about 82.3% of the old had a single episode of fall.
Conclusion & Limitation	The morbidity due to falls includes injuries, fractures, restricted mobility. The results of this study reflect on the circumstances observed in the indoor and outdoor falls like falls on the footpath, in the bathroom, while using stairs etc. The consequences like bruises and internal injuries followed by sprains, cuts, and fractures have been observed. The study suggests possible ways of preventing falls.

Quality Of Article	CASP 7/10 70%
15	
S.No	15
Author	Jeri Benson and Florence Clark
Journal	The American Journal of Occupational Therapy
Study design	Article
No. of Subject	
Result	
Conclusion & Limitation	Test planning, construction, and validation require time and patience. The compressed guide to instrument development and validation presented in this paper provides an overview of the steps required
Quality Of Article	
16	
S.No	16
Author	Ashok Kumar
Journal	Journal of Advanced Practices in Nursing
Study design	Review of articles
No. of Subject	
Result	The article reviews the steps and process involved in tool development
Conclusion & Limitation	This article concludes with the correct methods to adopt a rational, organized and structured pathway to tool development. The article presents a framework of the process involved through item analysis, factor analytic and related methods. The article demonstrates approaches to decide and determine the reliability and validity of the new tool

2.8. Summary

The literature review of the sections described in the above sections reveals the various means of gait analysis tools and methods of evaluation. On review, it is clear that there is a lack of studies done on uneven outdoor terrain and to quantify the same. The literature further suggests that falls occur predominantly in the outdoor environment and most of the studies conclude that the reason may be because of the unevenness of the terrain. In India where there is a high incidence of outdoor falls, and where most of the activities are outdoor, there is lack of scientific research on the changes in gait pattern pertaining to walking in the patient's own environment and quantification of the gait components by a tool.

CHAPTER 3

METHODOLOGY

3. METHODOLOGY

The methodology of the study is as follows

3.1 Study design : Observational study

3.2Study source : General population of Mysuru

3.3 Sampling strategy : Convenience sampling

To recruit the population for the observational study[16,17], a group meeting with all the class representative of BPT and MPT was held. In the course of the group meeting the class representative was requested to inform all their classmates regarding the study and for participation in the study. People who volunteer to participate and who fulfill the inclusion criteria after signing the informed consent (**Appendix C**) form were included in the study.

3.4 Sample Size: The sample size was determined by the maximum number of participants necessary to reliably determine the stability of each gait outcome variable and when data saturation occurs. Data saturation[16, 17]occurred with the sixth participant where the components of the outdoor gait tool started showed the same repetitive measures in their central tendency.

3.5. Participants criteria

Inclusion criteria:

(i) Typical male & female adults of JSS institutions who voluntarily participated in the study.

(ii) Individuals aged between 20-45 years.

Exclusion criteria

Individuals with

(i) Neurological and orthopedic injuries to lower extremities in the past 6 months.

(ii) Who had undergone recent surgeries.

(iii) History of longitudinal fall in the past six months.

3.6. Materials required

1. Custom constructed outdoor uneven terrain of 10 m based on the feedback of a random population residing in Mysuru
2. Colored tape markers (25mm)
3. Two web cameras (Logitech B525 webcam) with two tripods
4. Two laptops
5. Kinovea 0.8.15 software
6. Stopwatch
7. Inch tape 100 cm

3.7 Operational definition

Outdoor ambulation

The outdoor ambulation is walking on an uneven terrain selected for the study measuring 10 x 3 meters.

Kinematic variables of gait

The kinematic variables of gait are the measure of the body segments, time and distances variables moved in the 10 x 3 meters uneven terrain.

3.8. Procedure

Phase I

Requisite permission from institutional research committee of JSS College of physiotherapy was obtained. Review of literature was conducted to support the hypothesis. The component generation for the outdoor gait analysis tool was done by review of the literature and expert opinion, the proposal of the study was submitted to the ethical committee of JSS Medical College for ethical clearance (**Appendix B**).

Components generation:

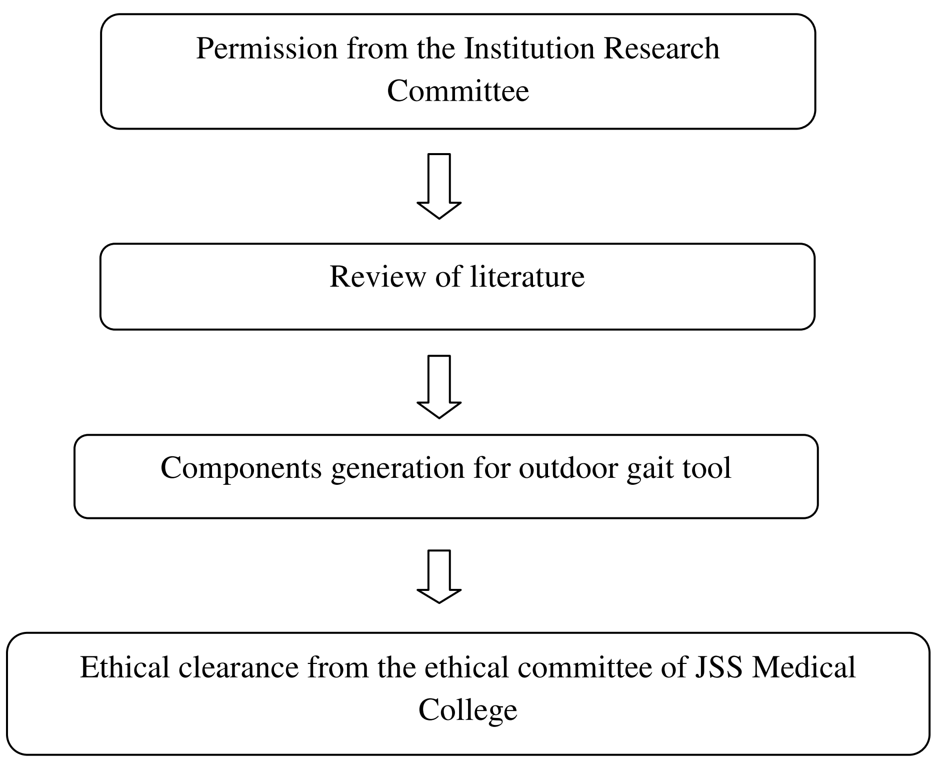
The component generation for the outdoor gait analysis tool was done by review of the literature and expert opinion. The items used in the scale were derived from recent articles and research papers that describe normal and pathological gait, clinical observations, current gait assessment forms, items from falls assessment scales based upon the Indian terrain, culture, and custom of the Indian population. The items were generated from existing variables of gait measurement so that they are consistent with the constructed structure of the new tool. The items that emerged from the item generation were then pooled. The next step involves examining the competency of the content generated by reviewing with expert opinion. The expert views were taken regarding the contents of the items and then items were modified and rephrased with respect to the practicality of the items and the procedural issues with respect to the population to be tested.

The selection and reduction of the items were based on the findings of the research studies, systematic reviews, literature, and expert opinion. The items refined were based on the human adaptation process when walking on uneven unpredictable terrain. Studies based on obstacle walking revealed the importance of maximal hip and knee flexion, hence these components were incorporated. Further, during stance improved stability on an uneven surface is achieved by reducing the height of the center of mass (MacLellan & Patla, 2006) through a crouched position with increased hip and knee flexion (Gates et al., 2012). In addition, trunk and lower extremity adaptations assist in maintaining a steady head position to allow the visual and vestibular system to operate from a stable position and contribute more effectively to maintaining balance. Similarly, during the gait cycle, the interdependence of the ankle joint to the proximal joints will necessitate the measurement of ankle range of motion. The other ankle components were taken based on literature cited, which states increased co-contraction of ankle invertors and evertors shortly after initial contact (Wade et al., 2010). Further while walking in an uneven terrain their adaptive foot postures for a firm foothold on the uneven terrain. Thus foot rotation, valgus and varus components were selected. Compared to walking on a level surface, walking on uneven terrain results in significantly increased pelvic accelerations (Menant et al., 2011; Menz, Lord, & Fitzpatrick, 2003a) but healthy young individuals demonstrate no significant change in head accelerations (Menz et al., 2003a), Hence to confirm whether any attenuations at the pelvic existed the pelvic components were incorporated.

Human walkers in unconstrained environments adopt a preferred walking speed characterized by a combination of step length and step duration that minimizes the energetic cost. Similarly, the upper limb movements are a way of synchronizing with the lower limb progression. Hence the specific distance parameters of step length, step width as well as the time parameter of cadence were selected. To measure the upper limb synchronization shoulder and elbow range of motion was selected. Further, the neuro-muscular strategies adopted by the body when walking on an uneven unpredictable terrain requires changes in the pattern and magnitude of joint kinematics, kinetics, and electromyographic (EMG) activity between tasks (Winter and Eng., 1995). Hence the components of ATOGA were based on these research findings.

Figure 5: Flow chart adopted for procedure phase I

PHASE I



Phase II

Feedback of the uneven terrain

The study required an uneven and unpredictable terrain measuring 10m in length and 3m width in an outdoor environment, the terrain was selected in such a way that it resembles any outdoor walking environment seen in India. The nature of the terrain was based on feedback obtained from randomly selected individuals from Mysuru. The terrain that was selected for the study was a mix of flat, mixed and rough terrain. The texture of the soil moderately coarse (loamy soil) with intervals of grass with uneven shallow and elevated surfaces throughout with uneven gravel. The overall terrain had a gross elevation of 5 – 6 degrees. The terrain was selected with some simulation of rough rocky areas intercrossed over the terrain.

Plate 1: Terrain for gait analysis

Camera calibration

The study needed two cameras (Logitech B525 webcam) which were calibrated to satisfy the sharpness and clarity of the video. The cameras were mounted on a tripod. The cameras were then connected to Lenovo laptops for recording the video. The cameras were placed 3m from the sides and 3m in the front, from the terrain to view the frontal plane and sagittal plane walking of the participant. A prototype video of the gait analysis was done after the camera is mounted on the tripod. The clarity, sharpness, resolution and the view settings are adjusted to accommodate the full body view of the participant from the foot to the head. The prototype video picture is then analyzed in the kinovea software for standardization.

Participant selection

Participant selection was done according to the inclusion and exclusion criteria. To recruit the population for the study, a meeting was held with all the class representative of BPT and MPT. In the course of the group meeting, the class representatives were requested to inform all their classmates regarding the study and for participation in the study. People who volunteer to participate are then recruited and subject to the fulfillment of the inclusion criteria, the participants were requested to sign the informed consent form (**Appendix B**).

Gait analysis procedure

Instructions were given to the participants regarding the procedure to walk on the uneven terrain (10m x3m) selected for the study. Colored tape markers were placed directly over the bony landmarks (**Appendix D**). The participants were walking from the pre-marked starting point to the marked endpoint in their respective natural walking speed and turn around and return back to the starting point. Two cameras (Logitech B525 webcam) connected to two laptops were used for the recording. The cameras were mounted on stationary tripods. The cameras were then connected to Lenovo laptops for recording the video. The cameras were placed 3m from the sides and 3m in the front, from the terrain to view the frontal plane and sagittal plane walking of the participant. One of the cameras was placed at a distance of 3m in front from the uneven walking terrain to record anterior and posterior views of gait. The second camera was placed at a distance of 3m from the mid-portion of the uneven walking terrain on the sides to record the lateral view. The placements of cameras are depicted in Figure 6. The placement of the camera is to ensure a clear field of vision of at least 6m of the central part of the uneven terrain consisting of about three to six cycles of gait, which were captured for gait analysis. Participants were instructed to walk without their footwear at his/her own normal walking pace on the uneven unpredictable terrain. The cameras were set to start recording simultaneously, as the participant started walking. Anterior and posterior view of the walking was recorded by ‘camera 2’ and sagittal view of the walking are captured by ‘camera 1’ as demonstrated in Figure 6.

Plate 2: Pictorial representation of gait analysis

Figure 6: Diagrammatic Representation of the gait path

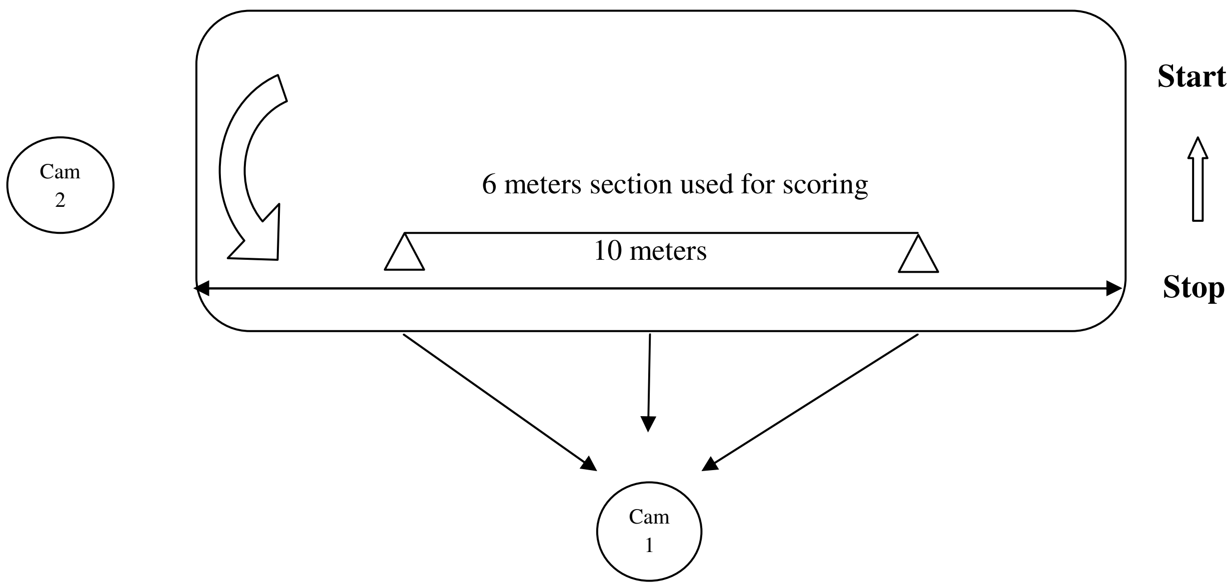
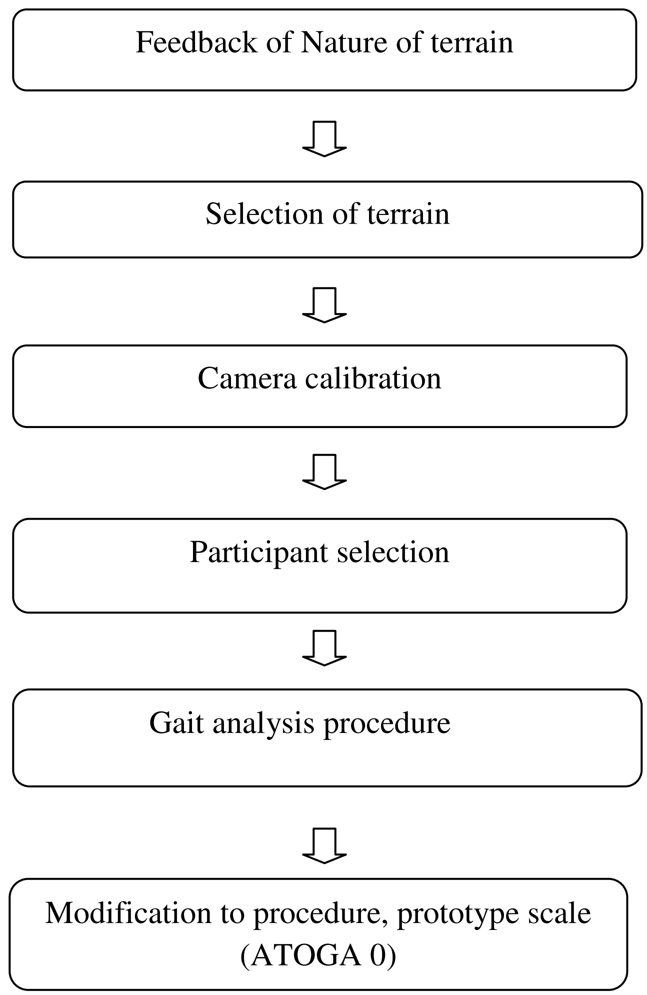


Figure 7: Flow chart adopted for procedure phase II

PHASE II



Phase III

Video Analysis

The videos of each participant comprising of anterior/posterior and lateral views were transferred to Kinovea 0.8.15 version video analyzing software. Slow motion analysis of the gait was done. The initial three cycles and final three cycles were excluded from the analysis so as to control for acceleration and deceleration. Thus, the cycles covered in the middle 6m (3–6 cycles) were analyzed. The kinematics of each event, of each joint, was analyzed using cross marker tool, line tool and angle tool of the software. The bony landmarks were highlighted using the cross marker tool with bright contrast color for better visualization of the points in the video. Each event was paused and the measurements of angles of all the joints were taken. To increase the accuracy in measurement, joint angles at the same event was taken from at least three cycles.

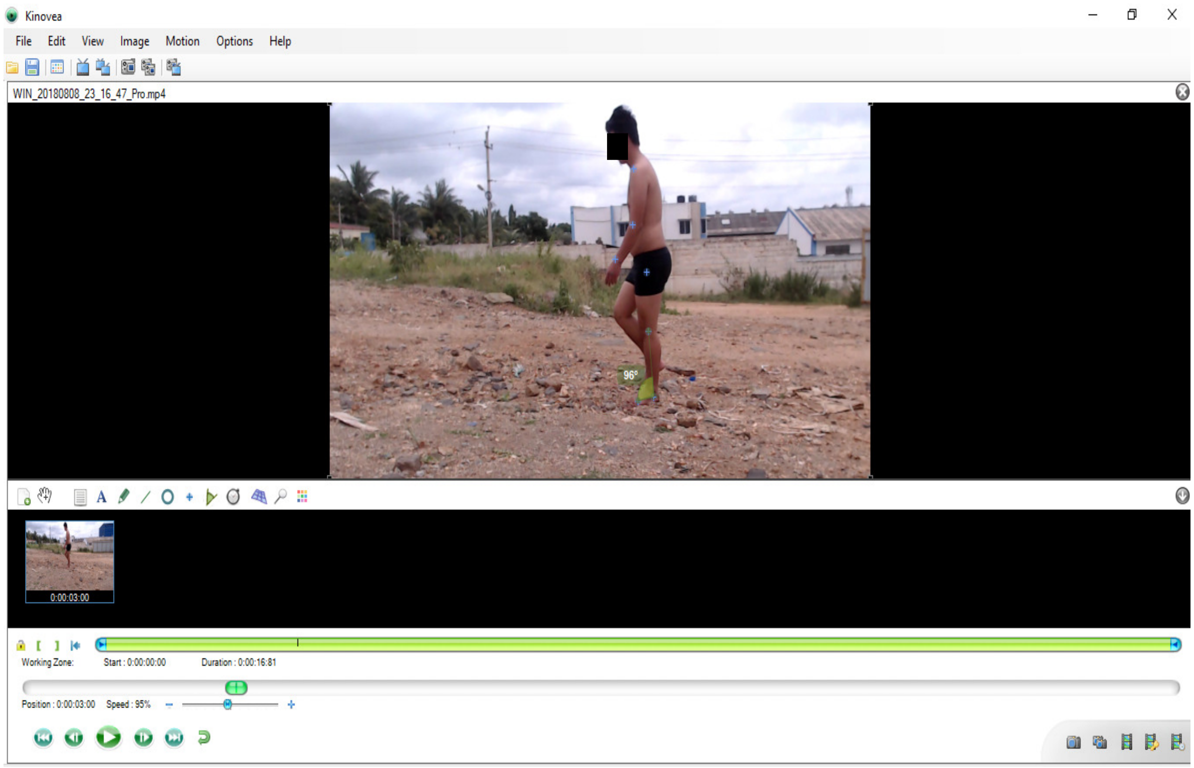


Plate 3: Pictorial representation of kinovea analysis

Data Analysis

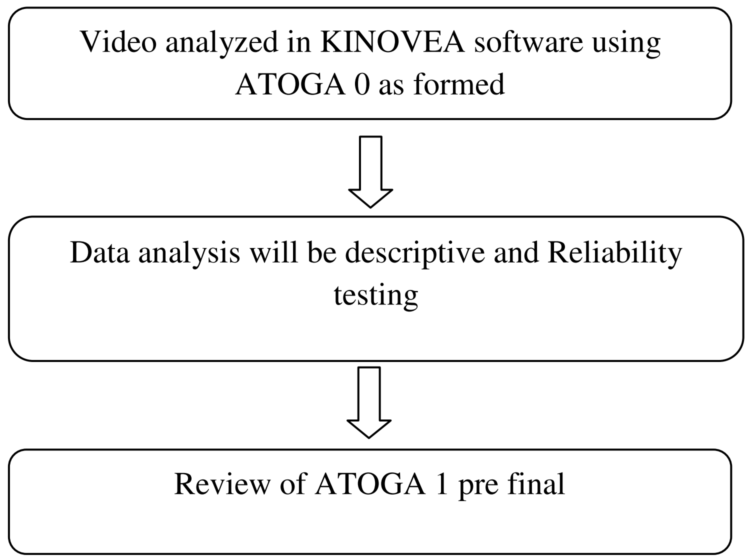
Descriptive statistics of the data was done by compiling the ranges of motion at joint during the stance events of the gait cycle.

Development of the Assessment Tool for Outdoor Gait Analysis (ATOGA 0)

The development of the Assessment Tool for Outdoor Gait Analysis (ATOGA 0) is based on the data analysis derived from the kinematic components of the outdoor gait tool. The data obtained were statistically analyzed and the descriptive results obtained were categorized.

Figure 8: Flow chart adopted for procedure phase III

PHASE III



3.9. Data analysis

Data analyses were be done as follows,

Phase I

The review of Literature and expert opinion was done to compile the components of the gait analysis tool.

Phase II

In phase II, Item reduction, calibration of camera and standardization of the terrain was done and the modifications required were done by expert opinion.

Phase III

In phase III, Data obtained by gait analysis will be analyzed by kinovea software and the data of the components will be described by central tendency value. The descriptive statistics of Mean and the standard deviation was calculated to tabulate the values obtained for each component of the outdoor gait analysis tool. The reliability testing was done by comparing the mean and standard deviation of ten more healthy subjects. The tool thus standardized was henceforth termed as ATOGA 1.

CHAPTER 4

RESULTS

4. RESULTS

A total of 10 subjects (n=10) from JSS College were included in the item reduction phase of ATOGA. The mean age and SD of the participants were given in Table 2.

Table 2: Demographic Data

Age#	Gender	
Mean ± SD	**Male**	**Female**
24.1 ± 2	3	7

 # - Mean age in years

The components of the ATOGA were analyzed by kinovea software (version 0.8.15). The videos of the participants were analyzed in kinovea and the joint angles of the upper limb and lower limb were analyzed using mean and SD.

Table 3.A: Descriptive data for Ankle joint in Sagittal plane

Gait phase	Right side Mean ± SD *	Direction of Movement	Left side Mean ± SD*	Direction of Movement
Initial contact	15.94 ± 5.7	Plantar Flexion	11.95 ± 3.18	Plantar Flexion
Loading response	10.25 ± 2.65	Plantar Flexion	8.27 ± 3.94	Plantar Flexion
Mid-stance	5.33 ± 1.73	Dorsiflexion	5.83 ± 2.06	Dorsiflexion
Terminal stance	10.61 ± 3.60	Dorsiflexion	9.5 ± 3.8	Dorsiflexion
Pre-swing	10.19 ± 4.58	Plantar Flexion	13.5 ± 7.3	Plantar Flexion
Initial swing	16.34 ± 5.19	Plantar Flexion	19.4 ± 7	Plantar Flexion
Mid-swing	4.92 ± 1.81	Dorsiflexion	7.7 ± 3.5	Dorsiflexion
Terminal swing	16.1 ± 5.54	Plantar Flexion	13.8 ± 3.9	Plantar Flexion

*** Mean ± SD in degrees**

The peak angles in the ankle joint during the phases of gait were analyzed taking the mean and SD (Table 3.A). The maximal ankle dorsiflexion required to walk in the uneven terrain was (10.61 ±3.60) which was recorded during the terminal stance and plantar flexion was (19.4 ± 7) during the initial swing. The kinematics of the visual gait analysis in the normal terrain the maximum ankle dorsiflexion required was 5° during the stance phase while it is evident from the data that the peak dorsiflexion was 10.61 ±3.60. Similarly, the plantar flexion required for walking in an even terrain as per the gait analysis in the lab was 25° during the phase from mid stance to toe off(Table 3.B).

Table 3.B: Peak ankle JROM during the gait cycle in sagittal plane

Ankle	**Uneven terrain**	**Even terrain**
	Mean ± SD*	**Maximum ROM***
Dorsiflexion	10.61 ± 3.60	5°
Plantar flexion	19.4 ± 7	25°

*** Mean ± SD in degrees**

Table 4.A: Descriptive data of knee joint in sagittal plane

Gait phase	Right side Mean ± SD*	Direction of Movement	Left side Mean ± SD*	Direction of Movement
Initial contact	21.9 ± 4.8	Flexion	17.7 ± 5.03	Flexion
Loading response	29 ± 4.7	Flexion	25.6 ± 5.63	Flexion
Mid-stance	11.7 ± 3.9	Extension	14.63 ± 5.22	Extension
Terminal stance	15.05 ± 4.69	Flexion	16.37 ± 9.76	Flexion
Pre-swing	41.57 ± 7.8	Flexion	45.14 ± 8.87	Flexion
Initial swing	57.11 ± 6.9	Flexion	62.67 ± 9.75	Flexion
Mid-swing	59.34 ± 13.65	Flexion	56.10 ± 11.40	Flexion
Terminal swing	23.90 ± 3.28	Extension	19.21 ± 6.5	Extension

*** Mean ± SD in degrees**

The peak knee flexion required to walk in the uneven terrain was 62.67 ± 9.75 during the initial swing (Table 4.A). The knee flexion required in the gait cycle in the even terrain was 60 and in the data obtained while walking in the uneven terrain corresponds to the value (Table 4.B). The peak knee flexion obtained was 62.67 ± 9.75

during the initial swing. In the even terrain gait analysis during the terminal stance the knee goes into extension and as evident from the data the knee in uneven terrain continues to be in flexion (16.37 ± 9.76). Further, the peak extension moment was seen during the mid-stance and the mean value was found to be between 11.7 ± 3.9 and 14.63 ± 5.22. During the terminal swing, the mean value of knee flexion was between 23.90 ± 3.28 and 19.21 ± 6.5.

Table 4.B: Peak knee JROM during the gait cycle in sagittal plane

Knee	**Uneven terrain**	**Even terrain**
	Mean ± SD*	**Maximum ROM***
Knee flexion	62.67 ± 9.75	60

*** Mean ± SD in degrees**

Table 5.A: Descriptive data of hip joint in sagittal plane

Gait phase	**Right side**	**Direction of Movement**	**Left side**	**Direction of Movement**
	Mean ± SD*		**Mean ± SD***	
Initial contact	25.36 ± 4.03	Flexion	29 ± 4.5	Flexion
Loading response	19.45 ± 2.31	Flexion	23.15 ± 4.7	Flexion
Mid-stance	6.95 ± 2.60	Flexion	5.71 ± 3.36	Flexion

Terminal stance	9.97 ± 4.15	Extension	5.96 ± 4.94	Extension
Pre-swing	8.96 ± 3.53	Extension	6 ± 3.5	Extension
Initial swing	14.3 ± 6	Flexion	10.5 ± 3.05	Flexion
Mid-swing	35.9 ± 3.35	Flexion	38.64 ± 4.5	Flexion
Terminal swing	32 ± 4.45	Flexion	35.5 ± 2.97	Flexion

*** Mean ± SD in degrees**

The peak hip flexion obtained was 38.64 ± 4.5 during mid-swing which is more than the data available for walking in the even terrain (Table 5.A). The peak Hip flexion occurs during the mid-swing to the terminal swing phase. Literature suggests that the maximal hip flexion at 30° during this phase. As for the normal gait cycle in the even surface, the peak hip extension moment was during terminal stance 9.97 ± 4.15(Table 5.B).

Table 5.B: Peak hip JROM during the gait cycle in sagittal plane

Hip	Uneven terrain	Even terrain
	Mean ± SD*	Maximum ROM*
Hip flexion	38.64 ± 4.5	30°
Hip extension	9.97± 4.15	15°

Note: * Mean ± SD in degrees

Table 6: Descriptive data of shoulder joint in sagittal plane

Gait phase	Right side	Direction of Movement	Left side	Direction of Movement
	Mean ± SD*		Mean ± SD*	
Initial contact	21.7 ± 4.9	Extension	17.57 ± 4.15	Extension
Loading response	15.9 ± 4.32	Extension	10.83 ± 3.8	Extension
Mid-stance	5.18 ± 1.12	Flexion	6.45 ± 2.51	Flexion
Terminal stance	15.1 ± 4.01	Flexion	14.68 ± 4.90	Flexion
Pre-swing	11.75 ± 3.69	Flexion	13.05 ± 6.07	Flexion
Initial swing	6.37 ± 2.85	Flexion	8.17 ± 4.11	Flexion
Mid-swing	10.56 ± 3.54	Extension	10.36 ± 5	Extension
Terminal swing	12.51 ± 2.75	Extension	16.16 ± 2.7	Extension

Note: * Mean ± SD in degree

Table 7: Descriptive data of elbow joint in sagittal plane

Gait phase	Right side	Direction of Movement	Left side	Direction of Movement
	Mean ± SD*		Mean ± SD*	
Initial contact	17.52 ± 6.31	Flexion	19.60 ± 4.09	Flexion
Loading response	17.13 ± 9.23	Flexion	19.8 ± 7.0	Flexion
Mid-stance	26.30 ± 6.41	Flexion	28.08 ± 6.34	Flexion
Terminal stance	30.78 ± 5.9	Flexion	32.72 ± 8.16	Flexion
Pre-swing	27.58 ± 10.5	Flexion	22.2 ± 7.5	Flexion
Initial swing	23.8 ± 3.23	Flexion	20.23 ±8.9	Flexion
Mid-swing	14.6 ± 6.94	Flexion	14.35 ± 4.03	Flexion
Terminal swing	13.7 ± 7.6	Flexion	10.08 ±5.46	Flexion

Note: * Mean ± SD in degrees

The descriptive data of shoulder and elbow joint shows that shoulder flexion was between5.18 ± 1.12 and14.68 ± 4.90 and the elbow flexion was between10.08 ±5.46 and 32.72 ± 8.16. The peak of shoulder flexion occurred during terminal stance. The peak of shoulder extension was in the initial contact21.7 ± 4.9. Similarly, the peak of elbow flexion occurred during terminal stance. The synchronized movement of the shoulder and elbow and the peak values during the terminal stance corresponds with the normal gait cycle (Table 6&7).

Table 8: Descriptive data of pelvis in frontal plane

Gait phase	Right side	Left side
	Mean ± SD*	**Mean ± SD***
Pelvic obliquity in mid-stance	5.3 ± 0.6	6.0 ± 0.7
Maximum lateral shift	4.2 cm	3.7 cm

Note: * Mean ± SD in degrees

The pelvic obliquity was found to be ranging between 5.3 ± 0.5 and 6 ± 0.7. The normal obliquity was 8.8 ± 2.8 as per literature. The maximal lateral shift was between 3.7 cm to 4.2 cm(Table 8).

Table 9: Descriptive data of foot in frontal plane

Gait phase	Right side	Direction of Movement	Left side	Direction of Movement
	Mean ± SD*		**Mean ±SD***	
Foot rotation	19.8 ± 3.0 1.2 ± 0.3	IR ER	21.6 ± 1.6 1.3 ± 0.3	IR ER
Hindfoot varus and valgus	5 ± 2.3 9 ± 1.7	Varus Valgus	8 ± 3.9 11 ± 4.1	Varus Valgus

Note: * Mean ± SD in degrees

The foot rotation and the hindfoot varus and valgus are marginally more than the normative data while walking in the even terrain. The maximal inward rotation was 21.6 ± 1.6 and outward rotation was 1.3 ± 0.3. Similarly, the maximal varus position adopted in the uneven terrain was 8 ± 3.9 and the valgus position was 11 ± 4.1(Table 9).

Table 10: Descriptive data for the distance variables

Distance variable	Right side	Left side
Step length	0.6m ± 0.1	06m ± 0.09
Step width	15.7 cm ± 4.2	
Cadence	103.6 ± 9 steps / min	

The descriptive data of the distance variables shows that the step length and width fall within the normative values of the data as in the even surface. The cadence also was well within the normal values. The mean cadence seen among the participants was 103 steps ± 9 per minute (Table 10).

The analysis of the data suggests that the mean values observed during peak knee flexion, peak plantar flexion and peak hip flexion differed from the already available values in the gait analysis of the normal terrain. There were no significant changes in the distance variables.

CHAPTER 5

DISCUSSION

5. DISCUSSION

Instrumented gait analysis remains the gold standard for evaluation and assessment of gait dysfunction. However, cost, time, and access to instrumented gait analysis laboratories prevent routine clinical use of such tools (Hawkins et al 2017). Therefore, the development of reliable and accessible Observational Gait Analysis (OGA) tools is necessary for the wide variety of patient populations seen in clinical practice. Most of the OGA tools available are laboratory-based and on an even terrain (Voloshina2013). Literature suggests that most of the falls that occur in the community are due to walking in uneven unpredictable terrain. In India where most of the population living in a rural environment and the terrain are very much uneven and unpredictable, the incidence of falls in the community is high (Savitha et al 2015, Jagnoor et al 2011). Hence the need for a tool to analyze the gait in the outdoor environment that is uneven and unpredictable is required for helping the patients to be gait trained in their own environment. It was assumed that the kinematic parameters would differ in the uneven and unpredictable terrain. It was also assumed that uneven unpredictable terrain is common in the outdoors where falls are common and prediction of falls in the outdoor uneven unpredictable terrain during walking is necessary as a part of gait assessment. Hence this study was undertaken for a quantitative evaluation of sagittal and frontal plane joint angles and distance variables on uneven and unpredictable terrain.

The study required an uneven terrain measuring 10m in length and 3m width in an outdoor environment, the terrain was selected in such a way that it resembles any outdoor walking environment seen in India. The next step involved the item generation. The items used in the scale were derived from recent articles and research papers that describe normal and pathological gait, clinical observations, current gait assessment forms, items from falls evaluation scales. The next step involved reviewing by an expert for content competency. The expert reviewed the tool regarding the contents of the items and then items were modified and rephrased with respect to the practicality of the items and the procedural issues with respect to the population to be tested. The scale thus developed was named as ATOGA 0.

The study was done to find out the practicality of the items in the scale on 10 participants. Participant selection was done according to the inclusion and exclusion criteria. The participants were instructed to walk on the terrain and the whole procedure was videographed. The gait cycle thus obtained was analyzed by kinovea software for computing the angle measured at each joint based on the item components of ATOGA to be observed during the different phases of the gait. Data analysis by SPSS version was done to compute the mean and standard deviation of the obtained values under each component. The descriptive analysis thus provided normative data for ATOGA 0.

On analysis of the mean angle at the ankle joint it was observed that the maximal ankle dorsiflexion required to walk in the selected uneven terrain was the maximum during the terminal stance and plantar flexion was maximum during the initial swing. On analysis in the kinovea software, it was evident that the participant's kinematic gait parameter for ankle were different when compared with the gait parameters in the even terrain were the average dorsiflexion was 5-7 degrees (Norkin). There was no significant difference in the mean angle for plantar flexion between the uneven and even terrain. The participant's initial contact was not on the heel and this resulted in plantar flexion moment during the initial contact phase. The peak of ankle dorsiflexion moment was seen during the terminal stance during the toe of the stage of the contralateral extremity. This synchronizes with the peak ankle plantar flexion moment achieved during the initial swing to prepare the limb for swing phase. The eversion and valgus angle also correlated with the ankle plantar flexion during the terminal stance through the initial swing. Similarly, the peak of inversion and dorsiflexion was achieved during the terminal stance of the gait cycle when the limb progressed from mid-stance to terminal stance. This was possibly for weight acceptance and accommodating the foot in the uneven terrain.

On analysis of the joint angle of the knee joint, the peak knee flexion observed to walk in the uneven terrain was the maximum during the initial swing. The peak extension moment was observed during the mid-stance. During the terminal swing, the mean value of knee flexion was between 23.90 ± 3.28 and 19.21 ± 6.5. The mean angle observed suggests that when the participant prepares to go for unilateral limb stance in an uneven terrain more amount of dorsiflexion and knee flexion is required to maintain the balance and equilibrium in the uneven terrain. This strategy allows the walker to analyze the postural state of their body before the start of each step so that the resulting trajectory motion of the center of body mass (COM) will help in the placing the foot on the intended foot spaces as well as maintaining the equilibrium. The peak of knee flexion was seen during initial swing where the swinging extremity prepares for ground clearance. The peak knee flexion seen was more than the knee flexion seen during the same gait phase during gait analyses in the even terrain (60 degrees). The data available also synchronizes with the normal gait cycle where the peak extension moment was seen during the mid-stance phase, which also corresponds to the ankle dorsiflexion moment seen.

The results of the mean joint angle observed at the hip joint suggest that the peak hip flexion obtained was during mid-swing and the peak hip extension moment was during terminal stance. The peak hip flexion corresponds to the peak knee flexion and peak ankle plantar flexion in ATOGA, which corresponds to the ground clearance and the phase where the contralateral extremity is in single support and in the phase of peak ankle dorsiflexion and knee flexion as described above. This phase corresponds to the phase in which the COG is bought as low as possible for equilibrium in uneven terrain. The peak extension seen during terminal stance correlates with normal gait phase in even terrain. The excess amount of hip flexion seen when compared with the data in the literature for an even terrain (30 degrees) is probably because of an excess amount of flexion required for ground clearance and equilibrium. The degree of pelvic obliquity and tilt was decreased as compared to the existing literature three-dimensional analysis of the pelvic and hip mobility during gait on a treadmill and on the ground (Staszkiewicz et al 2012). The decrease in the tilt seen in this uneven terrain walking might probably to reduce the unsteadiness and to maintain the equilibrium.

The descriptive data for the distance variables did not reveal any significant deviation from the normative values of the even terrain. The step length and step width fall within the normative values of the data as in the even surface. The cadence also was well within the normal values. The mean cadence seen among the participants was the same as observed in the even terrain (Norkins).

The analysis of the data suggests that the mean values observed during peak knee flexion, peak plantar flexion and peak hip flexion differed from the already available values in the gait analysis of the normal terrain. There were no significant changes in the distance variables. On a natural outdoor terrain, there is always an unpredictability of the surface textures, sloping, dampening, incline and decline. Hence walking in an uneven and unpredictable terrain requires adaptation of the walking cycle, the gaze and limb coordination. The study quantifies some of the adaptations as measured by the components of the ATOGA. The study was not able to precisely quantify the joint angles with respect to the walking surface during each cycle of gait as the terrain was irregularly uneven. The observed mean value of three successive cycles of the gait of each participant was taken to tabulate the mean of the components of ATOGA. Since the incline and decline of the terrain were irregularly uneven it was not possible to compute the mean of each cycle with respect to the angle of inclination and declination of the terrain. As the purpose of the study was to develop a tool to quantify the kinematics of the lower limb during walking in uneven and unpredictable terrain, simulated terrain with precise elevated levels and flat levels was not done. Hence data were analyzed based on the kinematic changes seen in the joint angles as per the components of ATOGA while walking in the selected terrain. One of the other limitations of the study was when the participants were made to walk on this uneven terrain, most participants selected a pathway adapting to his or her ability and wish. This was one more reason the data were not analyzed for a mean joint angle for each cycle of the gait. The angles observed in the ATOGA components were consistent with the kinematic gait parameters of even terrain and the consistency among the components was seen. The limitation of the ATOGA pertains to the inability to measure the angle of inclination, declination and the elevation of the terrain and thus the difficulty in measuring the joint angle during each phase of the gait cycle. The peak mean angle and standard deviation at various joints was a reflection of the mean of three cycles of the gait observed during the walking in the uneven terrain. The ATOGA needs to undergo the reliability and validity testing to pass through as a reliable and valid scale to evaluate the gait in outdoor uneven terrain in the community. The limitation observed in the study may be corrected by future study in which an uneven unpredictable terrain can be constructed with a detailed reference angle of elevation, inclination, declination with respect to the plane of the terrain.

5.1. Strengths

The strength of the study is that it is an unprecedented study as no prior studies have been conducted to develop a tool for outdoor gait analysis and this is the first attempt to develop an outdoor gait analysis tool.

5.2. Limitations

The study was not able to precisely quantify the joint angles with respect to the walking surface during each cycle of gait as the terrain was irregularly uneven. Furthermore, the main limitation of the study is that the inclination and the declination of the uneven terrain were not measured for each gait cycle. In addition, the participants choose their own pathway to walk in the uneven terrain. The study has shown the kinematic variables of joints in uneven terrain but it cannot be taken as the baseline measurement to measure the kinematics of any other terrain as the inclination and declination were not measured.

5.3. Future implications

Future implications must concentrate on the limitation observed in the study in which an uneven unpredictable terrain can be constructed with a detailed reference angle of elevation, inclination, declination with respect to the plane of the terrain. In addition, the ATOGA needs to undergo reliability and validity testing.

CHAPTER 6

CONCLUSION

6. Conclusion

The study was concluded by developing ATOGA. The mean angles of the ATOGA components were considered without taking the angle of inclination and declination of the terrain. Hence the mean angles observed cannot be taken as the reference angles for uneven terrain.

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APPENDICES

8. APPENDECES

Appendix A: RGUHS review

ACA/DCD/SYN/JJSCOP-M/T046/2017-18

5		ELURI MANI SANDHYA DEVI	MR.VIJAY SAMUEL RAJ.V DESG: LECTURER	DEVELOPMENT OF AN ASSESSMENT TOOL FOR OUTDOOR GAIT ANALYSIS (ATOGA)	**Status: Prov. Registered** **Observations:** Described And Well Structured However The Numbering Of The Side-Heading Is Not Correct As Per RGUHS Synopsis Proforma. It Should Be As Below Brief resume of the intended work: 6-6.1 need for the study 6.2-review of literature 6.3 -objectives of the study 7-7.1 Source of data 7.2-Method of collection of data(including sampling procedure, if any) 7.3-Does the study require any investigations or interventions to be conducted on patients or other humans or animals? 7.4-Has ethical clearance been obtained from your institution in case of 7.3 8-List of references CORRECTION IS MADE WITH REFERENCE PROFORMA FOR REGISTRATION OF SYNOPSIS FOR DISSERTATION **Remarks :** Follow the Performa for registration of synopsis for dissertation RGUHS	**PROVISIONALLY REGISTERED** STATUS OF ADMISSSION - **APPROVED**

DR. DCD

5

Appendix B: Ethical clearance certificate from IEC

JSS MEDICAL COLLEGE

(Constituent College)

JSS Academy of Higher Education & Research

(Deemed to be University)

Accredited 'A' Grade by NAAC

JSSMC/IEC / 3107 / 09 NCT /2018-19 Date: 06.08.2018

INSTITUTIONAL ETHICAL COMMITTEE

CERTIFICATE

This is to certify that the below mentioned Project was discussed and reviewed and the same has been cleared and approved by the Institutional Ethical Committee at its meeting held on 31.07.2018 at College Council Hall, JSS Medical College, Mysore.

Title of Project	"Development of an Assessment Tool for Outdoor Gait Analysis (ATOGA)"
Principal Investigator	**Ms. Eluri Mani Sandhya Devi** Ist Year MPT Student JSS College of Physiotherapy Mysore
Guide	**Mr. Vijay Samuel Raj, MPT** Lecturer JSS College of Physiotherapy Mysore

6/8/18

MEMBER SECRETARY

Member Secretary,
Institutional Ethical Committee
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APPENDIX C: Subject information sheet

Title: Development of an assessment tool for outdoor gait analysis.

Principal investigator: Eluri Mani Sandhya Devi, JSS College of physiotherapy, Mysuru.

Site: JSS College of physiotherapy primacies, Mysuru.

Phone no: 09047082970

Please read this form carefully. If you don't understand the language or any information in this document, please discuss. If you decide to volunteer to take part in this study you must sign at the end of this form.

Purpose of research: I have been informed that this study is to find the various movements happening in the body while walking outside.

Procedure: I understand that I will be made to walk on an uneven surface of 10 meters and video will be taken. I may withdraw from the study without any reasons if i want.

Risks and discomfort: I have been informed that there will be no risks during the study. Every effort will be made to minimize the risks.

Benefits: I understand that the results of the study will help the physiotherapists to find the kinematic variables of outdoor gait analysis in adults.

Payment for participation: I understand that I may not be paid for participation and that this is a non-funded research.

Confidentiality: I understand that information produced as a result of this study will be treated as confidential. It will not to be revealed to any person without my written consent. However, the information may be used for statistical analysis, publication or for teaching purposes with your right to privacy retained.

Request for more information: I understand that I may at any time request more information about the study. I will be informed about any significant new information that may affect me or influence my further participation in the study.

Withdrawal from the study: I understand that I may at any time withdraw from the study and my participation is completely voluntary.

Injury statement: I understand that it is unlikely to get injured directly during my participation in this study, and in such case, first aid will be given but no further compensation would be provided by the department or hospital. I am aware that by agreeing to participate in this study, I am not waiving any of my legal rights.

Investigator's statement: I have explained to the subject, the purpose of the research, the procedures required and the possible risks and benefits to the best of my ability.

Sign of Investigator: Date:

I have read this form, and I understand the test procedures, the risks, and discomforts. Knowing these risks and discomforts and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this test.

Sign of Participant: Date:

Informed Consent Form

Thesis title: Development of an assessment tool for outdoor gait analysis.

Name of the Research Subject:

Age of the Research Subject:

I have read the Subject Information Sheet and its contents were explained. I had the opportunity to ask questions and received satisfactory answers. I understand that my participation in the study is voluntary and that I have the right to withdraw at any time without giving any reason, without my legal rights being affected.

I agree to take part in the above study. I confirm that I have received a copy of the subject information sheet along with this signed and dated informed consent form.

_____________________________ __________

Signature & name of the participant Date

_____________________________ __________

Signature & the name of the witness Date

Appendix D. Components of outdoor gait analysis tool

FOOT:

1. Peak ankle dorsiflexion ROM
2. Peak plantar flexion ROM
3. Hind-foot varus in stance
4. Hind-foot valgus in stance
5. Foot rotation in stance

KNEE:

6. Peak extension stance
7. Terminal swing position
8. Peak knee flexion in swing

HIP & PELVIS:

9. Peak hip extension in stance
10. Peak hip flexion during swing
11. Obliquity at mid-stance

TRUNK:

12. Maximum lateral shift

UPPER EXTREMITY:

13. Shoulder flexion ROM
14. Shoulder extension ROM

15. The degree of elbow flexion

DISTANCE & TIME VARIABLES:

16. Step length

17. Step width

18. Cadence (step/min)

Appendix E: List of bony landmarks

Segment	Bony prominence
Foot	–Head of 1st Metatarsal (Dorsal) –Head of 3rd Metatarsal (Dorsal –Head of 5th Metatarsal (Lateral)
Ankle	–Medial and Lateral Malleolus –Calcaneal Tuberosity –Achilles Tendon
Knee	–Lower 1/3rd of Tibia (Anterior) –Lateral Condyle of Femur –Midpoint of Patella
Hip and Pelvis	–Greater Trochanter –Anterior Superior Iliac Spine –Posterior Superior Iliac Spine
Upper limbs	–Radial and Ulnar Styloid Process –Medial and Lateral Condyles of Humerus –Acromion Process –Sternal notch

Appendix F: Level of Evidence

Canadian Medical Association Journal (CMA) 1998

Level I: Evidence is based on RCTs (or meta- analyses of such trials) of adequate size to ensure a low risk of incorporating false- positive or false- negative results.

Level II: Evidence is based on RCTs that are too small to provide level I evidence.

Level III: Evidence is based on non- randomized, controlled, or cohort studies, case series, case- controlled studies, or cross- sectional studies.

Level IV: Evidence is based on the opinion of respected authorities or those expert committees as published consensus conferences or guidelines.

Level V: Evidence expresses the opinion of those individuals who have written and reviewed guidelines, based on their experience, knowledge of the relevant literature, and discussion with their peers.

Appendix G: Critical Appraisal Tools

G1. CASP for systematic review

JBI Critical Appraisal Checklist for Systematic Reviews and Research Syntheses

Reviewer______________________________________Date____________________________________

Author ______________________________________Year_______________Record Number______

	Yes	No	Unclear	Not applicable
1. Is the review question clearly and explicitly stated?	☐	☐	☐	☐
2. Were the inclusion criteria appropriate for the review question?	☐	☐	☐	☐
3. Was the search strategy appropriate?	☐	☐	☐	☐
4. Were the sources and resources used to search for studies adequate?	☐	☐	☐	☐
5. Were the criteria for appraising studies appropriate?	☐	☐	☐	☐
6. Was critical appraisal conducted by two or more reviewers independently?	☐	☐	☐	☐
7. Were there methods to minimize errors in data extraction?	☐	☐	☐	☐
8. Were the methods used to combine studies appropriate?	☐	☐	☐	☐
9. Was the likelihood of publication bias assessed?	☐	☐	☐	☐
10. Were recommendations for policy and/or practice supported by the reported data?	☐	☐	☐	☐
11. Were the specific directives for new research appropriate?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

G2. CASP for Cross-sectional study

CEBMa
center for
Evidence-Based Management

Critical Appraisal of a Cross-Sectional Study (Survey)

Appraisal questions	Yes	Can't tell	No
1. *Did the study address a clearly focused question / issue?*			
2. *Is the research method (study design) appropriate for answering the research question?*			
3. *Is the method of selection of the subjects (employees, teams, divisions, organizations) clearly described?*			
4. *Could the way the sample was obtained introduce (selection)bias?*			
5. *Was the sample of subjects representative with regard to the population to which the findings will be referred?*			
6. *Was the sample size based on pre-study considerations of statistical power?*			
7. *Was a satisfactory response rate achieved?*			
8. *Are the measurements (questionnaires) likely to be valid and reliable?*			
9. *Was the statistical significance assessed?*			
10. *Are confidence intervals given for the main results?*			
11. *Could there be confounding factors that haven't been accounted for?*			
12. *Can the results be applied to your organization?*			

G3. CASP for unfamiliar Qualitative study

Screening Questions

1. **Was there a clear statement of the aims of the research?** ☐ Yes ☐ No

   Consider:
   – *what the goal of the research was*
   – *why it is important*
   – *its relevance*

2. **Is a qualitative methodology appropriate?** ☐ Yes ☐ No

   Consider:
   – *if the research seeks to interpret or illuminate the actions and/or subjective experiences of research participants*

Is it worth continuing?

Detailed questions

Appropriate research design

3. **Was the research design appropriate to address the aims of the research?** Write comments here

   Consider:
   – *if the researcher has justified the research design (e.g. have they discussed how they decided which methods to use?)*

Sampling

4. **Was the recruitment strategy appropriate to the aims of the research?** Write comments here

   Consider:
   – *if the researcher has explained how the participants were selected*
   – *if they explained why the participants they selected were the most appropriate to provide access to the type of knowledge sought by the study*
   – *if there are any discussions around recruitment (e.g. why some people chose not to take part)*

Data Analysis

8. Was the data analysis sufficiently rigorous?

Write comments here

Consider:

- *if there is an in-depth description of the analysis process*
- *if thematic analysis is used. If so, is it clear how the categories/themes were derived from the data?*
- *whether the researcher explains how the data presented were selected from the original sample to demonstrate the analysis process*
- *if sufficient data are presented to support the findings*
- *to what extent contradictory data are taken into account*
- *whether the researcher critically examined their own role, potential bias and influence during analysis and selection of data for presentation*

Findings

9. Is there a clear statement of findings?

Write comments here

Consider:

- *if the findings are explicit*
- *if there is adequate discussion of the evidence both for and against the researcher's arguments*
- *if the researcher has discussed the credibility of their findings (e.g. triangulation, respondent validation, more than one analyst.)*
- *if the findings are discussed in relation to the original research questions*

Value of the research

10. How valuable is the research?

Write comments here

Consider:

- *if the researcher discusses the contribution the study makes to existing knowledge or understanding (e.g. do they consider the findings in relation to current practice or policy, or relevant research-based literature?)*
- *if they identify new areas where research is necessary*
- *if the researchers have discussed whether or how the findings can be transferred to other populations or considered other ways the research may be used*

Data collection

5. Were the data collected in a way that addressed the research issue?

Write comments here

Consider:

– If the setting for data collection was justified

– If it is clear how data were collected (e.g. focus group, semi-structured interview etc)

– If the researcher has justified the methods chosen

– If the researcher has made the methods explicit (e.g. for interview method, is there an indication of how interviews were conducted, did they used a topic guide?)

– If methods were modified during the study. If so, has the researcher explained how and why?

– If the form of data is clear (e.g. tape recordings, video material, notes etc)

– If the researcher has discussed saturation of data

Reflexivity (research partnership relations/recognition of researcher bias)

6. Has the relationship between researcher and participants been adequately considered?

Write comments here

Consider whether it is clear:

– If the researcher critically examined their own role, potential bias and influence during:

  – formulation of research questions

  – data collection, including sample recruitment and choice of location

– how the researcher responded to events during the study and whether they considered the implications of any changes in the research design

Ethical Issues

7. Have ethical issues been taken into consideration?

Write comments here

Consider:

– If there are sufficient details of how the research was explained to participants for the reader to assess whether ethical standards were maintained

– If the researcher has discussed issues raised by the study (e. g. issues around informed consent or confidentiality or how they have handled the effects of the study on the participants during and after the study)

– If approval has been sought from the ethics committee

G4. CASP FOR RANDOMIZED CONTROLLED TRIAL

(A) Are the results of the trial valid?

Screening Questions

1. Did the trial address a clearly focused issue? ☐ Yes ☐ Can't tell ☐ No

HINT: An issue can be 'focused' In terms of

- The population studied
- The intervention given
- The comparator given
- The outcomes considered

2. Was the assignment of patients to treatments randomised? ☐ Yes ☐ Can't tell ☐ No

HINT: Consider

- How was this carried out?
- Was the allocation sequence concealed from researchers and patients?

3. Were all of the patients who entered the trial properly accounted for at its conclusion? ☐ Yes ☐ Can't tell ☐ No

HINT: Consider

- Was the trial stopped early?
- Were patients analysed in the groups to which they were randomised?

Detailed questions

4. Were patients, health workers and study personnel 'blind' to treatment? ❑ Yes ❑ Can't tell ❑ No

HINT: Think about

- Patients?
- Health workers?
- Study personnel?

---

5. Were the groups similar at the start of the trial? ❑ Yes ❑ Can't tell ❑ No

HINT: Look at

- Other factors that might affect the outcome such as age, sex, social class

---

6. Aside from the experimental intervention, were the groups treated equally? ❑ Yes ❑ Can't tell ❑ No

(B) What are the results?

7. How large was the treatment effect?

HINT: Consider

- What outcomes were measured?
- Is the primary outcome clearly specified?
- What results were found for each outcome?

8. How precise was the estimate of the treatment effect?

HINT: Consider

- What are the confidence limits?

(C) Will the results help locally?

9. Can the results be applied in your context? (or to the local population?)

☐ Yes ☐ Can't tell ☐ No

HINT: Consider whether

- Do you think that the patients covered by the trial are similar enough to the patients to whom you will apply this?, if not how to they differ?

10. Were all clinically important outcomes considered? ❑ Yes ❑ Can't tell ❑ No

HINT: Consider

- Is there other information you would like to have seen?
- If not, does this affect the decision?

11. Are the benefits worth the harms and costs? ❑ Yes ❑ Can't tell ❑ No

HINT: Consider

- Even if this is not addressed by the trial,
  what do you think?

Appendix H: Similarity index certificate

Turnitin Originality Report

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Thesis By Sandhya Eluri

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