A Study on Developing an Interactive Stepping Exercise Tool to Improve Physical Balance of Elderly Population in India

A thesis submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

By

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2021

Dedicated to

My parents

&

My late Uncle

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DECLARATION

I now declare that the work contained in this thesis entitled "A Study on Developing an Interactive Stepping Exercise Tool to Improve Physical Balance of Elderly Population in India" is my work done under the supervision of Dr. Swati Pal, at the Department of Design, Indian Institute of Technology Guwahati (IITG), Assam. I hereby declare that to the best of my knowledge, it contains no materials previously published or written by another person, or a substantial proportion of material which have been accepted for the award of any other degree or diploma at IITG or any other educational institute, except where the due acknowledgment is made in this thesis. Any contribution made to the research made by others, with whom I have worked at IITG or elsewhere, is explicitly acknowledged in the thesis. I also with this declare that the intellectual content of this thesis is the product of my work, and as per general norms of reporting research findings, due acknowledgments have been made wherever the research findings of other researchers have been cited in this thesis.

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CERTIFICATE

This is to certify that the work contained in this thesis entitled "A Study on Developing an Interactive Stepping Exercise Tool to Improve Physical Balance of Elderly Population in India" submitted by Ms. Nilakshi Yein to the Indian Institute of Technology Guwahati, Assam (India) for the award of the degree of Doctor of Philosophy has been carried out under my supervision. This work has not been submitted elsewhere for the award of any other degree or diploma.

Swati Pal.

Place: Mumbai

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Thesis Summary

Fall in the elderly population is a serious hazard to their livelihood. In India alone, aging people are increasing every year, and the elderly of our society deserve an independent and active life. In India, a fair sum of the elderly faced brain injury; and loss their independence due to falls. This makes the elderly fall into a significant worldwide health concern. Balance exercises have extensively assisted the aging population in avoiding falls. However, elderly people are unwilling to do traditional exercise due to negative self-worth, laziness, boredom, not motivated, negative physical worth, busyness in other works, etc. Exergames (gaming movements that required physical movements to finish the game task via an interface: computer/ screen/ mobile) are useful solutions to motivate the elderly to perform the exercise. As most of the research is based on the developed nations (e.g., Wii, Dance Dance Revolution (DDR), etc.), they are not appropriate for developing nations' context-specific conditions (language, real-life relevance, the relatability of the game- avatar, etc.). To our knowledge, no such extensive research has been done considering the Indian scenario.

This research provides a new understanding into the field of elderly fall research in India by providing a more thorough insight into the use of exergames as a fall preventive measure for older adults, particularly concerning balance improvement. The thesis results indicate that exergame influence the elderly's motivation towards exercising. In designing the exergame, choosing exercise's particular purposes, such as stepping abilities and balance, need to be selected and developed considering the context-specific issues. The design process precisely considered the preferences of the elderly in India, along with the stepping exercises' movements aimed to mimic the players' movements during gameplay. Exergaming has an excellent prospective to become an essential part of future tailored medical technology in elderly fall research.

An exergame tailored is being introduced in this research for the elderly population of India. The investigation also addresses the perceptions and experiences of the elderly towards exergame. It also indicates the initial approach that included developing a stepping-exergame tailored for the elderly in India as a preventive measure to fall. The interface concept is developed using the Technology Acceptance Decision Tree (TADT). The design process includes Indian Anthropometric data for designing the prototype-mat with a computer interface. The designed exergame is specially tailored for the elderly in India, termed Therapeutic Stepping Exergame (TSE). The design process has carefully considered the minute details found in the literature survey, the ethnographic study, personal

interview, and TADT. In the elderly exergame experience, self-paced game speed, avatar, and game theme related to the elderly in the Indian context come out as a desirable game aspect along with the usefulness of the exergame. The investigations employed in the thesis are a mixed methodology approach utilizing quantitative and qualitative methods of data collection and analysis. Qualitative aspects of these design-based experimental investigations helped us capture user experiences and inductively derive relations between various complex subjective parameters experienced by the elderly in the field. After the statistical analysis is done to test the validation of the research hypothesis, it is found that TSE has improved the balance and balance confidence in the Indian elderly. It has significantly reduced the fear of falling and has motivated the elderly to exercise. The descriptive statistics and subjective assessment indicate that the user has accepted the TSE, signifying the validation of the design heuristic proposed in the TSE design. The TSE acceptance and the essential constructs for its use by the elderly in India have been evaluated using UTAUT2 (Unified Theory of Acceptance and Use of Technology 2 exergame) and subjective assessment.

In this thesis, based on the insight knowledge gathered from literature, field investigation, experimental investigation, and prototype development, design heuristics for the elderly are developed. This thesis recommends design heuristics for exergame, a game story, and game movements so that researchers can further study the exergame for the elderly while designing for Indian or similar contexts. However, to realize the full potential of exergames as a rehabilitation tool and fall preventive measures for the elderly, there is a need for further introduction of new exercise movements during gameplay. It is necessary to gain knowledge and understand which technology to use for rehabilitation purposes or exercise. Establishing the results in achieving long-term adherence to the exergames is also indispensable. This thesis has presented numerous essential steps towards achieving the understanding of the end-users' (elderly in India in this research) need for the exercise measure in an exergame. In the future research path, EXG with exoskeleton specific for elderly users as a rehabilitation paradigm might be a breakthrough in the elderly fall research.

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Abbreviations

A	Anterior
ABC	Activity-Specific Balance Confidence scale
CoP	Centre of Pressure
DDR	Dance Dance Revolution
EXG	Exergame
FES	Fall Efficacy Scale
FOF	Fear of Falling
FPBE	Fall Preventive Balance Exercise
HCD	Human Centric Design
LE	Lower extremities
M	Mean
PL	Posterolateral
PM	Posteromedial
PRQ	Preliminary Research Question
RQ	Research Question
R	Multiple correlation coefficient
R^2	Squared multiple correlation coefficient
SD	Standard Deviation
SEBT	Star Excursion Balance Test
TADT	Technology Acceptance Decision Tree
TAM	Technology Acceptance Model
TSE	Therapeutic Stepping Exergame
UTAUT	Unified Theory of Acceptance and Use of Technology
VR	Virtual reality
WBB	Wii Balance Board
WHO	World Health Organisation
YBT	Y- Balance Test
Yr.s	Years

Glossary of Terminology

In this generic section, information is given that refers to the frequently used terms in the thesis.

Avatars: *A virtual image (in the thesis, an older adult) of a body presented in the form of a cartoon.*

Balance/postural stability: *It is defined as the ability to maintain the body's center of mass within the limit of the base of support* [1].

Context of use: *Users, equipment (software, hardware, and materials), tasks, and the social and physical environments in which a product is used (ISO 9241-11:1998, def. 3.5)* [2].

Dance Dance Revolution (DDR): *It is an interactive dance-based game created by Konami* [3]. *It aims to get people moving on a dance mat to changing music, using forward and backward movement and side to side arrows.*

Effectiveness: *Accuracy and completeness with which users achieve targeted goals (ISO 9241-11:1998, def. 3.2)* [2].

Efficiency: *Resources expended on the accuracy and completeness with which users achieve goals (ISO 9241-11:1998, def. 3.3)* [2].

Elderly: *People of age 60 years and above are defined as "Elderly" or "Senior citizen"* [4]. *In this thesis, instead of the elderly,* ***"older adult"*** *is also used.*

Exergaming: *Exergaming is an experimental activity that includes playing computer-based games, or video games is used to encourage physical activities that are additional to sedentary activities and requires strength, balance, and activities that involve flexibility* [5], *for example, XBOX Kinect™, Dance Dance Revolution, or Nintendo Wii™, few cases of a commercial (market available) product.*

Experiment: *The study in which the independent variable is manipulated, and a dependent is measured, and other variables are controlled* [6].

Fall: *A fall is an event that causes a person to come to rest involuntarily on the floor or ground, or other lower level. Its code in the International Classification of Disease-9 (ICD-9) is E880-E888 and W00-W19 in ICD-10* [7].

Fit elderly: *Elderly who are living independently at sheltered accommodation or home. They are freely ambulant and without significant renal, hepatic, cardiac, metabolic disorder, or respiratory on either clinical examination or laboratory investigation. They do not receive regular prescribed medication.* [8]**.**

Frail elderly: *Elderly who are dependent on others for activities of daily living, and often in institutional care. They are not independently mobile - while they do*

not have an overt hepatic, cardiac, respiratory, renal, or metabolic disease, minor abnormalities may be revealed in laboratory investigation. They may need regular prescribed drug therapy. Frailty conditions usually include Alzheimer's disease, Parkinsonism, healed fracture events, osteoarthritis, osteoporosis, and multi-infarct cerebrovascular disease [8]**.**

Functional ability: *The capabilities of a person to do and be what they have reason to value, which includes their ability to grow; to meet their basic needs; to learn and make decisions; to build and maintain relationships, to be mobile, and to contribute to the society* [9].

Healthy ageing: *The process of developing and maintaining functional ability, which helps in wellbeing in older age* [9].

Human-Centered Design (HCD): *It is an approach to interactive system development that aims specifically on making systems usable. It incorporates the multidisciplinary application of human factors and ergonomics considering human skills, capabilities, limitations, and needs to enhance the effectiveness and efficiency of the interactive systems, improves the human working condition, and counteracts possible adverse effects of use on human safety, health, and performance* [10].

Informed consent: *the process by which subjects are first informed about what they will experience if they participate in the study, and, second, whether they consent to take part* [6].

Interactive system: *A combination of software and hardware components that receives input from a human user; and also communicate output back to them to support his or her performance of a task (it is often called system) (ISO 9241, definition 3.1)* [2].

Nintendo Wii™: *Released in 2006, the Wii is a popular exergame that uses a handheld Wii remote to control the Avatar characters by pointing the remote at the screen. Wii-habilitation- the use of the Nintendo Wii as a method of physical therapy used within a rehabilitation setting for a variety of clinical conditions.*

Participant or Subject: *An Individual who performs the experimental task and whose behavior is the object of the analysis* [6].

Pilot: *To test the aspects of a study before conducting a formal study* [6].

Prototype: *It is the complete or partial representation of a product or system, although limited in some way, can be used for evaluation (ISO 9241, def 3.1)* [2].

Response: *The unit of subjects' behavior; maybe verbal answers, moves in a problem environment, etc.* [6].

Satisfaction: *Freedom from discomfort and positive attitudes towards the use of the product (ISO 9241, def. 3.4)* [2].

Usability: *It is the extent to which a product can be used by a specific set of users to achieve defined goals with effectiveness and satisfaction in a specified context of use (ISO 9241, def. 3.1)* [2].

User: *The individual interacting with the system (ISO 9241, def. 2.2)* [2].

Unified Theory of Technology Acceptanc2e (UTAUT2): *A structured questionnaire designed to assess people's behavioral intentions for future use* [11].

XBOX Kinect™ *– an interactive exergame that captures movements of the body in real-time without the need to use worn or handheld controllers; the user's body acts as the controller recognizing the gesture of the body.*

Chapter 1. Introduction

1.1 Introduction to research context and thesis

In elderly, age-related deviations in cognitive, sensory, and psychomotor ability affect their balance control mechanism and postural reflexes, etc., resulting in impaired mobility. Literature suggests that up to 75% of elderly aged 70 years & older face balance-related impairment [1]. The balance-related problem in the elderly leads to an increase in the risk of tripping and injury; hence they become more prone to fall while doing activities like crossing roads or walking on uneven footpath [12]. The utmost critical risk factors for falls in the aging populations' problems with gait and balance and muscle weakness [13, 14]. Elderly fall has a tremendous impact on family, society, and health and healthcare costs [15]. Falls result in hospitalization, disability, injury, and loss of independence in the elderly, making it a severe public health problem [16]. In a review, the author stated the mean cost per hospitalization for fall-related injuries is Rs. 44, 266 [17]. These estimates are US-based, though, in India, such statistics are not available; it is evident that a large amount of money got invested in the fall problem [18]. The literature predicted approximately one in three elderly would experience a fall annually, and about half of the individuals have suffered more than one fall per year [19]. The most reported reason for elderly falls is “accidental” [20].

Fall often contributes to fear of falling, or FOF can develop in the absence of a fall [21]. A study showed that among the elderly participants, 80.556% has FOF that leads them to avoid doing activities like using the staircase, walking in the yard, in fact, avoiding various walking-related day-to-day life activities, etc. [22]. FOF is evident in both recent fallers and of those not reporting recent falls [23]. Up to 70% of fallers and up to 40% of people who have not recently fallen acknowledged the FOF, and 50% of people had reduced physical and functional activities and restricted or eliminated social and physical activities because of the fear and anxiety about falling [24]. The avoidance of activity may further lead to loss of functional independence, restricted mobility, reduced functional capabilities, and further increases in FOF and fall risk. FOF influences the balance and gait control in them. The elderly with no FOF has a higher center of pressure (COP) amplitude during eyes-closed quiet standing than those with FOF, and walking measures and quiet standing are linked to balance confidence in the elderly [21]. The elderly with high levels of FOF has a higher risk of future falls, but the elderly with low levels can be protective of falls, irrespective of their balance impairments [25].

Balance is a fundamental factor in almost every activity of our daily lives, as it is the crucial component of all functional movements. Balance is the ability to keep a body's COM (center of mass) within the limit of the base of support [1]. Exercise interventions are promising intervention showing evidence that can improve balance and gait as well as increase the capability to get up after a fall and also enhance the mood; it may also help to reduce the FOF by enabling more daily activities, and to maintain the balance without falling [25]. Fall preventive interventions, like muscle strengthening and balance retraining programs like Tai Chi, etc., can improve flexibility, leg strength, and balance [26, 27]. Factors like attitudes of the elderly, monotony, boredom, negative aging stereotypes, fear of falling, too busy, laziness, etc., influence the exercise domain [28, 29, 30, 22]. The care of the elderly has to date, focusing on managing chronic disorders but not on promoting exercise among the elderly in a self-motivated way. For that reason, firstly, it is crucial to analyze the difficulties, potential risks, and the possible solution targeting the current resources for the elderly fall prevention interventions. This is a possible scope in the fall preventive measure, which might become one of the best solutions for the elderly fall problem and enhance the knowledge in the field of elderly fall research in India.

It is essential to encourage the elderly's healthy lifestyle and to prevent falls by identifying the end user's actual requirement. To motivate the elderly to exercise, exergaming (EXG) can play a beneficial role in India. The previous research shows that digital games can cater to a motivator, emotional, and social level of meaningful and cherished activities [31]. Exergames (EXG) can reduce the negative attitudes in the elderly. EXG, like DDR, Wii, may form balance research for the elderly in a new constructive direction. EXGs are interactive video games that involve exertion or physical activity tracked as body movement [32]. EXG, like Wii, DDR, etc., are mostly influenced, designed, and implemented in developed countries. Most of the EXG needs excellent infrastructures for Wi-Fi, or network connection, camera installation provision, etc. These EXGs will need personal awareness and architectural interventions; changes might involve infrastructural changes, behavioral changes, awareness or uses to enhance advanced technology system, etc.

In India, before introducing a new approach such as EXG in the elderly, it is necessary to consider the individual's values, lifestyle, cultural beliefs, ethnicity, or gender-specific factors. In developing countries, determinants like the social environment and the economic condition have a sufficient impact on the fall problem among the elderly population [15]. The environmental determinants such as the availability and access to services,

place of residence, or economic condition of the family in which the elderly lives should also be contemplated before designing a new approach towards such an intervention for elderly falls. In developing countries like India, it is critical to support health service providers, decision-makers, the elderly, the research community, and stakeholders to grow dissemination, production, and knowledge of elderly falls [15].

In India, elderly fall intervention should be obtainable in ways that are tailored realistically for the elderly, considering the resources available and India's cultural preferences. Exergame may shape the field of fall- a study in India's aging population, in a progressive way. As a fall-preventive measure in exercise, intervention stepping exercises significantly affect balance improvement [33]. The implication of self-paced activities is the most in need of interventions to improve adherence to exercise in overweight and sedentary adults [34]. Therefore, a design intervention in traditional exercise practice, i.e., Therapeutic Stepping Exergame, TSE, is introduced in the elderly Indian population to determine whether such interventions can benefit the elderly community in India in case of balance improvement, reducing FOF, and an increase in the balance confidence.

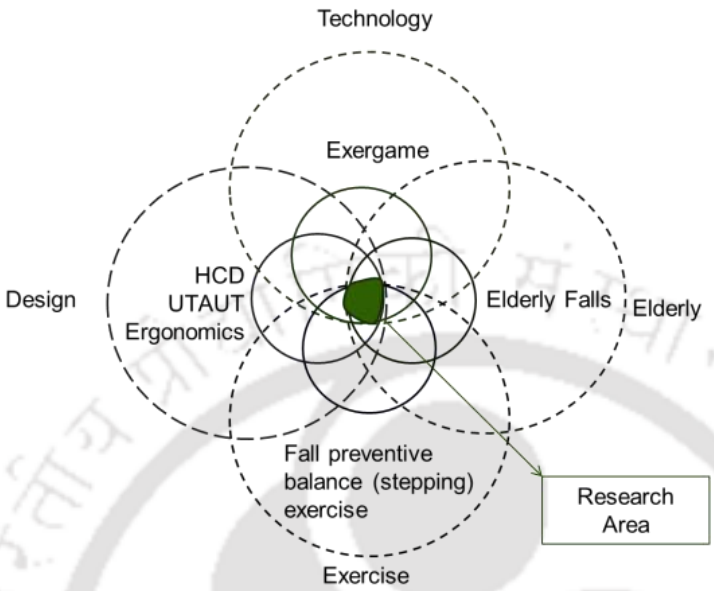
In the Indian context, as of our knowledge, no study is available about the elderly' acceptance and use of EXG for balance exercise and what key constructs they prefer for the use of EXG. Based on the insights gathered from experimental investigations and prototype development process reported in this thesis, design implications and heuristics towards developing TSE have been derived. These heuristics will be helpful for designers and researchers working in a similar field of research. Further investigations to test and validate these heuristics can be carried out as future work.

The research stages set for this thesis are:

1) To assess the effectiveness of the designed stepping exercise intervention in terms of balance confidence, fear of falling, and balance confidence in the Indian elderly.

2) To determine whether the Indian elderly will accept an effective intervention for balance exercise (stepping), typically designed in a specific context and culture- if they do, which variables are affecting it.
3) To formulate the design heuristics for exercise interventions in the Indian context that can bridge the gap between the elderly's non-adherence towards exercise and new technology in a self-motivated way.

The thesis is interdisciplinary, and it derives knowledge from the different domains: design, technology, exercise intervention, and elderly (see Figure 1. 1.)



Note: HCD- Human-Centric Design
UTAUT- Unified Theory of Acceptance and Use of Technology

Figure 1. 1. Knowledge domains of the research area of this thesis

1.2 Motivation and need for this research

The following are the motivation for undertaking the research.

Fall with able-bodied elderly (with no other physical impairment or disability) is maximum, which is 51.9% of fall and elderly with some physical disabilities/ impairments like visual impairment, hearing impairment, is reported approximately 11.1% for each, and elderly having mobility problems are mentioned as 22.2 %, as shown in Figure 1. 2 [13].

- In the literature review process, it is found that various factors are missing in the field of Indian elderly fall research. In balance exercise (here considering stepping), the elderly people feel bored, lazy, or doubting self-worth, leading to avoidance in exercising. Self-motivation in the elderly population is essential to minimize negative stereotypes in the elderly towards exercises.

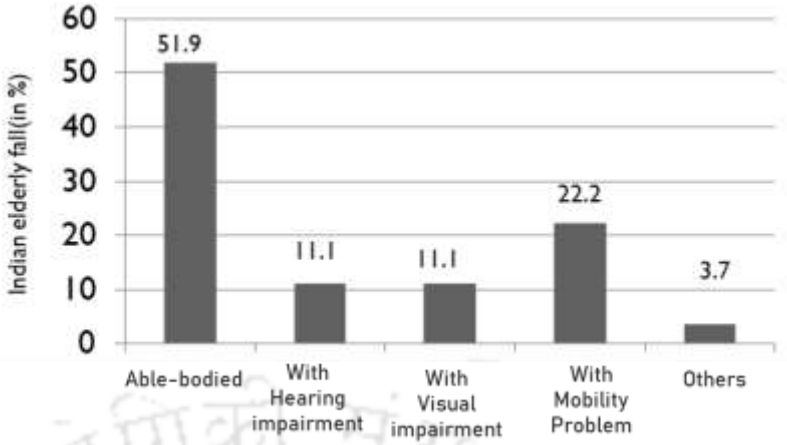


Figure 1. 2. Incidence of elderly fall in India

- In the EXG design process, elderly issues like physical limitations, cognitive load, and interest in the fall intervention have not been considered.
- It is essential to investigate the designed intervention with clinically approved tests.
- In the intervention design process, considering the Indian aspect of culture, the Indian elderly's perspective on fall intervention, feasibility, and the facilitatory situation in the household environment for fall intervention is required.
- The intervention needs the Indian elderly's acceptance and fulfills its usability aspects.
- Research gaps observed in literature need to be filled through conducting further research.
- It is essential to widen the possibility of using exergame as a measure for balance improvement by the elderly and enhance the knowledge in the field of elderly fall research in India.

Figure 1. 3 represents the various aspects from a different domain that cluster into the research area and motivation to carry the research further.

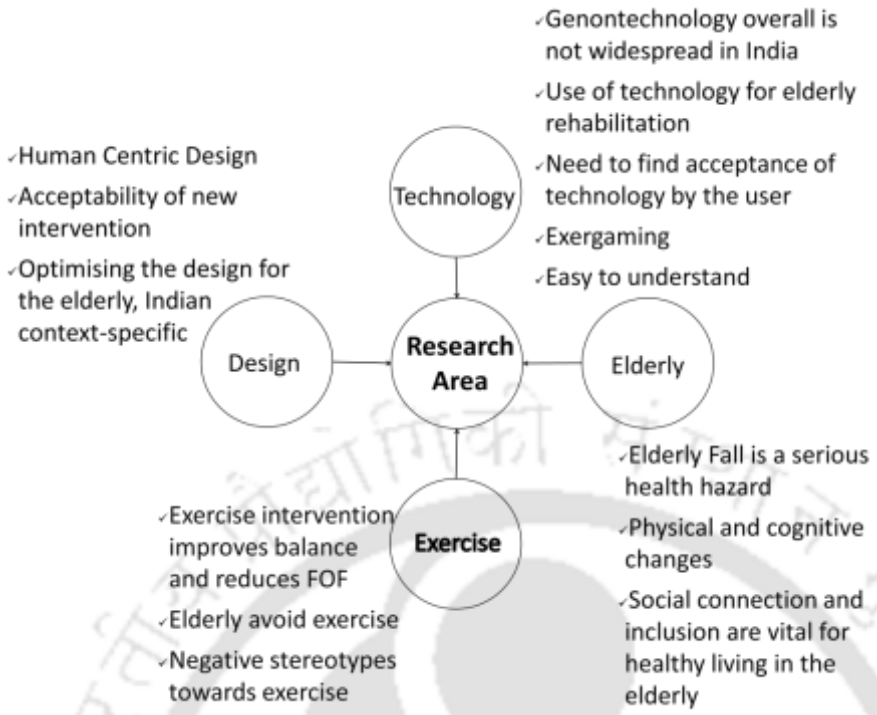
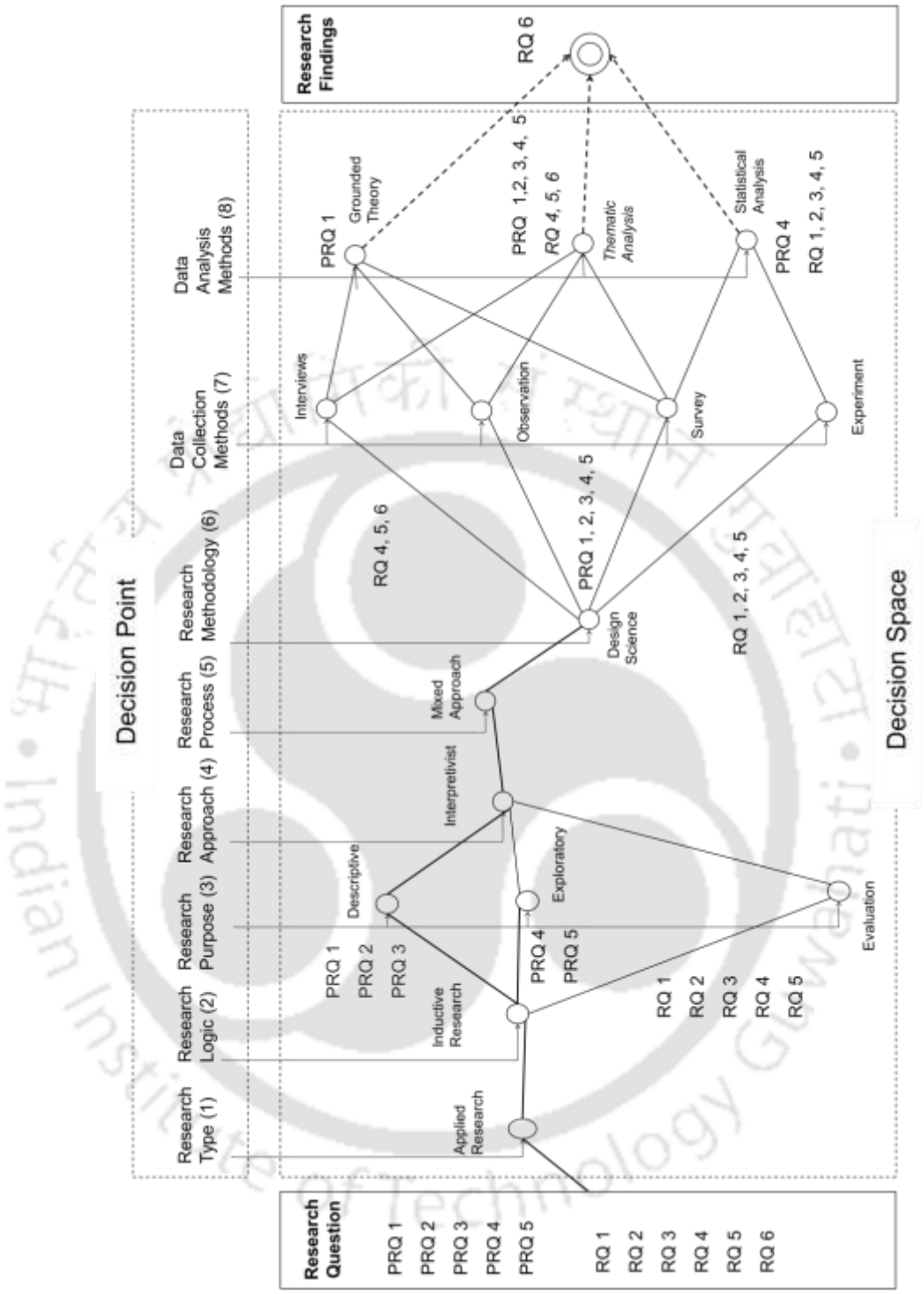


Figure 1. 3. Pictorial representation to represent the need of the RA (Research Area)

1.3 The methodology of the overall research

The research logic in this thesis is Inductive research. The research process is based on Mixed Methods, where there will be a combination of qualitative and quantitative analysis. It uses various measures of contextual understandings like interviews or observations along with statistics or facts. The research started with literature review as well as field study with research questions (few basic questions, termed as preliminary research questions (PRQ) that leads towards the gap and few more Research Questions (RQ)), PRQ, and RQ guides to collect empirical data which leads the research into generating a testable hypothesis. These hypotheses are confirmed with additional data. Figure 1. 4 shows the decision-making points used in this thesis adopted and how the research process is continued throughout the thesis [35, 36, 37].

In this research, initially, the literature on the elderly fall is studied through numerous research articles, books, review studies, and chapters with the help of published books, journals, and the internet. The search engines used for the research include Google Scholar, PubMed, Taylor & Francis Online, IEEE Xplorer, ACM digital library, Science Direct, Springer, and other digital libraries. After thoroughly understanding the numerous pieces of literature and analyzing the existing research gaps, few preliminary research questions were generated.



PRQ= Preliminary Research Question
RQ= Research Question

Figure 1. 4. The methodology of the research investigation in this thesis

A few field surveys have been conducted to bridge the difference between the literature and the current scenario of the elderly fall in the Indian context and re-research the existing research gap. An effort has been made to rectify

the problem that existed. The research activities are continued by understanding the fall interventions in the Indian background and studying the impact of existing intervention products, and understanding different aspects of the Indian elderly's acceptance as well as their balance improvement to avoid falls.

After thoroughly researching the existing gap in the elderly fall research, Exergame (EXG) has come out as a possible fall intervention in the Indian elderly. To evaluate whether EXG can be used as a fall intervention, a Therapeutic- Stepping- EXG (TSE) is designed using the Scratch game engine, open-source code device Mackey Mackey, and pressure sensors. Based on the preliminary experiments, user studies are conducted to validate the hypothesis by introducing the TSE prototype to the elderly in India. Finally, the TSE has been tested on 27 subjects (elderly in Indian); and results were analyzed, and hence inferences are drawn from the results.

The various phases of the overall research are shown in a diagram, Figure 1. 5.

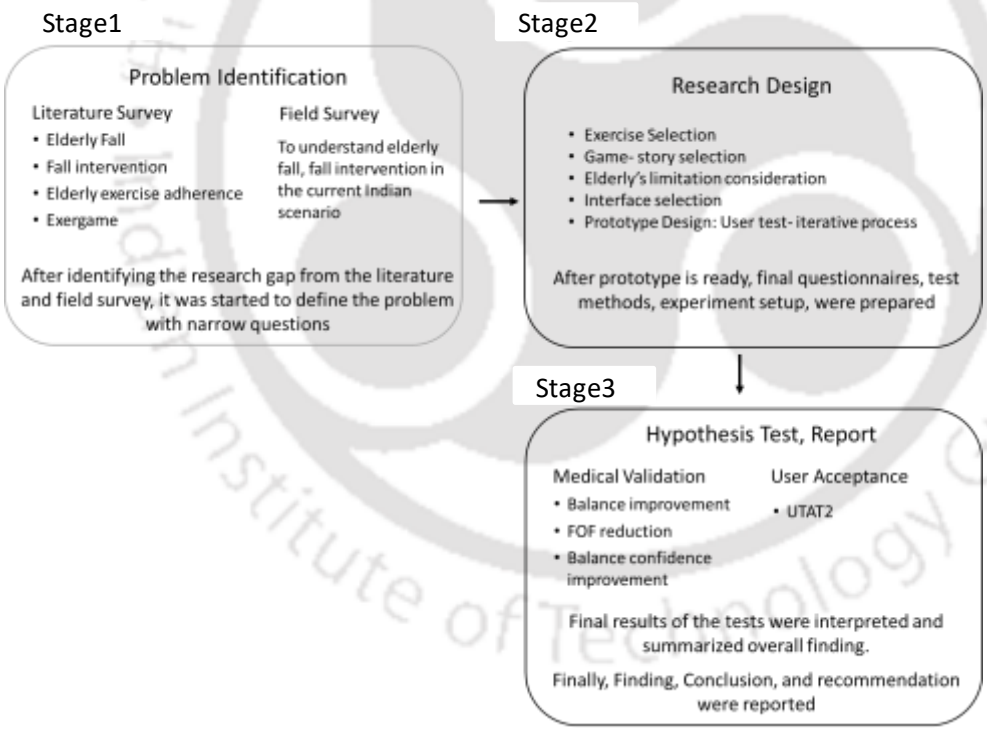


Figure 1. 5. The overall flow of the research

In the thesis, the descriptive statistics, such as means, standard deviation, and the test statistics, the obtained value of the tests has been reported. A total of 148 participants participated throughout the research at different phases (ethnographic study, N=72 (pilot study (PS) I); interview with doctors/ physiotherapist (PS2), N= 7, Questionnaire survey (PS3), N= 30;

User study with existing EXG (PS4), N=7; User (iterative) testing during prototype development, N= 5; User study with prototype TSE, N= 27). Among which 141 Indian elderly participants (senior citizen of India [4]) (Male= 77, Female= 64) and 7 are doctors/ physiotherapist. For the data analysis, SPSS (Statistical Packages for Social Sciences) is used as a statistical tool.

1.4 Thesis outline

Chapter 1: Introduction: Presents the interdisciplinary context of the thesis and also highlights the current issues, context background, and research motivation, and closes with the summaries of all thesis chapters.

Chapter 2: State of the Art Literature Review: The chapter outlines the systematic process of review of the literature and background literature of the study. It describes the research gaps and opportunities based on the review of the literature and field survey. The chapter also presents the research argument and questions formulated for further investigation in this thesis, further followed by the aim of the thesis

Chapter 3: Research Methodology and framework: This chapter presents the design research framework and outlines the experimental plan followed during the research.

Chapter 4: Concept Generation, Designing, and Prototyping Therapeutic Stepping- Exergame (TSE): In this chapter, discussion regarding the design modification of the TSE, its prototyping based on the feedback of participants on the Dance Dance Revolution (DDR), and the initial prototypes during the earlier experiments have been incorporated. The design modification of the TSE is to make it more relatable to the elderly in India and reduce discomfort reported by participants earlier and improve task performance. In addition to these, the chapter also discusses the working model of the prototype designed along with the functionalities, game stories, and features of TSE.

Chapter 5: Design Validation of the Newly Designed Stepping Exercise Tool TSE for elderly Balance Improvement, FOF, and Balance Confidence: This Chapter presents experiments conducted amongst a sample of the elderly population of India. This chapter addresses the initial three research questions of the thesis and completes the first three research objectives set for this research mentioned in chapter 2. It reports the statistical analysis of the data collected during the experiment. The design experiments are conducted to test the TSE prototype and validate the

working hypotheses. Detail discussion of the statistical results has been done. The results are discussed in light of the hypothesis.

Chapter 6: Validation of Inferential Guidelines through Technology Acceptance and Behavioural Intention study of TSE: It presents an evaluation process of the proposed design consideration of the TSE prototype. The experiment helps to evaluate the acceptability and key factors influencing the acceptability of TSE by the elderly in India. This chapter answers the research questions 4 to 6 of the thesis.

Chapter 7: Design implication and Heuristics towards designing Therapeutic Stepping- Exergame (TSE) for Indian Elderly: This chapter presents the design heuristics that can be implemented by future designers, HCI, interaction, and gerontechnology researchers in the design of EXG for the elderly. Elderly fall researchers can also use these to design fall preventive EXG in India.

Chapter 8: Discussion, Contributions, Limitations, and Future Study of the thesis: This chapter presents a detailed discussion of the thesis. It highlights the contributions of this thesis. The practical and theoretical implications of the results and their limitations are also elaborated in the chapter. Finally, it offers a future scope of the research with a conclusion.

Chapter 2. State of the Art-Literature Review

2.1 Introduction

A systematic search in the vast fields of literature is carried out. The purpose of the literature review is to understand the present state of the art and identify research opportunities. Various literature from the field of elderly fall interventions like exercise intervention in balance training and interventions in technology has been explored to understand how technology can be adopted and used innovatively in the elderly in a fall preventive way. Literature from elderly research, both physical and cognitive areas have been considered. Also, the literature on the elderly's attitude towards exercise has been reviewed to understand how the technologies can be used to form a new intervention in the exercise domain that is capable of improving elderly balance in the lower limb.

Figure 2. 1shows the highlights of the literature review process to identify the research gaps. To gain relevant insights, a comprehensive study is done from different published literature studies, journals, articles, books, reports that belonged to various knowledge pertinent domains for this thesis. The searched research areas are categorized into seven areas, depicted as in Figure 2. 1.

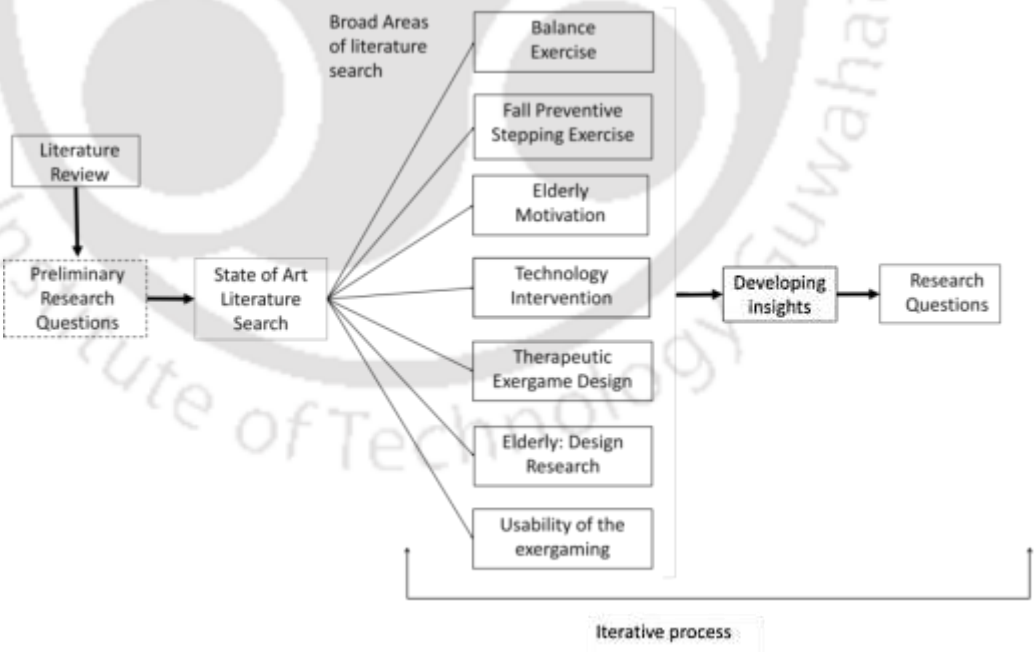


Figure 2. 1. Systematic Literature Review

2.2 Background of the research

Population aging, which entails an increasing share of older persons in the population, is an emerging demographic trend of the twenty-first century across the world. The increased longevity along with improved healthcare and declining fertility have jointly increased the population of 60 years and above persons, defined as "Senior citizen" or "Elderly" ("National Policy on Older persons' in January," Government of India, 1999) [38, 39]. Globally the number of elderly populations increased from 9.2 % in 1990 to 11.7 % in 2013, and it is predicted to reach around 21.1 % by 2050 [40]. In India, most of the population aged less than 30 years, so the problems and issues related to the elderly have not been taken seriously, and only a little study has been attempted in our country [38]. The elderly population of India is likely to grow over the years from 7.4% (in 2001) to 12% (in 2031) and 17% (in 2051) [41]. There is an emerging need to pay more attention to health issues in the geriatric population of Indian society.

2.2.1 Elderly Fall

> *"Fall is defined as "inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest in furniture, wall or other objects. Falls is coded as E880-E888 in International Classification of Disease-9 (ICD-9), and as W00-W19 in ICD-10, which include a wide range of falls, including those on the same level, upper level, and other unspecified falls"* [7].

Fall is one of the most critical and common events in the aging population, limiting their ability to remain active and self-sufficient. If fall remained unnoticed for prolong duration, this might lead to death. Fall causing accidents and death is more common than any other cause of accidents; it is a significant cause of disability, pain, loss of independence, and even premature death. Fall causing injuries are the sixth leading cause of death in the elderly (65 years and above), and falls are the leading cause of injuries [15]. Age-related changes in cognitive, sensory, and psychomotor ability affect balance control mechanisms and postural reflexes, etc., resulting in impaired mobility. Due to these, the risk of tripping, injury increases, and the elderly become more prone to fall while crossing roads or walking on the uneven footpath [12].

Fall research in the International scenario

Around 75% of accidents occurred in homes, with 34% of falls, followed by some fracture [42]. In the elderly, 95% of hip fracture results from falls;

fall in the home result in hip fracture cases seen among elderly males is 63.5% and in the female 80.6% [15]. Falls lead to mild-to-severe injuries (20% to 30%) and emergency department visits (10- 15%) [43].

The incidence of falls increases with age and frailty level. Approximately 35 -45 % of elderly (aged 65 and over) fall each year [44], and 32-42% are of age over 70 years [7]. After a fall occur, around 23 % of injury-related deaths happen in the elderly of age 65 years and 34 % in those over 85 years of age [45]. Fall with able-bodied elderly (with no other physical impairment or disability) is the maximum, which is 51.9% of fall and elderly with some physical disabilities/ impairments like visual impairment, hearing impairment, is reported approximately 11.1% for each, and elderly having mobility problems as 22.2% [26]. The incidence of falls varies among countries. For instance, in China, 6- 31% of elderly fall each, whereas in Japan, it is 20 %, while in America (Caribbean region/ Latin) found the percentage of elderly who have fallen each year ranges from 21.6% in Barbados to 34% in Chile [7]. Among the elderly, due to their vulnerability in routine tasks performed in the home, causes 75% of accidents and 34% of falls followed by some fracture [42].

Fall research in the Indian scenario

The elderly fall problem is also a severe concern in India too. There are varying reports of fall prevalence in the elderly in India. In the Indian elderly, the incidence of falls ranges from 14% to 53% over the years (2003-2011) [27]. Every year, nearly 1.5 to 2 million people are injured in India, and 1 million died, and 20%-25% are due to fall, causing traumatic brain injuries [17]. The soft tissue injury is around 28.4%, and other injuries where physical treatment is required is 47.37%; a study showed elderly women fell 47% whereas, men fell 31.2%, and fall causing fear among the elderly is 52.8%, and 30.6% reported activity restriction mostly outdoor [43]. Fear of falling is related to the gait and balance of the elderly, which will increase the risk of falls [21]. Literature showed that in India, the elderly with some mobility assistance (mobility aids or personal assistance) fell more 58.6 %, compared to the elderly without mobility aid that is 34.2%; place, where maximum fall occurred, are road 30.5%, bathroom/ toilet 21.1%, and most prevalent causes for fall are slipped 44.2% and trips 25.3% [43]. In Northern India (2000) (Rural population of Haryana State of India and Chandigarh City) reported that due to falling fractures among females are 26.4% are stated more frequently than males, that is 16%, and fractures are reported more in urban subjects, that is 29.4% in comparison to the rural subjects, 13.4% [17]. A study conducted by Kerala Aging

Survey (KAS) showed that falls and fractures are a significant issue among the elderly (60 - 100 years), and 54% of them are female [17].

In developing countries like India, the socioeconomic risk factor is also one of the significant reasons for falls and related injuries. The low education level and income, lack of community resources, inadequate housing, lack of social interactions and social services, and limited access to health care [27] are a few examples of such factors.

Fall risk factors/ determinants

Fall and its related injuries are directly or indirectly associated with different factors. Like socioeconomic risk factors, environmental risk factors, behavioral risk factors, and biological factors. These factors are classified as "intrinsic" and "extrinsic" factors [17].

The intrinsic factors include muscle weakness, especially in the legs, impaired balance and gait, vision problem, cardiovascular disease, hypertension, diabetes, osteoarthritis, cognitive impairment**,** depression, sensory impairments, urinary incontinence, postural hypotension, history of previous falls, vitamin D supplementation, being underweight or overweight with severe poly-neuropathy, certain medications which cause dizziness, alcohol utilization [46, 47, 48].

The extrinsic risk factors include wet, slippery, or uneven floors or surface (kitchen, bedroom, bathroom, bathtub), stairway, bumpers and curbs, poor lighting, electrical cords, inappropriate eyewear usage, even everyday activities such as transferring on and off beds, chairs, and armchairs without handrails, lack of bathroom and toilet grab bars, tripping over rugs, carpets or door thresholds, decreased illumination and unsuitable footwear [46, 49, 50].

Determinants in Elderly Fall the Indian Scenario

India is a developing country. There are various determinants, which a researcher has to consider before considering any design intervention in the Indian context for the elderly.

Economic determinants

Lower-income is associated with an increased risk of falling; the elderly People of the lower-income group are associated with an increased risk of falling; the elderly female living alone or in rural areas with inadequate revenues face an increased risk of falls [7]. The poor living environment and poor diet lead to the fact that they cannot access health care facilities even when they are suffering from severe illness, which exacerbates the

risk of falling. The adverse phase of poverty is evident in rural areas and developing countries [7].

The estimated mean cost (US-based) of fall is around US$10,749 per fall, US$3476 per faller, and US$26,483 per fall required for the hospital admission [46]. Though in India, such statistics are not available [18], it is evident that a large amount of money got invested in the fall problem. So, fall-related injuries may increase the economic burden of caregivers: as in India, most of cases family members are acting as a caregiver, and affect a person's savings. In India, a large percentage of 30% of them are below the poverty line, and 80% of the total elderly population stays in rural areas [22]. Around 65% of the elderly are economically dependent on others, especially widowed women, employees of the private sector may or may not get retirement benefits and pensions [43]. In such cases, the elderly became financially dependent on someone else. Long-term physical and financial dependence can increase the risk of abuse, depression, and neglect in the elderly [17].

Determinants related to the social environment

It is reported by WHO that inclusion and social connection are vital for healthy living in the elderly. Social interaction is contrariwise associated with fall risks. Loneliness and isolation are usually experienced by the elderly, especially those who live alone or lose their spouses. Lack of social participation leads to isolation and depression be, which might trigger a rising FOF and vice versa. FOF can increase fall risks and reduce social involvement that leads to loss of personal contact that causes an increase in isolation and depression. Literature suggests that social support and opportunities for the elderly, participation in social activities, help them maintain active interaction with others and decrease their risk of falls. A tailored approach, either personal or group contexts – can significantly improve the chance of the elderly engaging and maintaining an intervention program [7]. The following pictorial diagram shows different risk factors for in elderly; see Figure 2. 2.

A practical approach towards elderly fall might minimize the fall risk and reduce its severe injuries. Limitation in physical ability affects the functional quality-of-life and independence of an older adult. It is necessary to focus on more intervention approaches because serious falls/ sudden injury appear to be amenable to the low-intensity environment/ behavioral efforts. So, in the next section, fall-related available interventions are briefly mentioned.

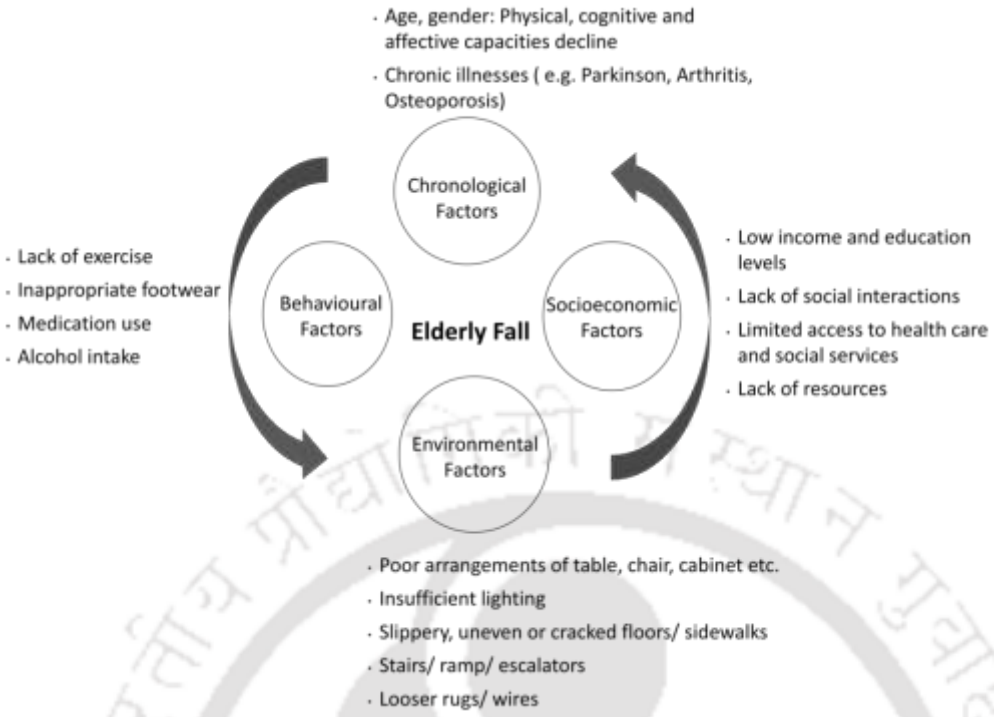


Figure 2. 2. Summary of fall risk factor

2.2.2 Fall Interventions

Fall interventions are designed based on the purpose of elderly falls (risk factors for fall) to minimize the further adverse effect of it in the elderly. Diverse studies have established various fall interventions based on fall risk factors, which includes: (i) individual management, i.e., addressing patient-specific factors, (ii) getting up training after fall, (iii) reducing medication appropriately, (iv) education regarding safer behavior strategies like avoiding hurry, addressing fear of falling, (v) reducing environmental hazards, and (vi) exercise programs to improve aerobic capacity, balance, and strength, (vi) technology system, assistance.

The fall problems can be avoided by preventive programs that include either taking precautions, being aware of safety behavior, modifying architecture. Accidents that the elderly might be exposed to could be prevented by family directions and few physical changes in the space of a household environment. With this modification, it is possible to enhance an older adult's quality of life from the perspective of safety, comfort, physical and social health. In the population of the elderly, the utmost critical risk factors for falls are the weakness of muscle and problems with balance and gait [13, 14]. Effective fall prevention interventions like muscle strengthening and balance retraining programs (e.g., Tai Chi) can address the intrinsic risk factors like an impaired neuromuscular function by

improving flexibility, leg strength, and balance [24, 27, 51, 26]. So, keeping active the lower body muscle, especially with physical activities, exercise, etc. With the help of technological assistance, the elderly can get immediate attention if they fall. Canes and walkers are used for centuries without high-cost or negative side effects with excellent clinical results [27]. However, the use of low-technology devices (canes, walkers) is a debatable issue. The literature suggested that mobility aids have been identified as a risk for falls or related to fall-related injury [43]. Other interventions that can be used to reduce fall or after fall effect, such as, use of sole sensor insole, hip protectors, vibrating insoles to facilitate plantar cutaneous sensation (a phenomenon of stochastic resonance), vinyl railing, vitamin D supplement, dietary amendments and supplementation, Yaktrax walker (specific shoe), technology interventions such as: speedy (a wrist- wearable watch-like fall detector), home monitoring system based on ZigBee wireless sensors, fall detection, airbag based fall-detection systems etc. [24, 52, 27, 53, 54, 55, 56, 57, 58]. Figure 2. 3. Summary of fall intervention, as represented below.

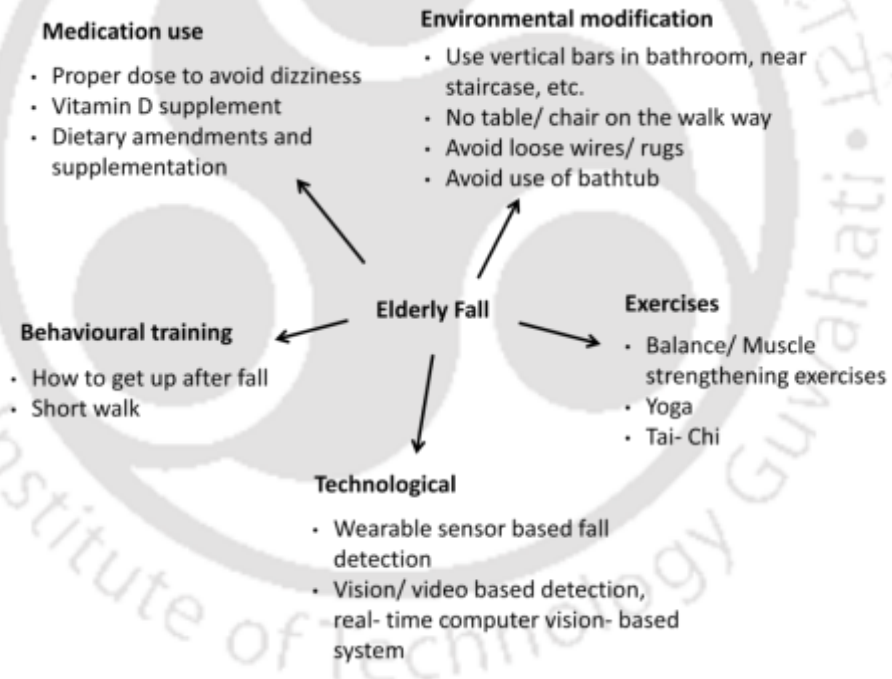


Figure 2. 3. Summary of fall intervention

To minimize the fall and related injuries in the elderly is to minimize the environmental hazards, with the help of addressing architectural modifications. Environment support can reduce these difficulties [59]. Some of the guidelines that can minimize falls through environmental modifications from the studies carried out in the western country are described below.

A study [60], mentioned the two vertical bars configuration in *bathroom/ toilet-related* that is considered as the most effective toilet grab-bar configuration for preventing fall, the height of it must consider the shortest adult can reach, and tallest is to be avoided head knocking [61]. A study suggested [42] in *the kitchen area and cupboards,* lower cabinets should have enough space to move the legs or wheelchair when necessary, and drawers should add safety lockers. Such precautions can minimize falls in the elderly. In *furniture and cabinets*, the elderly should avoid or change rickety chairs and stools to prevent falls [42]. It is also essential that the elderly should give attention while stepping on chairs or stools, leaning on tables or chairs, or any appliances that might be a risk during a stand-up. For *Lighting, s*witches should be placed so that it is easily accessible by the elderly. Tre must have proper lighting for the elderly to minimize injuries and most-fall issues due to lesser eyesight in the elderly [42].

Apart from environmental modification, exercise interventions help the elderly to prevent falls. The exercise intervention, such as muscle strengthening and balance retraining programs, can improve flexibility, leg strength, and balance for fall prevention as well as has motivational outcome [26, 27, 34, 62]. The balance Training (BT) method improves healthy older adults' balance performance [63]. It is seen that stepping exercises have a significant impact on balance improvement [33]. The implication of self-paced exercises for exercise prescription can help, especially among sedentary adults, overweight people, who are most in need of effective interventions to improve adherence to exercise programs [64]. Although the elderly are aware of the positive impact of exercises, the elderly avoid doing exercises at recommended levels due to the negative aging stereotypes (negative self-views such as physical self-worth) [30, 28, 65, 66]. In the exercise domain, there is a need for further refinement of traditional balance training and balance assessment techniques to prevent elderly falls [67].

Technological interventions, such as fall detection system, or monitoring systems, can reduce post-fall problems encountered by older adults. It can differentiate an elderly's active daily life activities with falls accurately and can contact an ambulance or send a message or trigger alarm when necessary. Fall detection technology may include sensors, cameras mounted on wearables in a particular location with a tiny computer to sense, process, and storage and communicate the input and output data. It can be roughly categorized into three techniques, wearable sensor-based, vision or video-based detection, and detection through a mixed approach. The pictorial representation of the operational units related to the methods of obtaining and processing the situational data from cameras or sensors is

shown in Figure 2. 4. For example, if a camera or wearable sensors detect elderly falls, data can be processed using a segmentation algorithm to recognize all the features captured in the real-time accidental scene; simultaneously, it may transmit the information for confirmatory testing. The results- along with the appropriate response (like an alert for immediate help required or elderly fall is detected), a signal can be generated for communication to the hospital in real-time that can potentially save a life or communicate to the user's family and friends or for remote health monitoring.

Fall detection or monitoring system are based on various sampling techniques to detect older adults' falls and differentiate them from the activities of their daily life. The detection process can be classified through signal sampling techniques, which includes Video Technology (using the camera), Wearable Sensor Technology (gyroscope, accelerometer, etc.), Environmental Sensor Technology (pressure sensor, Doppler radar sensor, etc.), Mixed Approach (a combination of any or all of the techniques) [68, 55, 69, 70, 71, 72, 73, 74].

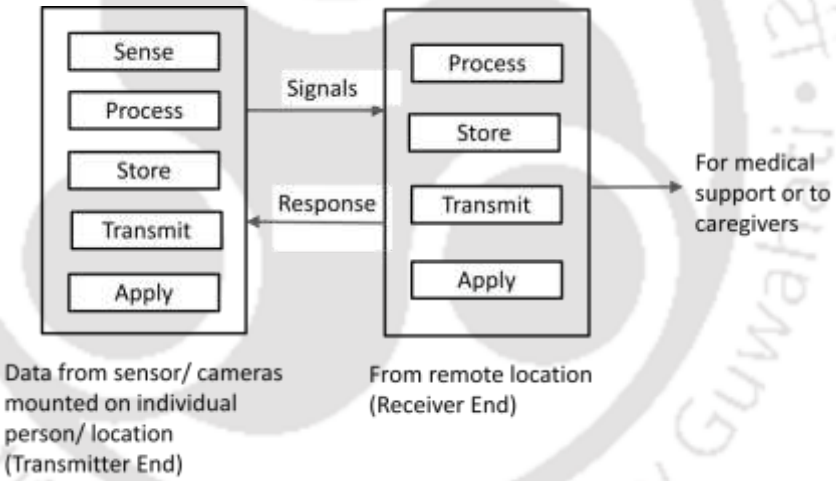


Figure 2. 4. A Pictorial summary of processing data using sensors/ cameras

Video-based fall detection technique has a limited detection range with a weak script, and there is a risk of disclosing the elderly's privacy. In the wearable fall detection methods, sensors are mounted on clothes, glasses, hats, shoes, etc. In the Environmental based fall detection method, sensors are mounted on locations like ceiling, ground, and floor. This method can overcome the privacy problem but has little accuracy. In a mixed approach, two or more techniques and multi-sensors are used to detect the fall. It is found that the wearable sensor-based fall detection system is more suitable as there will be no limitations of the detection location [68]. Different studies have been done based on the environmental sensor, wearable

technology, video fed technology, and mixed approach method, e.g., accelerometer, Arduino board, sensors, etc. The studies showed multiple different classifiers based on fall detection via an accelerometer [55, 71, 18]. In the case of remote health monitoring, the diagnostic system can be implemented on a wearable Shimmer device, and if a fall occurred, the base station receiver triggers an alarm with a source like a hospital or a designated carer and can get a response or required medical aid. The technological interventions are mostly post-fall interventions, apart from a few that promote exercise like exergaming. Exergaming is a technology that is based on developing exercises using gaming. Younger generations widely use it; in the recent decade, the elderly have also shown interest in them. A more in-depth study is needed in Exergaming technology as an elderly fall intervention, since the existing exergame like DDR, Wii, etc., are not explicitly designed for the elderly [75, 76]. In the Indian context, elderly and exergaming related researches are not found (as per our knowledge), so further investigation is required.

Few of the previous studies are showcased in the next section and showed in Table 2. 1. The table discusses interventions like technology, behavioral, exercise, etc., for fall detection classifiers, exercises like yoga and group assessment are concisely showcased.

Table 2. 1. Summary of selected literature on Fall Intervention

Sl. No.	Aim	Place	Mode of Intervention	Study Details	Comments Findings/ Comments/ Limitation
1	To see the effectiveness of the tailored group, individualized, and home-based exercise intervention designed to improve leg strength and core and dynamic balance[154]	London, United Kingdom	Falls Management Exercise (FaME) Intervention	Participants: 81women Age: 65 years and above Exercise group (50 women) and control group (31 women)	Fall rate reduced by 54%
2	For gait, mobility and balance improvement for elderly staying at home [77]	India	Yoga and a poly-herbal Ayurveda preparation	Participants: 69 Age:60-95 years The yoga session:75 minutes daily, for six days a week, Ayurveda group: 'Rejuvenating Tonic' that is a "Rasayana Kalpa" (poly-herbal preparation)	Among rheumatoid arthritis patients, yoga has improved their joint mobility, and it is also stated that the changes in the Ayurveda group may also improve sensory perception and their muscle strength
3	To give a review on the topic: accidental injury caused due to falling in the geriatric population [52]	India	Guidelines for Physical Exercises	Review Based 14 studies (1977-1991)	Walking is the most applicable aerobic exercise. Before aerobic body should be warm-up for 10-15 minutes. Along with that, for elderly water exercises arc best-allowing movement with low impact on diseased joints &bones
4	To improve muscle strength, balance and aerobic capacity, reaction time, and coordination [155]	Southwest Sydney, Australia	Group exercise to improve balance	Participants: 16;5 Age: 65 years and above Duration: 1-hr., once a week over one year, a total of 37	The proportion of falls is 40% lower in the intervention group than the control group within 12 months trial period

Sl. No.	Aim	Place	Mode of Intervention	Study Details	Comments Findings/ Comments/ Limitation
5	To increase endurance, improve strength, balance, and mobility using a low- to a moderate-intensity exercise [62]	Los Angeles, California, United States	Group exercise program	Participants: 59; Age: 70 years and above Control group, n=28, experimental group, n= 31;12-week group exercise program 90 minutes, three times per week	A program of balance training, progressive resistance exercises, walking can enhance functional mobility and muscle endurance among older men with risk factors for falls and chronic impairments.
6	To keep the workplace safe [47]	_____	Recommend ation	_____	Walking speed: Should not be too fast. Gait: To walk like a penguin with a short stride that is pointing the toes slightly to the sides
7	To study the effectiveness of Tai Chi program (community-based) in reducing falls in the elderly [81]	Sydney, Australia	Tai Chi Trial	Participants: 702, of age 60 years and above Duration: Sixteen-weeks (community-based program); 1-hour period per week	In tai chi group falls seen less frequently than the control group
8	To detect fall by using an accelerometer, microprocessor, and wireless communication system [68]	China	Fall detection algorithm	Participants: 10, of age 60 years and above Experimental design: 50 sets of trials Algorithm: It analyses the threshold ranges of the energy of different actions with a different angle for auxiliary criterion, displacement, and temporal speed	In low-intensity, daily activities, falling actions are identified very efficiently In the case of high activity intensity, daily activities, falling actions are identified relatively difficultly There are a few false judgments during fall action without lying down and slipping action

Sl. No.	Aim	Place	Mode of Intervention	Study Details	Comments Findings/ Comments/ Limitation
9	To evaluate low-complexity fall using accelerometers attached at the wrist, waist, head [74]	Finland	Fall detection algorithm	Participants: 1 female of 38 years and 2 men with 42 and 48 years (although the participants are adults not elderly, the target population of the study is geriatric) Experimental design: Participants executed 3 directional falls (intentional) to a mattress (thickness 20 cm)	Accelerometer (tri-axial) worn at the head or waist: The threshold-based algorithms are used for the fall detection, it is simple and efficient with 100% specificity and 97-98% sensitivity In the waist-worn fall detectors (accelerometer) algorithm, recognize the after fall impact and posture, and detection is optimal. Limitations: Acceptance and Usability: Head-worn device and wrist-worn is not found to be an applicable site
10	To detect a fall using Real-Time Locating System (RTLS) [58]	USA	Real-Time Locating Systems (RTLS)	Participant: One female (30 yr.s) Experimental design of 2 phased trials. In Phase1 mannequin is used; in Phase2 human subject is used	Here human falls accurately identified a percentage of 80% and mannequin falls of 89%
11	Use of two pulses Doppler Range Control Radars (RCR) for fall detection [156]	USA	Doppler radar-based fall detection system	Experimental design: Samples: 450 divided into 2 classes: (1)Falls, (2) Non-falls. In the study to detect falls (any direction) more than a single sensor is used	Results : (1) Falls: 109, (2) Non-fall:3 41

Sl. No.	Aim	Place	Mode of Intervention	Study Details	Comments Findings/ Comments/ Limitation
12	A study to reduce false fall alarms [56]	Italy	Personal Emergency Response System (PERS)	Participant: 2 female of age 33 and 60 years, and 5 male of age range 20-67 years Experimental design: Includes fall-like actions: 86 Running/ Jumping/ Walking: 14 Lying/ Sitting: 14 Falls: 44 Hitting sensor (unintended): 14	Monitors: Movements of patients, recognizes a fall, and automatically sends a request for help to the caregivers Result: Distinguished false alarms 100% from real fall
13	Study of an automatic fall detection system (indoor environment) addressing privacy [69]	Italy	Depth-Based Fall Detection System	Experimental design: On-ceiling: Depth sensor (to analyze depth frames) Monitor the environment: Camera Algorithm (fall detection): Ad-Hoc segmentation	Results: It recognizes human during a fall. It is also effective in a complicated scenario, like when interacting with objects. The study shows the potentiality of the blob fusions in the depth-based algorithm
14	To develop a fall detection system based on a mobile application with a wearable sensor unit, and a website [73]	Portugal	The smartphone-based fall detection system	Participant: 1 (age not revealed) Experimental design: Executed forward, side, and backward falls; and falls from walking, chair, standing, running, and sitting that is, activities of daily living (ADL)	Result: No false positives are detected, and if it detects fall, in the 30s a pop-up window appears on the screen

Sl. No.	Aim	Place	Mode of Intervention	Study Details	Comments Findings/ Comments/ Limitation
15	To propose a Kinect sensor-based fall detection system [70]	China	Depth-Based Fall Detection	Experimental design: Kinect sensor is used to record the video (for depth sequence)then using the horizontal and vertical projection histogram statistics the depth of the images are converted to the disparity map	Result: Detection of fall is effective

2.2.3 The role of Fall Interventions in the Indian context:

2.2.3.1 Literature Review

In India, falls are a significant problem among the elderly [52]. Most studies are related to muscle strength and balance improvement; only a handful of studies are done in architectural and technology intervention associated with elderly fall problems. A study [77] with a poly-herbal Ayurveda preparation and Yoga has done for mobility improvement, gait, and balance for the elderly staying at home. Results indicated Yoga had improved the mobility in joints among rheumatoid arthritis patients. It is also stated that as hypothesized in traditional Ayurveda texts, the improvement in muscle strength and changes in better sensory perception in the Ayurveda group could be related to the "Rasayana Kalpa," Table 2. 1.

A review study [52] suggested that walking is the most appropriate aerobic exercise, and along with that, exercises allowing movement with low impact on diseased joints & bones are effective. Another review [17] indicated that exercise, Tai Chi, medication review, vision correction, and environmental modifications are effective in randomized control trials.

Another study was conducted [78] in visual perception, depth perception, and balance training among 20 elderly (60 years and above). A total of fifteen subjects (8 females and seven males) are re-evaluated (5 participants quit) on all three assessments. The activities for balance training, depth perception, and visual perception lasted for six weeks. The participants are tested on the Timed up and Go test (TUG), a depth perception instrument, and Test of Visual Perceptual Skills (TVPS), before and after the remedial program. Results showed that intervention improved confidence for outdoor activities, visual understanding, sense of well-being. A review study [55] mentioned a tri-axial accelerometer to measure dynamic and static acceleration (principal component), various sensors, and systems in the technological intervention. Tri-axial accelerometers capture human motion, monitor them, and senses tilt in X, Y, and Z axes (3 directions) by real-time detection of acceleration and the three degrees of freedom measuring acceleration, rotation, and translation due to gravity. A fall detection system designed for geriatric and its associated problems like ectopic of heart, Parkinson's disease, vestibulocochlear defects, etc. [18]. In this study, the fall detection system showed 96% accuracy. The concept is to send an alarm to the doctor or the concerned person when needed. While detecting fall or not, body posture derived from the acceleration change in three axes is measured using the triaxial accelerometer. Out of

50 trials, the developed prototype showed zero false alarms for daily activities like skipping, jogging, picking up objects, and walking on stairs.

Implementation of the interventions has its advantages and disadvantages. In technology interventions, the disadvantages literature has mentioned difficulties in using assistive technology, technology malfunction, lack of competence or training, lack of financial resources, privacy disquiet, acceptance of such technology, etc. [72, 79]. The main advantages of fall detectors with wearable sensors are portability and cost-effectiveness. Nevertheless, these sensors reduce the user's mobility since the device has to put on the individual's body, and it may get disconnected if the wires are poorly connected. So, older adults might feel the discomfort of wearing the gadget, and they may forget to wear it always. Other disadvantages include privacy issues, a limited field of view, non-portability, vulnerability to environmental noises, and maintenance charges if installed in smart homes. Though privacy issue is an essential factor for acceptance, it is found that 87% of respondents, from a study, are willing to give up their privacy to get help during fall and emergency [79]. Perceived ease of use and perceived usefulness of the technology are key influencing factors to facilitate the condition [80]. In order to overcome the elderly's inhibition towards technology-based products in India, it is essential to revisit the existing techniques used and to redefine the technologies used for fall intervention so that we can link the gap and can offer social and cognitive support to the elderly people as well as their family members with advanced technology [22]. So, design intervention considering technology assistance can be further studied in India. In terms of exercise interventions, training programs, and exercises like yoga, tai- chi are mainly for muscle strengthening purpose that needs a long-term course. Group sessions with trained-balance and muscle strength-exercises, for example, tai-chi, yoga, etc., relatively low-tech and affordable interventions can be accepted within the societies [81]. Although more research is necessary, and many elderly people may prefer exercises delivered at home with some professional guidance [7]. It is essential to study the end-user's actual need and which mode/s of fall intervention is preferred in the Indian context.

2.2.3.2 Preliminary Research Questions (PRQ)

To understand the elderly fall problem in the Indian context, more in-depth information is required; for that reason, primary data collection is needed. A few preliminary research questions (PRQ) arise from the systematic literature, which are not answered in detail by the previous studies; for that purpose, secondary data collection is done. The literature review leads

towards PRQ 1 and 2, for which a field investigation is done with the elderly population of India and practiced physicians. The detailed interview with them guided us towards our 3rd PRQ, which is further researched with the help of existing literature review and field research; that leads to the 4th and 5th PRQ. On further investigation, light is spread on the gap of the present problem for elderly fall research in India. The visual summary of the process is shown in Figure 2. 5 and Figure 2. 6.

The PRQ are:

1) What are the salient factors that influence the elderly's Perception of Fall and related Interventions in India?
2) What are the available interventions for the elderly fall prescribed by doctors/physiotherapists and the views on the elderly regarding their avoidance of exercise?
3) What are the possibilities available to motivate the elderly towards exercise?
4) What are the attributes the elderly will consider in India for the technology-based intervention for fall?
5) What will be the responses of the elderly in India to the existing exergames?

The detailed studies to answer the PRQs are explained in the next section.

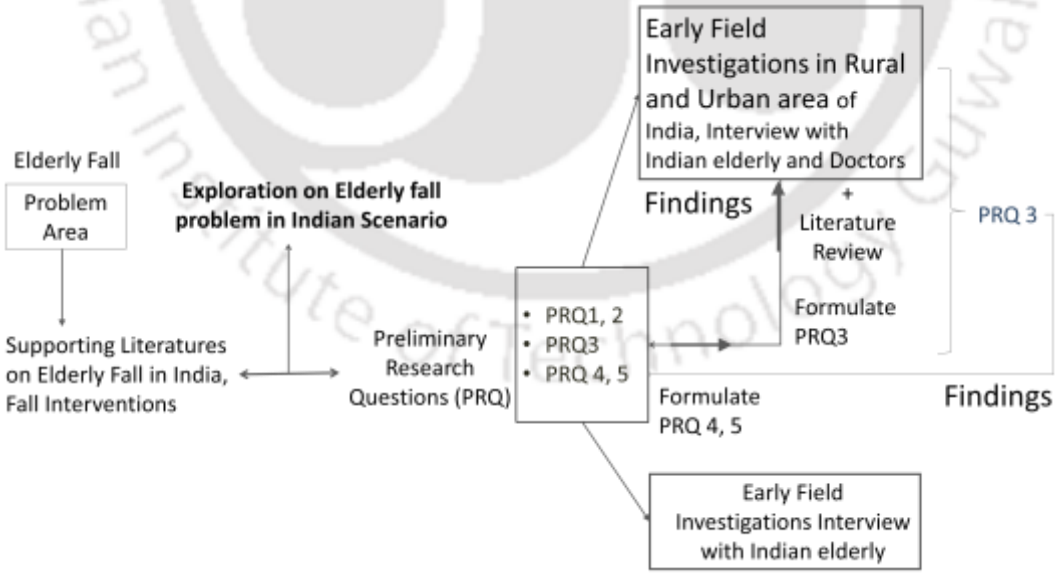


Figure 2. 5. Visual representation of the process of generating preliminary research questions (PRQ)

2.2.4 PRQ1.: Pilot study-I

Restating PRQ

1. *What are the salient factors that influence the elderly's Perception of Fall and related Interventions in India?*

Introduction

The elderly fall is defined as an event, which leads the elderly to rest on the floor or ground or other lower-level unintentionally [7]. The elderly fall studies are mostly done in developed countries [82]. India has a diverse culture; the economic and social arrangement is much different from the developed countries. Understanding the insight aspects affecting the elderly fall and its associated intervention will help this research in India from a broader perspective. It is essential to determine the elderly's perspective on fall problems and the kind of measures (fall intervention) usually taken by them (if any).

Aim: This study aims to understand the salient factors that influence the elderly's perception of falls and their related Interventions in India.

Participants selection and study methods

A pilot study has been carried out with the senior citizens of India. Participants are randomly selected samples from a different geographical location (rural, suburb, and urban) of India. The total sample size, N=72, with 37 female and 35 male participants of the age ranged from 60 years to 95 years old with a mean of 71·6 years and a standard deviation of 8·9 years. Among the sample, 51·4% are women with a mean age of 71·4 years. The number of participants from an urban area is 20, the village is 17, and the suburb area is 35.

Contextual Inquiry, direct observation methodologies are used to gather data and data analysis. Participants are made comfortable, and each interview is carried out in the participant's house. A set of predetermined open-ended questions are asked based on the knowledge gained from the existing literature. The participants are verbally informed regarding the research purpose, and photographs are taken when necessary; there are no audio or video recordings as they feel more comfortable talking without it. It is a semi-structured interview that is transcribed, and each interview lasts for an hour. Each of the conversations started with general questions to make the participant more comfortable for the discussion. Additional questions are asked to extract more information when needed (Annexure A2). Questions regarding the number of family members and how many earning members are there in the family are also asked and the source of

their income. In the process, some data are explored through initial open coding, and tentative linkages are established between categories and then returns to the field to collect further data. Data collection is progressively focused and informed by the emerging theory. The everyday life activities, walking aids (if any), the lifestyle arrangements (family structure, earning members, necessities and accommodation arrangement, etc.) are keenly observed. Additional issues like walking habits in mud, water clogging problems in the rainy season are also discussed.

Data analysis

Data analysis is done using grounded theory and thematic analysis, as described in the literature [36, 35]. The transcript data are read several times and highlighted the relevant materials accordingly, and initially, coding is done independently to summarize the data. Further, the transcripts are assigned codes based on key questions. In some cases, the same segment of text is assigned more than one code. Refinement of codes is done based on emergent categories or themes through discussions among investigators as needed. Based on financial condition, family structure, and geographical location, some of the responses' similarity is seen within and among the final coding groups. Income groups varied among "Rural, Suburb and Urban Area," as financial expenses are different among these geographical areas. The total revenue and total expenditure per person may deviate, depending on where they live. The number of family members also plays a vital role in the quality of living as total revenue might not fulfill the family's total expenditure per month. The coding for the economic income category is done based solely on the participants' interview responses regarding the questions of their number of family members versus the earning members and source of income and not on any other factors. The final refined coding process is done based on Grounded Theory to develop new context-specific categories, as shown in Figure 2. 6.

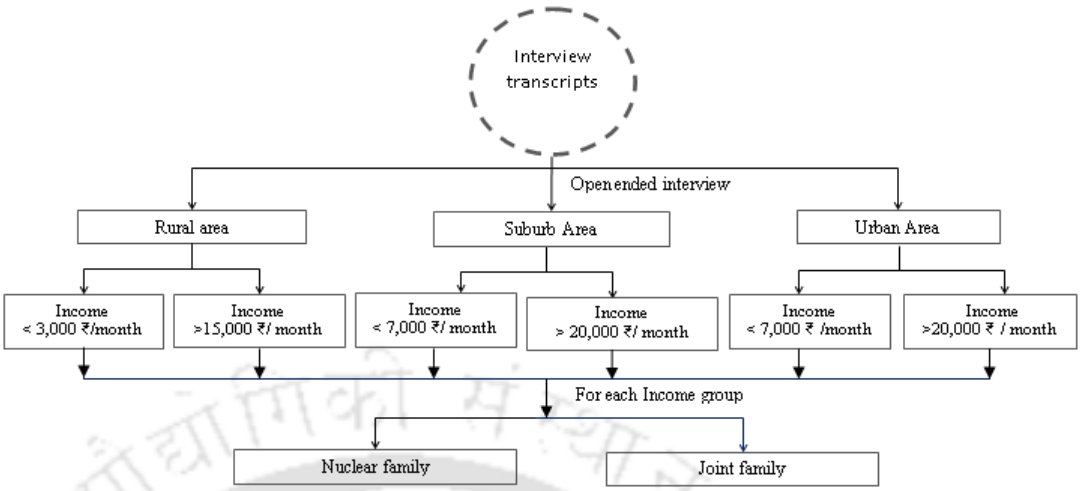


Figure 2. 6. Coding process for data analysis

Findings

The personal interview transcripts revealed that there is a variation in respondent's perception of the fall problem and its intervention. The difference found is mainly based on financial support, family structure, and locality. The analysis also showed participants sensed the importance of fall intervention, but they focused on cost, reliability, and their help in active engagement in daily life activities. The constructs, as mentioned above, are discussed below. Few quotes from the participant are also mentioned in the following text as a supportive narrative.

The analysis revealed that participants are not familiar with exercises like Tai-chi, fall detection technology, human airbag system, etc. Figure 2. 7 shows different factors influencing the elderly's perception of falls and related interventions in India. The "Family structure," "Geographical area," and "Family income" directly and indirectly have influenced older adult's perception of falls and related interventions. These factors also influence the element "Awareness on elderly fall."

There is a lack of awareness of the fall problem and existing programs among older adults. It is found that 56% of the elderly do not consider elderly fall as a problem and instead believed it like a common issue. Thus, they are unaware of the interventions dealing with elderly fall, like behavior strategies to avoid falls, exercise programs for muscle strength, technology solutions, etc. So "Awareness on elderly fall intervention" is the result of the joint or individual effect of the other four factors: "Geographical area," "Family structure," "Family income," and "Awareness on elderly fall." All

these factors influence the elderly's perception of falls and related interventions.

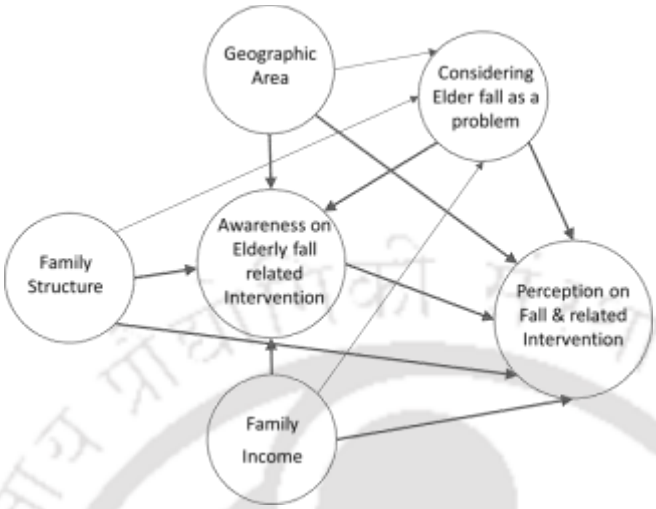


Figure 2. 7. Factors influencing Indian older adult's perception of fall and related intervention

Transcripts and direct observation revealed that the elderly staying in urban areas, the nuclear family seemed to be more conscious and/worried about the fall and related injuries irrespective of their fall experience. Elderly and their family members are concerned about elderly fall but not interested in making any architectural modification to intervene in the fall problem. Those families who have lower income (<Rs. 7,000 in rural and <Rs. 10,000 in a suburb/urban) are concern about elderly fall, but they have minimal information and relevant resources on this issue. This might happen due to their poor economic condition; they do not consider the elderly's problems as a serious issue over other requirements. In those areas where houses are situated nearby (suburb, rural, in a few cases urban area), informal, friendly meetings with neighbors are frequent. Such gathering gives them benefits of staying in a joint family, and the elderly get constant attention and care. However, even though the houses are adjacent to each other in most urban areas, such meetings are not frequent.

The emerging themes from the transcript and observation are given below. A few quotes from the participant are stated in the following text as a supportive narrative.

Non-adherence towards intervention: Among participants, 72% of the elderly are reluctant to do interventions like yoga, muscle-strengthening exercise, etc., and 41.667% elderly mentioned that they feel too old for exercise. They showed concern about their ability to perform such activity and worried about accidents and injuries that might occur while doing the

movements-steps in Yoga or any exercises. As exercise elderly go for a walk (mostly in the evening).

For technological intervention, they are not aware, but 36% elderly mentioned they try to understand what advantages and disadvantages the technology has or whether it is out-weighed or not.

Fear of Falling (FOF): FOF is the major problem among the elderly, 80.556%. Due to it, the elderly avoid doing activities like using the staircase, walking inside the yard, in-fact avoiding various walking-related day-to-day life activities, etc. FOF is seen especially during the rainy days, and mostly among nuclear families or families where an elderly couple is living alone or those who have experienced falls. FOF also influences their distress about doing exercise programs.

Sense of security: In India, family members (most of the cases) are the person who takes care of the elderly at home. In joint families, although the elderly people have FOF, due to more interaction of family members and care, they feel more secure after a fall injury. They believed they would be promptly rescued after fall. In families where informal, friendly meetings with neighbors are seen frequently, they got the benefits of staying in a joint family. In such cases, it seemed they have more sense of security than those staying in a nuclear family.

Hesitation for taking help: Using a cane-stick or seeking some other person's assistance is not considered as dignified by the elderly. A few elderly mentioned, "I don't like to use a cane or additional support. During ambulation, support of the wall, table chair is sufficient (in the case of home), but in the outdoor area, someone has to hold my hand for support." Family members of the elderly mentioned that older family members hesitate to take younger people's help in case of mobility, especially in front of the guest.

Informal measure for fall: In-home, it is expected that the elderly are asked to keep the bathroom door unlocked for safety reasons. "My wife and I always use a bucket in front of the door instead of a door lock. My daughter/son/in-law asked me to do so. In emergencies, it will be easier for someone to open the door from outside, and we will be rescued".

Elderly's views about fall intervention and exercise training:

1. Elderly and their family members are concerned about elderly fall but not interested in making any architectural modification to intervene in the fall problem.

2. Even the elderly are aware of the benefits of exercise; they feel bored performing it regularly. They prefer a more enjoyable approach, if possible.
3. The elderly go for a walk every evening, and they consider it enough for their exercise routine.
4. Elderly/ family members feel lazy to visit/ take them to the doctor in regular interval/ misses follow up sessions.
5. During the rainy season walking, they feel tough to walk, fear of fall due to mud. The elderly expressed that it would be helpful if some alternatives techniques or ways can be made available to reduce FOF.
6. It is suggested to design a support mechanism or tool or gadget that could help them get up or minimize possible damage.

Discussion

This study indicates the findings support the existing literature about elderly falls, their nonadherence to exercise, and the fear of falling in the elderly population [15, 27].

The study shows that the elderly in India are not acquainted with the technology intervention for falls. As Fisk mentioned, the elderly are not entirely against the use of technology if the approach is taken into consideration to the human factors way [79]. In this study, 36% of them are interested in understanding the technology if they are equipped with proper guidance. This study can further carry out considering the user (elderly) as a center of the approach.

The study also revealed that the elderly and their family members are not concerned about the environmental modification to intervene in the fall problem; it is observed mostly among those who have a lower income. Families are concerned about elderly falls, but they have minimal information and relevant resources on this issue.

This study shows the FOF is a significant problem due to falls, seen in 80.556% of the elderly. The elderly with high levels of FOF has a higher risk of future falls, but the elderly with low levels can be protective for falling, irrespective of the presence of balance impairments [25]. Exercise interventions are promising interventions showing evidence that can improve gait and balance as well as increase the ability to get up following a fall and also enhance the mood; it may also help to reduce the FOF by enabling more daily activities and maintaining the balance without falling [25]. This study shows that 72% of the elderly are reluctant to exercise, and 41.667% feel they are too old to exercise. There are similar pieces of

literature that suggest the elderly's negative stereotypes towards exercise [28, 83]. The exercise intervention needs a more enjoyable approach.

Based on this study's findings, a few more questions were raised, and another semi-structured interview is conducted with the experts.

2.2.5 PRQ2, 3.: Pilot study-II

Restating PRQ

2. *What are the available interventions for the elderly fall prescribed by doctors/physiotherapists and the views on the elderly regarding their avoidance of exercise?*
3. *What are the possibilities available to motivate the elderly towards exercise?*

Introduction

There is a generous sum of literature available on intervention programs based on different fall risk factors, as mentioned in section 2.2.2. However, before we conclude the fall interventions that can help India's elderly population get rid of FOF and have a positive attitude towards exercise, further knowledge is required. As mentioned in the previous section, these findings are mainly based on experiments and studies carried out in Western countries. In India, it is essential to determine what kinds of interventions are practiced and recommended by the experts.

Aim: This study aims to find out the interventions prescribed by doctors/physiotherapists for the elderly fall and the possible solution regarding the elderly's avoidance of exercise in India.

Methodology

To achieve this study's aim, (1) A pilot study with a semi-structured interview with the experts is done along with the (2) Market survey regarding interventions like technology and products.

A total of seven specialists and practicing physicians are randomly selected from Assam, India. The interviews are taken place in the experts' chamber or the hospitals at the prefixed time. A set of predetermined open-ended questions are asked (Annexure A3), based on the knowledge gained from the existing literature and pilot study conducted earlier (PRQ1). This process is to and fro. Each interview's content is transcribed, and simultaneously the market survey, along with the literature survey, is conducted to seek more information. Some data are explored through initial

open coding, and tentative linkages are established between categories and include multiple visits with concerned experts with additional questions to collect further data.

Findings from the Experts' interview

The results from experts' opinion are concise in the following points:

- At first, fall patients had to go through the screening process that includes: cause of fall, fall history, medicine use, medical history, etc., and then the experts provide the recommendation.
- For healthy elderly (those who can do the activity of daily living), recommendations for fall prevention are environmental changes, behavioral, exercise for balance, and muscle training.
- In the international market, there are many products like "Hip protectors," "Real-time monitoring system," "Human airbag system for fall," "Alarm system," "Exergame." Though they are available in developed countries, such interventions are not popular among doctors in India, but they appreciate the possibilities.
- The experts have mentioned that due to cost factors, hip protectors, etc. not recommend to patients. They also said that if the patient has used such products, they do not have the record.
- Walker is advised to elderly patients (those who have very little stability/ balance). However, it is difficult to use in all places and cumbersome to some elderly patients. Cane is also used by the elderly. But it becomes troublesome for them to use with cloths (long attire like saree, lungi, etc.) or even in many cases it is not advisable to use while moving upstairs or downstairs.
- The elderly feel uncomfortable wearing hip-protectors, as it has padded areas that cause pain in prolonged use. Apart from that, they find it uneasy due to size issues.
- Balance training is considered the most efficient to increase strength in lower limbs and to avoid elderly falls.
- Although the elderly are aware of the positive benefits of exercise, most do not engage them in exercising at recommended levels.
- The elderly male is more concerned regarding the exercise than the female.
- The elderly are not motivated to perform the exercise, and they skip days without exercising. Monitoring is required to complete the training as they tend to forget to do it step-by-step. Another issue is the elderly feel is bored while exercising and visiting the chamber/ hospital multiple times.

- Stepping pace varies among the elderly while doing the exercise. So, the elderly follow their own pace, and they are not interrupted by the medical personnel. Doctors do not force their training or gait speed, and the elderly are not obliged to do the exercise daily, as in many cases, they feel irritated or disrespected if they are asked to it more than one time. In these cases, they might refuse to exercise at all.
- For fall intervention, they have suggested the fall preventive balance exercise (stepping) or aid or tool that can motivate the elderly with playful physical training. The development of assistive measures might reduce the FOF. Reducing FOF and increasing balance confidence among the elderly is considered very important for intervention.
- Stepping exercises for balance improvement: "Simple standing with open eye/ close eye," "One leg stand," "Stepping over," "Sidestep over," "Sidestepping," "Figure eight," "Figure eight in one direction," "Tandem walking," "Back walking."
- A few of the exercises mentioned above have been asked to exclude as a safety measure, as these might cause a little problem in the knee pain or their safety in general. Those are: "Simple standing with a Close Eye," "One leg stand," "Tandem walking," "Back walking," and 6-inch lifting of legs by the elderly in "Step over," and "Side stepover." Simple walking without lifting in these two exercises is suggested by medical personnel.
- To motivate the elderly musical environment, or self-motivation are considered options by the practiced physicians.
- All the physicians are not aware of the exergame (Exercise in the form of gaming). Those who are, they mentioned, exergames are designed for kids, not for the elderly, and its effect on them is not still confirmed briefly.

Findings from the Market survey

In the market, especially global online marketing sites, products like hip-protectors, knee caps are available. Other products like the fall alarm system are not available in the Indian market. These products are not feasible to order/ get in all parts of India. In exergames, Dance Dance Revolution (DDR), Wii, etc., are available on India's online shopping sites. But those are not available in off-line medical and retail stores in Assam, India.

Findings from the Literature survey

The interview with the elderly and experts leads to a common problem: the elderly's lack of interest in the traditional exercise. Literature shows the digital games, Exergame (EXG), can cater as a motivator, emotional, and social level of meaningful and cherished activities [31]. EXGs are interactive video games that involve physical activity or exertion tracked as a body [32]. EXG, like Wii, DDR, may shape the fall research in the elderly population in a positive direction. Rademaker highlighted that the gaming environment of EXG, like SilverFit, highly values the motivational impact, and findings show that the intensity of movement is recorded higher when they are using SilverFit, [84]. EXG has excellent potential in the field of elderly fall research, which needs a more in-depth study, as the present EXG like, games Wii are found to be too fast or give too negative feedback and not mainly designed for the elderly [76]. The detail of the EXG research is mentioned in the next section, 2.3 of this chapter.

Discussion

This survey answers PRQ 2, 3. This study supports the literature review findings that exercise intervention is useful for improving balance and preventing the occurrence of falls [15, 85, 25]. The study revealed that experts prefer balance exercise intervention, and they believe that "*Prevention is better than cure.*" Experts have recommended a different kind of stepping exercises like "Simple Stand," "Stepping over," and "Sidestep over," which are considered as balance improvement exercise that can prevent fall in the elderly. Studies also advised that stepping exercises have a significant impact on balance improvement [33]. But this survey also shows that the elderly avoid exercising, miss the follow-up sessions due to busy schedules or boredom or missed reminders, etc. This is a similar finding discussed in section 2.1.3, PRQ1. EXG is one of the potential answers to the PRQ3, along with self-awareness, maintaining routine exercise, and motivation towards training.

The use of technology, such as EXG, is a possible way of fostering the elderly's inhibition towards exercise. Study shows online games can improve balance as well as psychological health [85]. Findings from PRQ1, 2 show that such technological measures are not accessible to the elderly in India. It is difficult to adapt these interventions directly for India's elderly, as there is a mismatch concerning their anthropometric dimensions, environmental factors, structural issues, etc. Many studies suggested that available EXGs are not designed for the elderly [86, 31], and in India, new technology is not popular as in the developed nations [22, 72]. For using any technological measure for fall first, it is needed to understand what kind

of attributes the elderly would consider before buying such products in India. Research, another pilot study, is designed with an online form.

2.2.6 PRQ4.: Pilot study-III

Restating PRQ

4. *What are the attributes the elderly will consider in technology-based intervention for falls in India?*

Introduction

Among the elderly to date, the technology is not widespread, and their limitations and preferences for purchase intention of fall relate technological measures are not yet considered in India. A pilot study is conducted to get some light in this area.

Aim

The study aims to understand the attributes considered by the elderly in India before purchasing or selecting any fall-related technological intervention.

Objective:

1) To explore which attributes are considered by the elderly in India in fall-related technological solutions.
2) To find out their opinion towards the use of technology-oriented fall intervention.

Study Procedure

With 19 numbers of Items (N), the questionnaire is selected for the study (Annexure A4), with an alpha value of 0.763, which shows the answers are acceptable and reliable.

The total sample size, N=30 (18 male and 12 female), participants (senior citizens of India) are randomly selected in this study. Among them, 23 participants have previous fall history within the last two years. The age of participants ranged from 60 years to 93 years old with a mean of 70·79 years and a standard deviation of 9.5 years.

Result

This study found 48.1% have fallen due to the slippery floor, and 44.4% have happened due to the balance problem. 85.2% of the elderly are not aware of the idea of technological measures related to fall.

The results reveal that 70.4% of the participants agreed to use technological measures if that is available to them. Among the participants, 29.6% of them are uncertain about using new technology. This is because they are not sure about the operational process and unaware of using technological measures. Regarding the visual design of fall-related aid, 88.9 % of the elderly are not worried about others while using it. The purchase attributes considered by the elderly are: "Usefulness," "Easy to carry," "Easy to understand: how it operates and it can be operated/ worn without any help," and "Cost-effectiveness"; where only 48.1 % of elderly considered cost factor and "How it looks" is the least prioritized attribute. "Usefulness" is the most crucial factor for fall prevention technological aid, 69.2%. Whereas 23.1% of the elderly believed understandability without any help as the essential attribute. 55.6 % of the elderly are afraid to make an error while using such an intervention. With the user-friendly product with proper guidance, they considered using a new technological aid, that is, 92.6%.

Discussion

The study provides supportive evidence that the elderly participants of India are agreed (70.4 %) to use a new technological measure for the fall problem. It also supports earlier studies (literature and PRQ1) that stated the elderly are tend to understand the technologies. With an appropriate design approach in the development process, it will be accepted by the elderly [79, 10]. The study also spread some light on the essential attributes of their purchase intention. However, further in-depth knowledge of technologies like exergame is required to provide any conclusion.

2.3 Summary of the findings of the problem area

The outline of the problem area in the elderly fall intervention in the current Indian scenario, indicated by the literature and field survey, is shown below.

Elderly adherence in doing Exercise:

- They are not motivated towards exercise.
- Skips days without performing the exercise.
- The elderly feel bored during exercise.
- Negative stereotype.
- Negative physical self-worth.
- Avoid going to the chamber/ hospital.

A possible solution to motivate the elderly in doing Exercise:

- Therapeutic exergames or digital games can address issues like cognitive, motivational, and emotional.
- As per our knowledge, no research has been conducted in India to investigate the effect of a user-centered designed exergame for the elderly in terms of balance-related stepping exercises.

2.4 Exergaming as an exercise intervention

The findings of the previous pilot studies and literature are leading this research towards EXG. For a profound understanding of the possibility of EXG in elderly fall research in India, the existing literature is revisited. This section shows the previous work done in the field of existing EXG.

2.4.1 Available Exergames (EXG)

Dance Dance Revolution (DDR)

Dance Dance Revolution is an interactive game produced by Konami Corporation that can be played on several game consoles, such as Sony PlayStation, Microsoft Xbox, and Nintendo Wii, as well as on a PC [3]. Figure 2. 8 shows the DDR game station. In Figure 2. 8 (a), the mat has no sensors. When the game starts, a lady explains the whole process, as shown in Figure 2. 8(b). The game has different soundtracks; the player can choose the track on which the player can do the dance steps by following the avatar on the screen, Figure 2. 8 (c). On the screen in front of the player, arrows drift from the bottom of the screen to the top of the screen, and participants need to synchronize each of their steps over the mat (Figure 2. 8 a) to correspond drifting arrow. The accuracy of the user has to monitor manually.

In DDR with pressure sensors, the player has to stand in the center of a 3x3 pressure-sensitive step pad (panel) and controls the game by stepping left, right, forward, and backward [3]. The DDR style games, available on the Nintendo® Wii™, Microsoft® Xbox, and PlayStation® (PS2 and PS3 platforms), have to either step or tap on a sensor located on a soft mat/pad or platform under the player's feet. The player gets to score points if they correctly step or tap the mat in the indicated direction of the cues on the screen.

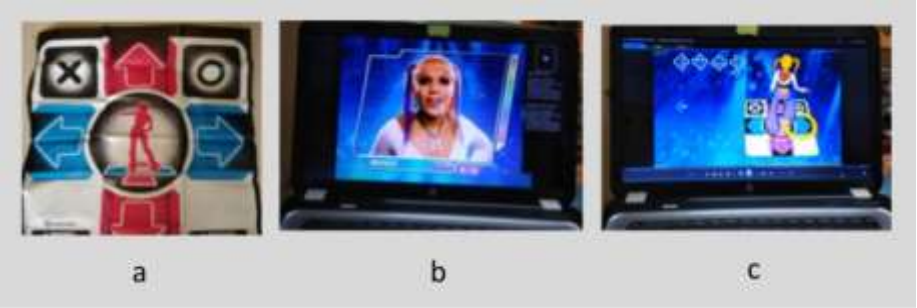


Figure 2. 8. DDR Game: (a) Mat, (b) On-screen Avatar, (c) On-screen Steps to follow the game

After each step response, the player has to return to the central panel. The feedback is given to the players based on their accuracy for each step in the form of a word on the screen, Perfect, Good, or Miss. Points are given according to how well participants performed the stepping task [3]. The game level ranges from 1 – 10; the most difficult levels have increasingly fast-moving indicators (arrow). DDR style games are fast-paced and require speed (often over 110bpm), coincident timing, attention, and entire balance [20].

Wii

These games include video gaming like Bowling, Boxing, Table Tennis, Soccer, Track, and Field, etc., as an alternative intervention in balance rehabilitation in the elderly population. Results showed such a tool could improve balance.

Figure 2. 9. Man playing bowling using "Wii mote" (remote)
[Source: https://static01.nyt.com/images/2009/04/21/science/21wii-600.jpg]

These are done via Wii with a remote control or using the balance board. Games are played by the users using a guided video, sensor, and virtual gaming environment. Other games include Ice skate, cycling, riding bike, Table Tennis, etc. In the Wii Fit balance game, a virtual representation of

the participant (called a "Mii") is moved on a television screen via displacement of participant Center of Pressure (COP) over the Wii Balance Board (WBB). Most games last between the 30s and 3 min and the player is given a game-specific score after playing that is reflective of their overall performance [87]. Figure 2. 9. Man playing bowling using “Wii mote” (remote).

WBB is initially designed as a video game controller; it is mostly used in combination with a video game console and its associated software. It has already been incorporated into the rehabilitation programs of neurological patients with balance defects [88].

SilverBalance Board

In this game, obstacle features appeared randomly in the game area (either from the right or left). The player has to avoid falling from the interruption that occurred due to obstacle features. In the second task, obstacle features covered the whole screen in different lengths. The player has to put pressure on the top half of the balance board until there is no contact between the player’s representative (on-screen) and the obstacle (executing constant pressure on the board represents ‘jumping action’) [89], see Figure 2. 10. A player is putting the pressure on the board to **balance.**

Figure 2. 10. A player is putting the pressure on the board to balance
(Source: https://watchusplaygames.files.wordpress.com/2012/05/family-plays-videogames-wii-fit.jpg.)

SilverFit

SilverFit (Figure 2. 11) is a virtual rehabilitation system. It utilizes a time-of-flight (TOF) camera that can track a player's full-body movement in three dimensions. The camera can trace within the region a 5x5 meter area of the system [84]. The camera input (motor movements, like body posture adjustments, arm movements, standing up, sitting down, walking, etc.) is

converted by specially designed software to interpret the player's movements and convert the input into game elements shown on HD flat screen or beamer [84]. The virtual game environments create cycling/ riding bikes on the road, fish tanks, picking a flower in the garden, etc. (depending on users' choice of level and environment).

Figure 2. 11. Demonstration of SilverFit
(Source: https://www.google.co.in/search?q=SilverFit&source=lnms&tbm=isch&sa=X&ved=0ahUKEwid24zMjqXUAhXEG5QKHVURABEQ_AUICCgD&biw=1517&bih=735#imgrc=F9kkWU0-B654EM)

Kinect Camera

Microsoft released the Kinect RGB-D sensor as a Natural User Interface (NUI), in November 2010, for its XBOX 360 gaming platform [90]. The Kinect sensor device comprises a depth camera, an RGB camera, an infrared laser speckle pattern projector, and a multi-array microphone [91].

Figure 2. 12. Kinect RGB Camera
[Source: https://3542-presscdn-pagely.netdna-ssl.com/wp-content/uploads/2013/05/kinect_1.png]

It provides color information of the player as well as the estimated depth for each pixel. An infrared camera captures the projected infrared speckle pattern from the projector. It is then compared part-by-part to the reference patterns captured previously (at known depths) and stored in the device. The sensor then estimates the per-pixel depth based on which reference patterns the projected pattern matches best [90].

2.4.2 Studies on the available Exergames (EXG)

This section presents the studies that have been conducted on exergames with the elderly. A few studies show positive improvements in balance, motivation, but many studies suggest no clear evidence of benefits, although none has reported any harmful effects [75, 87, 92, 93].

A study is done in 2014 explored the possibilities and usability of the exergaming as a measure of activating the elderly in their physical and cognitive capabilities [92]. The software is integrated with exercise bikes, cross cycle, restorator bikes, and treadmills. The interactive exerciser has motion control with the Kinect controller. The exergaming simulator is based on the Unity game engine. The multi-purpose simulator for exergaming is developed since 2013 to motivate and inspire people who exercise with cardio devices. The study had twelve elderly (aged 64- 87 yr.s). Participants were divided into two groups (n=5 and n=7). The game includes the following tasks.

The task aims to make the participants familiar with the exergaming simulation. To navigate in the virtual city "Kajani," this can be tracked by the Kinect motion controller. If the left hand is raised, the left turn occurs, and if the right hand is raised right turn. The maximum time limit is 3 mins.

The task is to collect the bananas as much as possible within 2.5 mins. The numbers of collected bananas are shown in the result screen, depending on the route choice, and the speed points will vary. In this study, the average collected points are increased by 2.6 from 1st trial1 to 3rd for all the participants.

(1) Bonus round, where the participants have to follow a restricted route, to wander in the forest where birds are singing. The task was completed in 3 mins.

The study concluded with a positive response from the elderly participants, who found the simulator as a motivating and appealing means to do physically activating exercises. The authors highlight the need for more research on the usability and benefits of exergaming.

Padala conducts a study to establish the efficacy of an interactive video-game-led physical exercise program using Wii-Fit to improve balance in the community-dwelling elderly (age: $\geq$ 60 yr.s), N= 27 (started with 30) in Veterans [32]. A randomized controlled parallel-group trial is conducted at the Veterans Affairs Medical Center. Twenty-six out of 30 subjects are male. The exercise group performed a Wii-Fit program (n= 15), and the control group (n= 15) for 45 minutes, three days per week for 8-weeks.

Exercise group shows (within-group analysis) significant improvement in BBS 4 weeks ($p < 0.001$) and at 8 weeks ($p < 0.001$) but control group shows no improvement at 4 weeks ($p = 0.70$) or at 8 weeks ($p = 0.22$) with 95% confidence interval. Among the games, mainly bowling has been considered suitable because the bowling game is self-paced; but they also found that playing Wii sports is difficult [32]. The limitations of this study are limited sample size; the study population primarily consisted of male Veterans, and Wii-Fit has an upper weight limit, and the duration of the exercise program is shorter than the recommended period of 11- 12 weeks [32, 90].

A study has investigated the training in the elderly via Nintendo's WiiFit to improve clinical measures of balance and retain the improvements after some time [94]. For the study, twelve healthy elderly (two males and ten females 70–92 yrs. old) are randomly divided into two groups (experimental and control group). In the experimental group, participants are trained with Nintendo's Wii Fit game while the control group did normal activities. All of the training lasted three times a week for three weeks. Total nine elderly completed the study (experimental group $n = 4$, control group $n = 5$). Four clinical measures of balance are assessed before training, one week after training, and one month after training: Berg Balance Scale (BBS), Fullerton Advanced Balance (FAB) scale, Functional Reach (FR), and Timed Up and Go (TUG). Results showed that the experimental group significantly increased their BBS after training while the control group did not. However, there is no significant change for either group with FAB, FR, and TUG.

The review study retrieved seven studies (initial screening 351 studies, further evaluation 39) related to Nintendo Wii Fit used to enhance standing balance performance in the elderly compared with no treatment or an alternative exercise treatment [93]. In the reviewed seven studies had a total of 285 elderly, with 126 participating in Wii Fit training and 159 in control groups. The number of subjects per group ranged from 9 to 30, with a mean of 14.5 (SD 7.13) in Wii and 14.18 (SD 6.03) in control groups. In four studies, Wii-based exercise's effect is compared with no exercise; the study report showed a positive impact on at least one outcome measure related to balance performance in the elderly. Other studies comparing Wii-based training with alternative exercise programs indicated that the balance improvements achieved by Wii-based training are comparable with those achieved by other exercise programs. The review study suggests that Wii-based exercise programs may serve as an alternative to more traditional forms of exercise aimed at improving balance control. The review

mentioned that due to methodological limitations, it could not suggest Wii as a definitive intervention as to optimal treatment protocols and a safe and effective home-based treatment. However, the National Stroke Foundation of Australia found that 84 of 111 (76%) metropolitan stroke rehabilitation hospitals purchased a Nintendo Wii console.

Another review study [87] on different game outcomes of the Wii Fit software balance assessments had mentioned that WBB (Wii Balance Board) COP (Centre of Pressure) data could be used to assess the changes in elderly balance over four weeks. Wii Fit interventions have shown to be effective, and no study has reported a negative impact of WiiFit. Despite the positive results, as there is a lack of convincing statistical support, a vital criticism of the WiiFit balance work is seen to date - as most of the studies conducted have utilized small samples. Among the 19 reviewed studies, 40% of studies conducted have tested five individuals or less, and 3 out of 4 studies conducted have had 10 participants or less. The study mentioned that the most prominent scientific use for the WiiFit had been neurorehabilitation-based balance interventions. It is found that poor validity and reliability for 12 of the exergames associated with the WiiFit software compared to a standard balance test. A study suggested that WiiFit software-based measures of balance ability are not sufficient, and the study needs larger-scale, randomized control designs in the future.

A study is piloted to investigate the efficacy of the Nintendo Wii among the elderly in Singapore (aged >=65) [75]. The aim is to find out older adults' perceptions of Wii. The research model is adapted from the Technology Acceptance Model (TAM). A self-reported questionnaire (7 points Likert scale), and video observation methods are used. The findings suggest that the elderly believed that Wii might provide opportunities to improve one's health ($p < 0.001$), and it create a new entertainment option with Wii ($p=0.017$). The study suggests that the elderly might have a low level of confidence when dealing with the latest technology.

A study is conducted to investigate the feasibility, acceptability, and safety of a supervised video game exercise program administered via Dance Dance Revolution (DDR) in individuals with Huntington's disease [95]. The study results showed that 17/18, 94%, participants (≥ 18 years old) reported that the game is fun, motivating, and more mentally than physically challenging, and 88% of participants improved their gameplay performance from first to last sessions (each session 45 minutes, two days per week for six weeks). The study suggested that intervention DDR

appears to be feasible, acceptable, and safe in individuals with Huntington's disease in a supervised manner.

A study is designed to inspect the effects of DDR on the cognitive control in elderly females (Twenty-six healthy elderly females) of the age range 65–75 years [96]. The sessions are done three times per week for three months. Participants are divided into Control group (CG): 8, Dance Dance Revolution group (DDRG): 7, and brisk walking group (BWG): 11. Results showed that DDR or a brisk walking intervention promoted the cardiovascular fitness of elderly females. At the behavioral level, DDR and the brisk walking intervention enhanced response speed in the flanker task.

A prototype of a rhythm game is developed that leverages the benefits of step-based exercise and dance video games that might improve balance and reduce falls in older adults [97]. For preliminary usability assessment, a sample of three physical therapists and four young, healthy participants (aged 16-43 yrs.) were involved. The system consists of a PC, low-cost Logitech web cameras (two), and two different coloured LED devices. LED devices are designed to attach to the user's right and left shoe with an adjustable band. The system algorithm incorporates the feature point-based motion tracking of the user using the two web cameras. The study needs further assessments for usability with the elderly.

The literature points out that it did not explore the suitability of Wii games/sports for the elderly, and further research needs to be done [75]. Another study mentioned that Wii is not designed for the elderly, and many games are found to be too fast or give too negative feedback [76]. In the literature, it is mentioned that when the elderly play in a group, if a co-player quit the game, they do not find it exciting as a younger adult.

The validity and reliability of balance measures using the Nintendo WBB study suggested that the WBB is not a valid measuring tool of standing balance [98]. The study participants are not elderly; twenty-four male and female subjects participated with the mean age of female subjects, n=4, is 20±0.8 yrs., the mean age of male subjects, n=20, is 24.4±8.0 yrs. The study indicated that using the commercially available step-based training (UdanceTM system, DDR) for physical/balance training could provide participants with a negative experience [97]. As the lowest game level, the movements are likely to be difficult for some older adults to complete successfully and safely and potentially reducing motivation and self-confidence. The study mentioned that there is a limited ability for alteration in speed, music style, and visual stimuli, and the background and graphics could be distracting.

In this study, the authors indicated that four studies informed about adverse events occurring like pain or discomfort after playing outside the intervention [99]. The authors reviewed 60 studies (53 studies, 2011- 2015) with a mean age of the participants is 65 years or above to provide an overview of the use of VR games /exergaming and explore whether this technology is safe and effective exercise and rehabilitation tool for elderly. Other than that, few game interfaces are colorful, visually busy, and accompanied by unsuitable music, noises, and running commentary. The authors highlighted that to make accessible and enjoyable activities for older adults, and such issues might be necessary to consider when implementing or testing certain exergames in the elderly population. The study concluded with a positive note about exergames, and it is regarded as a good potential as an exercise or rehabilitation tool for the elderly. For the future perspective, games can be designed that can target multiple physical functions to contribute to keeping older adults active and healthy. A case study of SilverBalance and explained the design of exertion games for elderly users [89]. For the study, nine elderly with an average age, 84 yrs. (77-91 yrs.), have participated. The author highlighted the elderly cognitive and motor limitations; the game should adapt to different motor skill levels. Stanmore et. al; conducted a trial on 56 participants, aged 55+years or older with 12-week strength and balance exergame programme [100]. This study indicates EXG as an acceptable, practical, and potentially cost-effective way to improve balance, pain, and fear of falling. A study reviewed the different exergames and discussed the persuasive strategies to motivate the elderly to exercise [76]. Persuasive technology is a set of technologies that attempt to change people's attitudes and behavior through persuasion and social influence without using coercion and deception [76, 101]. The changes in the subjects should be voluntarily accepted. Literature suggests that it has great potential to motivate and encourage older adults to change the sedentary lifestyle and become more physically active. In the study [76], persuasive strategies like display information, attractive, user-friendly interfaces, etc. are discussed. A study discussed how different theoretical guidelines for elderly game design could be used, using the example of the game “FishCatcher” [102].

Based on the existing commercial exergame, different researchers have proposed theoretical guidelines summarised below in section 2.5 [85, 76, 89, 99, 102]. It can be used in our research for designing Stepping-exergame for the elderly in India.

2.5 Theoretical Design Guidelines for elderly exergames from the literature review

1. Interaction mechanism: Should relate to real life.
2. Have to keep in mind elderly's physical condition: body movement, should adopt different motor skills, changes are decrements in posture, balance, gait, and fine motor skills, visual and hearing senses, impairment of short-term memory, attention and vigilance, and therapy to cover the range of motion.
3. Avoid far-reaching or sudden movements.
4. Should avoid small objects: Most existing games currently available on the market are not suitable for older adults because they consist of small, fast-moving characters and targets, producing strain and anxiety.
5. Reduce cognitive load: Reduce steps that create complexity.
6. The interactive mechanism should be simple to avoid frustration in the elderly.
7. Feedback should be immediate, with no negative feedback.
8. Attractive & friendly user interface: No additional graphics/ annoying messages at an inappropriate time (they should not get disturbed).
9. Should provide instruction to play: otherwise, elderly blame themselves for failure and avoid playing & get frustrated.
10. Should give visual and auditive feedback: Older adults are not as confident in their ability to use these technologies as the young, which causes computer anxiety. The players should be encouraged by positive feedback and successful experiences to avoid stress. Therefore, it is recommended to give positive feedback on learning goals rather than performance goals.
11. There should be a balance between challenges and player's skill levels.
12. Should not disturb the user with annoying messages at inappropriate times.

Although there is an abundance of studies discussing the EXGs with the elderly and theoretical guidelines for designing EXGs for the elderly, the products used in the study are not explicitly designed for the elderly, and they are not appropriate for them [76, 89, 103, 83]. The available EXGs have environment and game elements that are based in Western countries. More evidence will be required to provide a concrete conclusion on this possible solution for the elderly fall problem and exercise intervention in

India. It is not clear how the elderly in India will respond to such intervention in the fall problem.

A study is conducted to understand the need of the end-users, that is, the elderly in India, with an existing EXG (DDR).

2.6 User needs study: Understanding Exergaming as an interactive tool for Elderly fall preventive measure in Indian scenario

2.6.1 PRQ 5.: Pilot study IV

Restating PRQ

What will be the responses of the elderly in India to the existing exergames?

Introduction

In the Indian context, there is limited information available in the field of elderly - exergame research [86]. There is a need to explore how the Indian elderly respond towards such EXG to do the exercise, and if it is not favorable, what types of changes are required to make it suitable for the elderly in a context-specific way. For this study, DDR is selected because it has a gaming environment that needs stepping activity to play.

Aim: The study aims to find out how will elderly in India feel about the available exergames.

Methodology

The participants are given time to get familiar with the DDR according to their own pace. To ensure the safety of the participants while playing the DDR, a researcher always stood behind them. The study is conducted with seven elderly (three female, four male) age 60-67 yrs. (mean age 64.3 yrs.) of India. An open-ended questionnaire (Annexure A5) is used to take feedback from exergames and suggestions. The direct observation method is used to understand the situation more deeply. Participants used the DDR for 30 mins without showing any discomfort.

The DDR game has different soundtracks; the player can choose the track on which the player can do the dance steps by following the avatar on the screen (Figure 2. 8(c)). The arrows drift from the bottom of the screen (in front of the player) to the target arrows on the top of the screen. The participants need to synchronize each of their steps to correspond with the drifting arrow passing over the mat.

Findings

The elderly participated enthusiastically in the study. The elderly felt EXG could be beneficial for them, although they mentioned that the game environment is not relatable to their daily living environment (Figure 2.8 (c)). In the feedback given by the participants, it had been pointed out that the cost of DDR is high (4,000 in Indian rupee), and they have suggested developing a more cost-efficient product. The elderly found the Avatar not relatable to them (Figure 2.8 (b)). From direct analysis and feedback from participants, it is found that, for older women, the arrows on the mat are difficult to see, as all the female participants wore Saree/Mekhela - Saddar (traditional attire) during the play (Figure 2.13). Another problem the elderly face is game speed, as the game movements are too fast to cope with. Indian elderly suggested slower/self-paced movement control in the game and showed interest in using the tailored EXG.

Figure 2. 13. Example of the participant using DDR

Discussion

This study helps to understand the elderly's response towards technology like EXG in India. DDR is inspired by different social scenarios than India, due to which the elderly are not able to relate the game-stories or themes. To recognize EXG's possibility as a fall intervention for the Indian elderly, a similar approach to design EXG as developed or western countries or countries with different socio-cultural and economic strengths will not be enough. Creating an EXG in the Indian context is complex. It is required to to balance the needs of multiple stakeholders like the Indian elderly, caregivers /their family members, and doctors to use the exergame. It requires a multitude of areas of knowledge that need to be utilized and resources that spread across space and time.

2.7 Research gap and opportunity

In general, different researchers have shown their appreciation for the application of the EXG in the fall research field and attempted to address the drawback and mitigate the use of EXG in the elderly population. The

state-of-the-art review and field study conducted, shown in previous sections of this chapter, provides some thought-provoking directions for this thesis to understand how emerging EXG technologies can be applied in India for the elderly fall research. The process of finding a research gap and research questions is shown in figure 2.14. Several restraints and limitations have been observed in the field-survey sessions and through a literature survey summarised in figure 2.15, and this requires a human-centered approach for investigation. In this thesis, the user's perspective in fall intervention is captured a qualitative aspect using Grounded Theory.

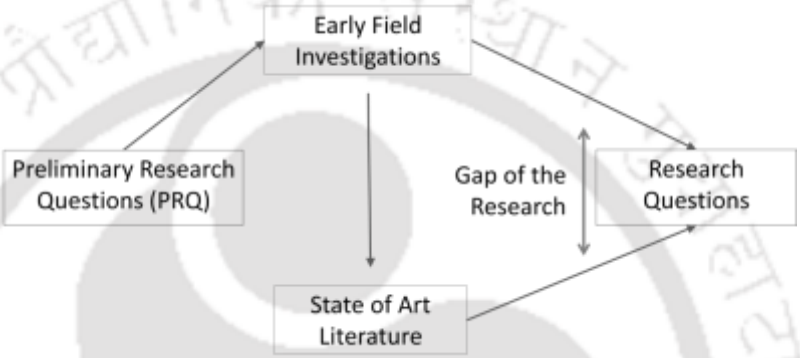


Figure 2. 14. Process of finding Research Gap for this thesis

Muscle strengthening and balance retraining programs can improve flexibility, leg strength, and balance for fall prevention [27, 26]. Among the elderly population, "Stepping" exercises significantly impact balance improvement [33]. The implications of self-paced exercises for exercise prescription are most in need of interventions to enhance adherence to exercise programs [64, 34]. Even low-intensity exercises improve the balance in deconditioned elders sustaining a severe injury and a high risk of falling [32]. The exercise needs an accumulated time span to show its benefits. The elderly have to do the prescribed exercise sets with the time properly. Previous pilot studies (section 2.2.4, 2.2.5) and literature have suggested that the elderly do not exercise as prescribed. In the exercise domain, the elderly show a lack of motivation, negative aging stereotypes (negative self-views such as physical self-worth), and attitudes of the elderly; literature review also supported these problems [99, 104]. Most of the elderly do not exercise at recommended levels [30, 22]. Digital games address issues like cognitive, motivational, emotional, and social benefits that have been associated with digital games [105, 106]. It can provide a meaningful and cherished activity that caters to healthy older adults on a motivational, emotional, and social level [30].

The literature reported that there is still a need for further refinement of both traditional balance assessment and balance training techniques for the prevention of falls in the elderly [67]. As seen from the literature review, there are significant research gaps, which are depicted in Figure 2.15. These need to be addressed. It invokes significant research questions that are described in the following Section 2.8.

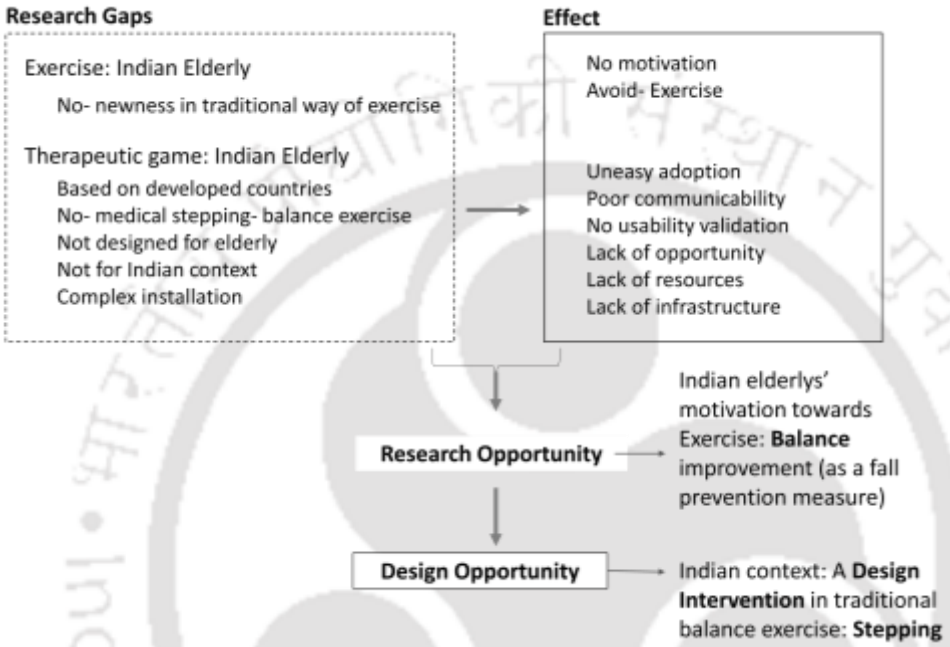


Figure 2. 15. Research gap and opportunity

Research gaps regarding exercise intervention required newness in the process, like helping the elderly understand the improvement balance precisely (quantitative output), and older adults can feel motivated by knowing their own improvement/ benefits from exercise (quantitative way). The quantitative data can also help physiotherapists/doctors on the matter.

Secondly, from pieces of literature, it is also identified that in EXG like Wii has a narrow board due to which the elderly might fall while they are playing the game, and it is not designed for the elderly [76, 75, 107]. In the case of studies [89], it is observed that such complex games are likely to be affected by age-related changes and impairments on various levels.

Further, there is a higher number of elderly interacting with EXG than the home-based training, real-time interaction is not as successful, and in the case of elderly, in group playing, co-player quit is not as exciting as a younger adult [76, 5, 104, 85, 99, 89]. We find that design guidelines

mainly focus on interaction design, and the studies have not considered cultural aspect, availability of accessing such advanced accessories for EXG (like Kinect, internet, etc.). EXGs available are Kinect based or tablet-based. It needs a camera to capture the whole-body movements [108]. As in the Indian household environment for buying Kinect, / availability of the internet and installing is not that convenient as the developed countries. In the Indian context, the technology is not widely accepted by the elderly in India (due to the combined effect of the lack of awareness, experience, facilitating arrangements, economic and social environment). The existing EXG is not related to the real-life scenario of the elderly in India, which is an essential aspect in theoretical guidelines [99, 89, 76, 102, 85, 84]. There is a need to gain more insight into how to use exergames for older adults as an exercise and rehabilitation tool [109].

EXG in the Indian context can be a novel way to address elderly fall research in terms of exercise and technological intervention. This can increase the period engaged by the elderly in the exercise by exercising fun than the traditional form of exercise and improving their balance. Therefore, this thesis proposes to use EXG as a fall preventive tool by improving balance among the elderly in India. To measure balance, Y-Balance Test is used [110, 111]. The Technology Acceptance Decision Tree (TADT) tool is proposed to be used in this thesis to design our proposed stepping exercise intervention. The Activities-specific Balance Confidence (ABC) Scale [112, 113] and Falls Efficacy Scale-International (FES-I) [23] are used to assess the elderly's balance confidence and their FOF before and after using the intervention. Technology acceptance of the designed EXG is measured using the Unified Theory of Technology Acceptance and Use of Technology (UTAUT2) developed by Venkatesh 2003 is used [114, 115, 11].

Here, the EXG prototype is a solution to improve the elderly's balance in a self-motivated way, to assist themselves in finding their improvement in finish time. The assistance is delivered to the elderly through the on-screen display of the finish time after each session automatically records the data.

The design heuristics require an understanding of how emerging technologies –balance exercise (fall preventive) be utilized and explicitly designed for the elderly in India.

2.8 Research Questions

Based on the research gaps identified from the literature review and the field survey, the following fundamental research questions are formulated to be investigated in this thesis.

1. If a design intervention in the Indian context is infused in the traditional way of doing balance exercise (like stepping), will it improve the balance in the elderly in India?
2. Whether using Therapeutic Stepping Exergame (TSE) can improve their balance confidence in them?
3. What will be the effect of TSE on the fear of falling in the elderly in India?
4. Whether TSE will be accepted by the elderly in India?
5. What are the key constructs considered by the end-users to use TSE?
6. What could be the design guidelines for stepping balance exercise intervention based on experiments?

2.9 Aim and Objectives

The research aim is to propose a design recommendation for balance exercise intervention (stepping exercise) for the elderly in India that increases their balance and balance confidence and reduces the fear of falling.

The overall objectives of the present research conducted for this dissertation are:

(1) To assess the effectiveness of the stepping exercise design intervention in terms of balance in the elderly in India.
(2) To assess the effectiveness of the designed stepping exercise intervention in terms of balance confidence in the elderly in India.
(3) To assess the effectiveness of the design intervention in stepping exercise in terms of fear of falling in the elderly in India.
(4) To find out whether the Indian elderly will accept an effective intervention for balance exercise (stepping), typically designed in a specific context and culture.
(5) To identify the variables influencing the design of a stepping balance exercise intervention for the elderly user in India.
(6) To formulate the design guidelines for exercise interventions in the Indian context.

2.10 Research Hypothesis

To address the aim and objectives, three primary research hypothesis is developed, which are:

H1. The use of TSE will improve balance in the elderly in India.
H2. The use of TSE will improve balance confidence in the elderly in India.
H3. The use of TSE will reduce the fear of falling in the elderly in India.

Chapter Summaries

The chapter discusses the extensive literature from the elderly fall to the possible solution to address the Indian elderly fall issue. It also presents the user research studies to understand the user's need and gather design requirements in the existing fall intervention: exercise. Various methodologies like contextual inquiries, interviews, and scenario-based design are adopted for this investigation to understand the gap of the study. The feedback provided by the elderly further directions to help conceptualize, design research approach, and experiment set-up and develop an EXG for the elderly in India. To provide a concrete conclusion on the possibility of EXG in India, addressing the exercise and technological intervention for the elderly fall problem, more evidence will be required. Figure 2.16 gives a summary of the research gap and possible design intervention. The following Chapter 3 discusses the design research approach and methodologies used in the thesis.

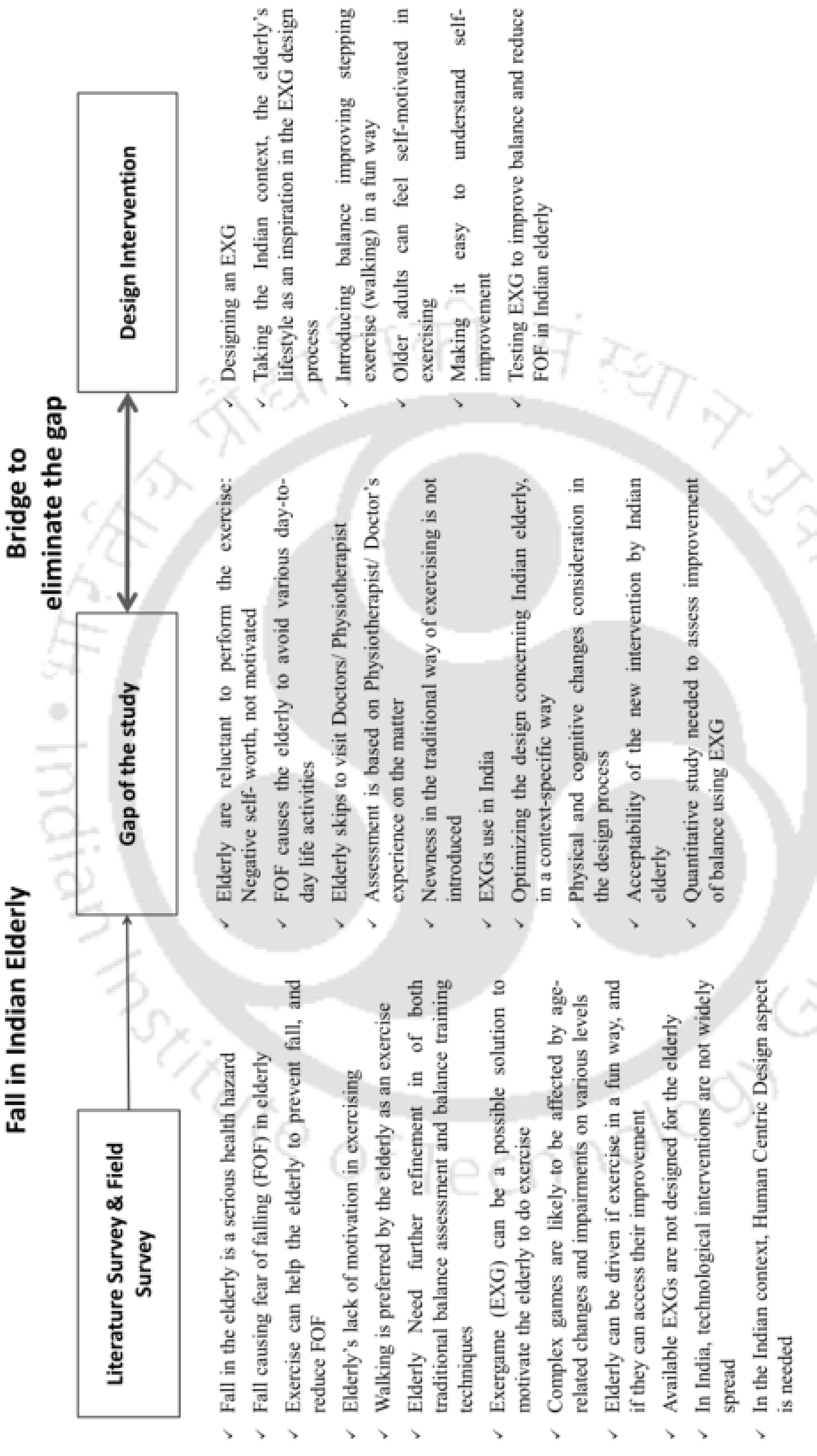


Figure 2. 16. Summary: research gap and possible intervention to bridge the gap between fall problem and elderly

Chapter 3. Research Methodology and framework

3.1 Introduction

The research gaps and research questions in this thesis addresses using design-based research [116] with emphasis on the human-centered design (HCD) approach [10]. Design-based research (DBR) infers outputs in both products and knowledge form, and the knowledge claim of DBR includes a form of design principles, which is evidence-based heuristics that can apprise future implementation and development decisions [116].

The research needed to go back and forth multiple times between the research question(s) and the gap to be identified in the literature till the research gap is clearly addressed and theories that may support the investigation of the research question(s). The literature and field survey helped to connect the bridge that can help to eliminate the missing aspect between the Indian elderly and fall research. As mentioned in the previous chapter 2, along with existing literature, in the Indian context, elderly fall research needs a more in-depth study. Once the research problem is identified, it helped to identify the research questions that justify the objective of the research work. Figure 3. 2 shows the overall research flow of this thesis. The generic flow is (1) formulating the research problem; (2) extensive systematic survey of the literature (collecting both primary and secondary data); (3) development of the hypothesis; (4) preparation of the design research; (5) determination of the sample design; (6) execution of the experiment; (7) collecting the data; (8) analysis of data; (9) hypothesis testing; (10) generalizations and interpretation, and (11) presenting the results and preparing the report (adopted, [117, 118, 116]). These steps continuously overlap, providing criteria for evaluation, and steps are not distinct and separate. They are not following each other in a specific manner and continually anticipating at each and every step in the research process the necessities of the following steps.

The problem statement in DBR identifies an opportunity or an issue to explore its background and provide a considerable and persuasive argument that the issue is worth and significant research [116]. So, understanding the problem statement is a crucial part of this research. To understand the depth of the problem statement, along with secondary data, primary data are also needed. The problem statement and the literature survey process to identify the research gap are marked as “A” (Figure 3. 2), described in Figure 3. 1. The design research is explained within section 3.4, Figure 3. 3, with the

overall research flow, went through various decision points, in Figure 3. 4, along with the method of experimenting is shown in Figure 3. 6.

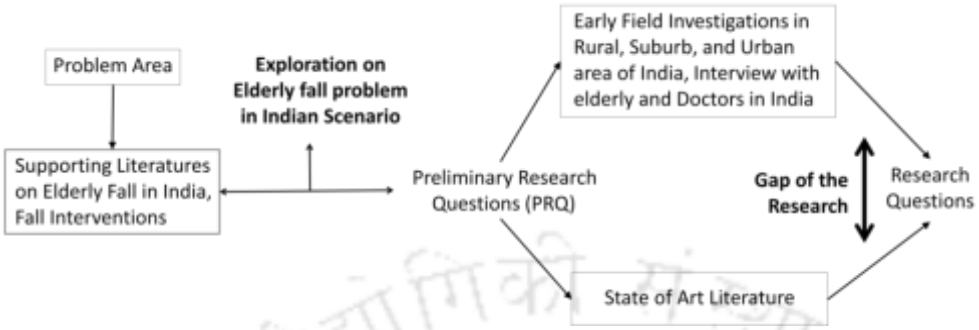
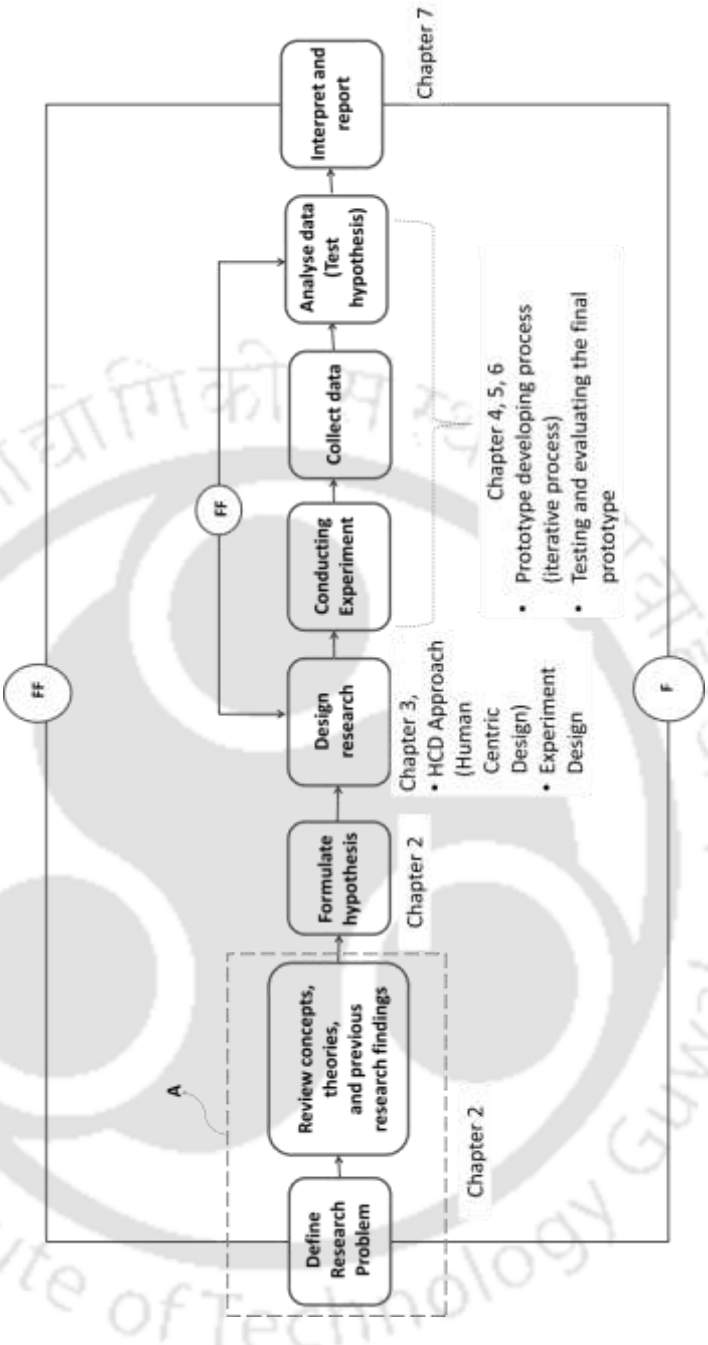


Figure 3. 1. The research method of identifying the Research Gap and formulating the Research Questions (A)



F= Feedback: helps in the refinement of problems, solutions, methods, and design principles
FF= Feed Forward: providing conditions for evaluation
HCD= Human-Centric Design

Figure 3. 2. The overall research plan of the thesis

3.2 Restating Research Questions

1) If a design intervention in the Indian context is infused in the traditional way of doing balance exercise (like stepping), will it improve the balance in the elderly in India?

2) Whether using Therapeutic Stepping Exergame (TSE) can improve balance confidence in them?
3) What will be the effect of TSE on the fear of falling in the elderly in India?
4) Whether TSE will be accepted by the elderly in India?
5) What are the key constructs considered by the end-users to use TSE?
6) What could be the design guidelines for stepping balance exercise intervention based on experiments?

3.3 Restating Research Hypothesis

From the research gap, as discussed in Chapter 2, it is identified that the elderly faced difficulties in completing the prescribed exercise sets. However, the elderly are aware of the benefits of exercise in preventing falls. TSE, an EXG, can be a possible solution in the field of elderly fall research. The following hypotheses are formulated and tested to test the effect of the TSE prototype on the Indian elderly on balance, FOF, balance confidence, and its reuse intention:

H1. The use of TSE will improve balance in the elderly in India.
H2. The use of TSE will improve balance confidence in the elderly in India.
H3. The use of TSE will reduce the fear of falling in the elderly in India.

3.4 Design Process used in this thesis

> *"Human Factors Integration is concerned with providing a balanced development of both the technical and human aspects of equipment procurement. It provides a process that ensures the application of scientific knowledge about human characteristics through the specification, design, and evaluation of systems* [119] *."*

A human-centered design (HCD) approach (ISO 13407:1999(E)) is adopted in this thesis to address the research gaps and questions identified in Chapter 2. This research enables the researcher to improve the elderly fall research in India: exercise and technological intervention. The human-centered design cycle depicts the essential processes which should be undertaken to incorporate the user-centered design (UCD) approach to let the system meet the requirements (ISO 13407, 1999). These processes are carried out iteratively and supported by a variety of UCD methods.

HCD is an approach that incorporates human factors and ergonomics knowledge and techniques to interactive systems development that enhances the effectiveness and efficiency, making systems usable. It improves human working conditions by taking account of human capabilities, skills, limitations, and needs. The HCD approach is characterized by the following (ISO 13407: 1999(E)): (1) The active involvement of the users and a clear understanding of user and task requirements: It provides a valuable source of knowledge regarding the context of use, and how users are likely to work with the system or product in the future. In the custom-made product developments, the users or appropriate representatives are directly linked to the development process. (2) The appropriate allocation of the function between users and technology. In the development process, the decision should be based on factors like relative capabilities, limitations of the user versus the technology in terms of reliability, the flexibility of response, strength, accuracy, speed, the financial cost of the technology. (3) An iterative approach to the design solution. The user's feedback is a crucial source of information, as active user involvement is an effective means to minimize the risk that the system does not meet users' in-depth requirements. (4) Multi-disciplinary design. The term multi-disciplinary means decision should be sufficiently diverse to make an appropriate design trade-off. It includes end-user, purchaser, application domain expert, user interface designer, human factors and ergonomics expert, human-computer interaction expert, etc.

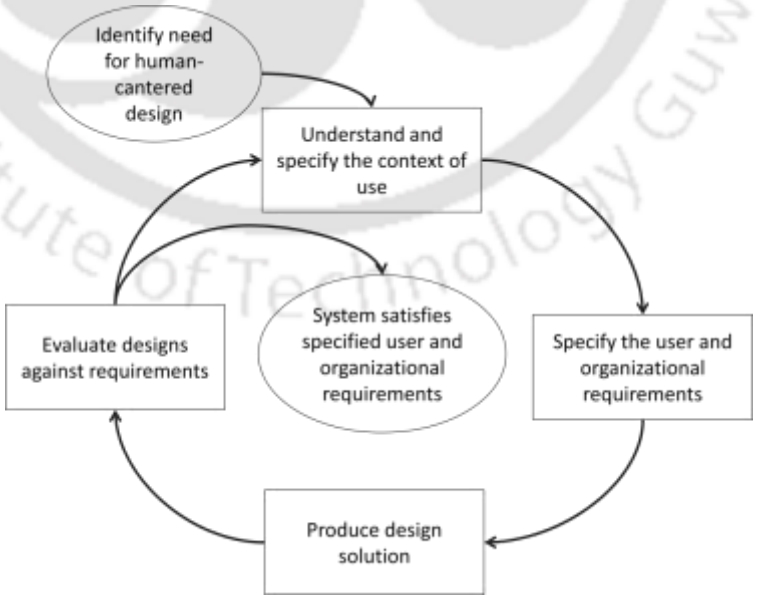
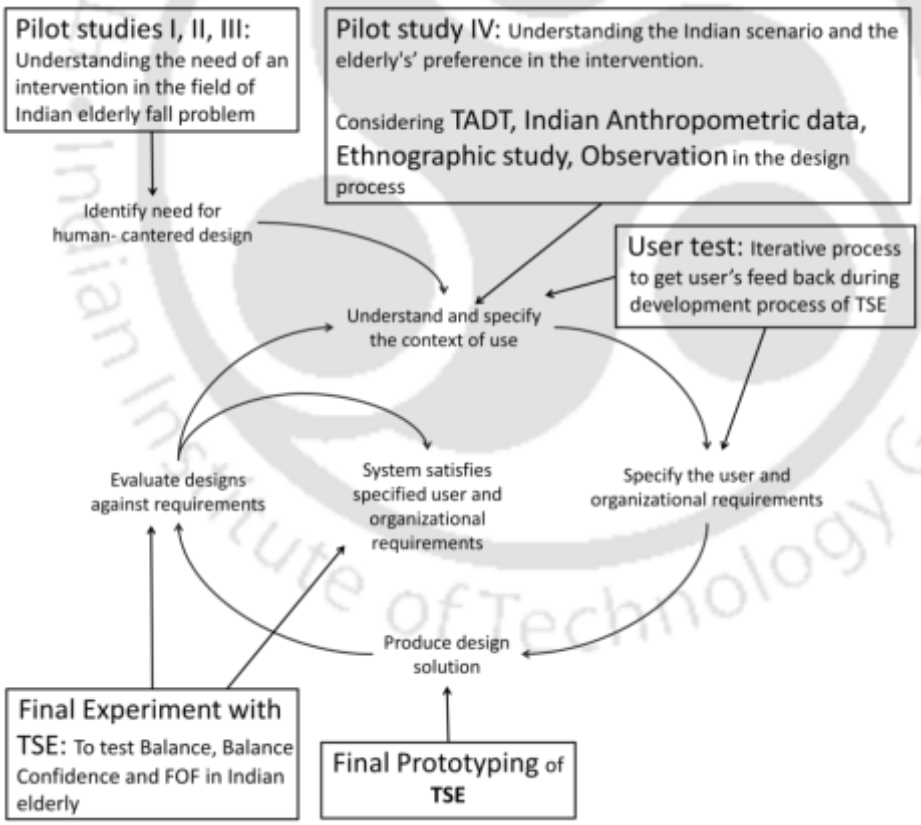


Figure 3. 3. The interdependence of HCD activities (ISO 13407, 1999)

Figure 3. 3 shows the interconnectedness of HCD activities [10]. The sequence in which these are implemented varies depending on the design environment and the stage of the design process; it has to be a repeated iterative process until the system meets the user's requirement. The need for an HCD approach can be identified from the operational objectives of the system. The HCD approach must understand and identify the context of use by specifying user requirements, producing prototypes, and evaluating it according to user criteria. In the design process, establishing feedback is an effective procedure; a suitable timescale to allow feedback, and possible design changes, need to be integrated into the design solutions. It is essential to gather the context information regarding the characteristics of the users, task, and the environment in which the system will be used. The task description includes the allocation of activities between humans and the system. The environment consists of the hardware, software, and other materials used in the process/ product. It also comprises the relevant characteristics of the physical, cultural, and social environment.



TADT= Technology Acceptance Decision Tree
TSE= Therapeutic Stepping- Exergame

Figure 3. 4. Summary of the Human-Centered Design process used in this thesis

Figure 3. 4 shows a summary of the HCD approach in the research plan of this thesis. In the thesis, several different data collection methods available in the Human Factor (HF) practitioner, including observation, interviews, questionnaires, usability, and the analysis of performance, are used [119]. The data regarding the usability of the system is collected and evaluated, and the same is analyzed and represented accordingly. Once the research problem and the research questions are identified, a conceptual decision path structure used in empirical software engineering is adopted and followed to investigate the research questions outlined and has been followed in this thesis [37].

The decision path structure involves the selection of (1) research type, (2) research logic, (3) research purpose, (4) research approach, (5) research process, (6) research methodology, (7) data collection methods, and (8) data analysis methods.

On the following page, Figure 3. 5 illustrates how multiple research methodologies are inherently connected and cultivate throughout the research in this thesis.

The research process in this thesis is a mixed approach; that is, the collected data in the thesis is analyzed using a qualitative and quantitative method where necessary. Thematic analysis with the grounded theory is done in the initial phase of the research. Data analysis with the grounded theory is an iterative process where data are collected, and analysis took place simultaneously: an insight emerging from the initial data outlines further data collection, which in turn adds to current understanding, and so on until no new insight develops from additional data collection. [35, 36].

To address the research questions and test the working hypothesis, an experiment set up is prepared and piloted with a sample of the elderly population in India. The participants selected for the experiments are fit elderly [8] who are capable of ambulant and do not receive regular prescribed medication (chapter 5, section 5.2), who are senior citizens of India and voluntarily participated in the TSE- session. All participants signed an informed consent form, adapted from the literature [35] (Annexure A1), before entry into the study and examined by medical personnel.

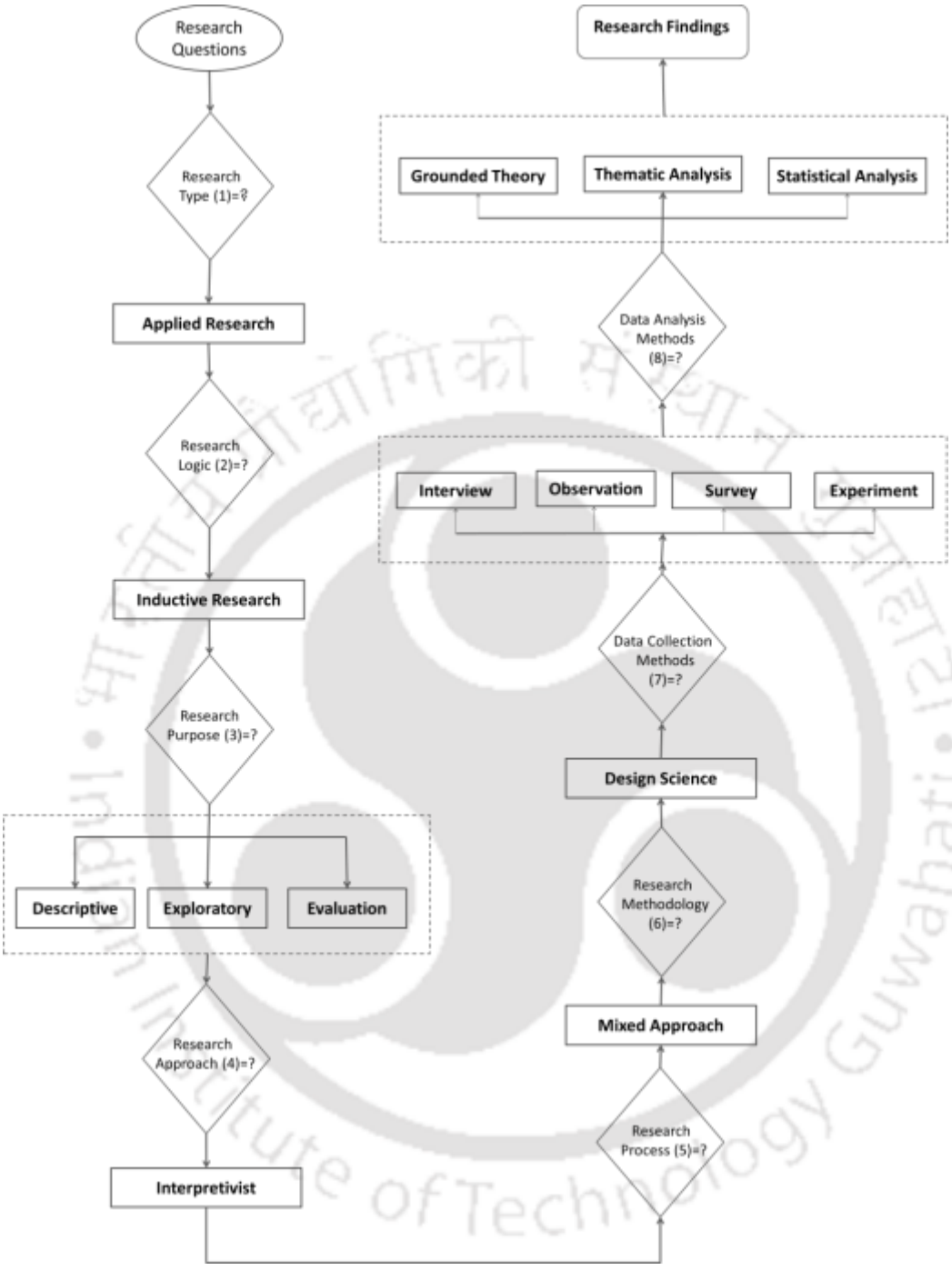


Figure 3. 5. Summary of the decision points for research investigation in the thesis

Figure 3. 6 shows the block diagram representation of the experiment setup. The experiment is conducted using a custom made EXG, specifically designed for the elderly to address the elderly fall problem in India. The designed intervention is termed as Therapeutic Stepping- Exergame (TSE).

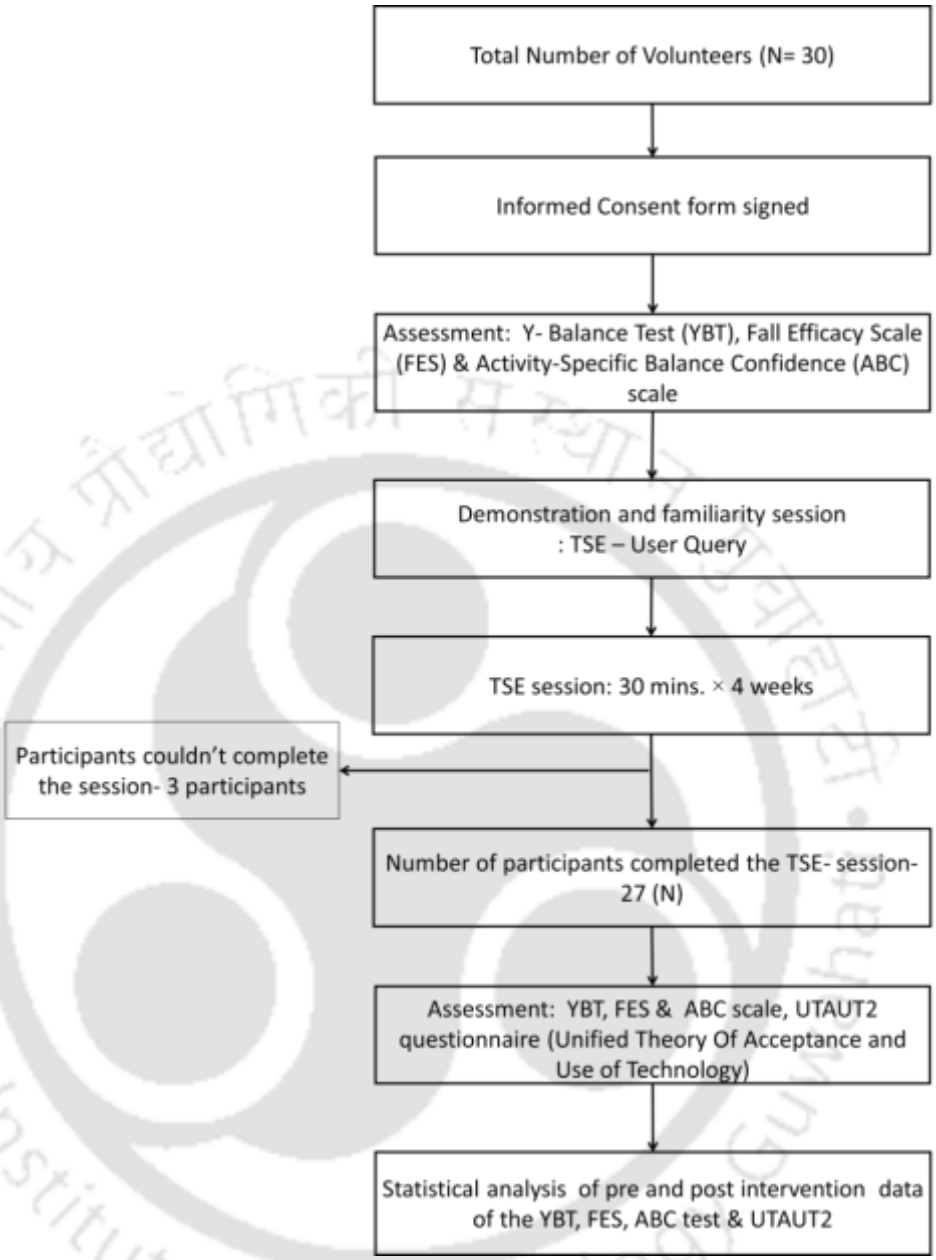


Figure 3. 6. Block diagram representation of the experiment setup

Figure 3. 7 shows the pictorial summary of the TSE- session, adopted [6].

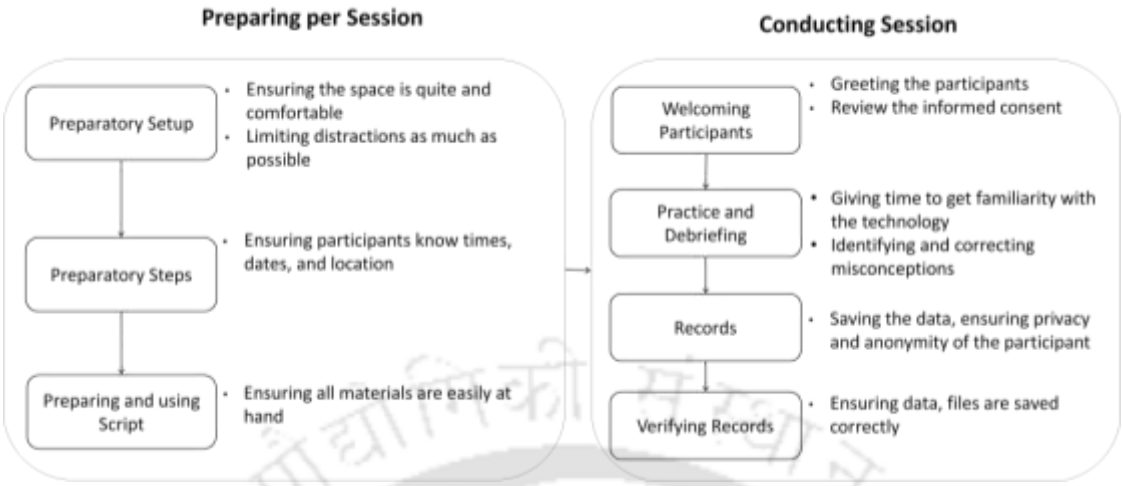


Figure 3. 7. Method of conducting the TSE- session

Figure 3. 8 represents the independent and dependent measures of the TSE-experimental studies conducted with the 27 elderly participants of India. The detailed discussion of the experiment and the participants are presented in chapter 5 and 6 of this thesis. The collected data is analyzed using inferential statistics. The statistical analysis is done using the tool SPSS20.

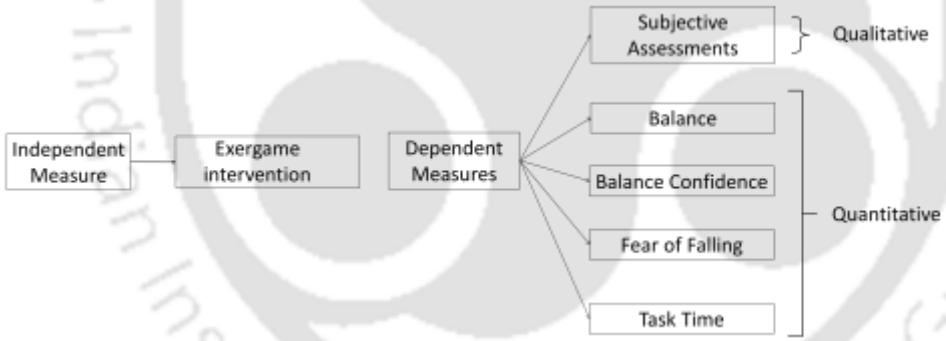


Figure 3. 8. Dependent and independent measures of the study

Chapter Summary

This chapter discusses the different decision-making points to conduct the research, the research methods, and the experimental approach to address the Indian elderly fall issue. The following chapter 4 will elaborately explain the design process, the concepts of each design, along with the hardware and software interfacing mechanisms.

Chapter 4. Concept Generation, Design and Prototyping Therapeutic Stepping- Exergame (TSE)

4.1 Introduction

The gap identified in the research leads it towards proposing a design recommendation for intervention in the balancing exercise via stepping for Indian Elderly. One of the questions that arise is whether incorporating design intervention (Indian context) in the traditional way of doing balance exercise (like stepping) will improve the balance in the elderly or not and, if yes, whether the Indian elderly will accept it. In this context, a custom-made stepping-related exergame is required to design and developed. The design process includes the HCD approach, as mentioned in the previous chapter 3. The EXG user in this research is the elderly population of India. So, in the design process, the needs and abilities of the older adults' physical and cognitive change, such as minor hearing loss or use of glasses, to mild deafness or the inability to move fast or all of one's body, are carefully considered. As the individual's abilities in using new technology will also vary substantially from that of a younger adult, the interface is designed accordingly.

More simply, Therapeutic Stepping- Exergame (TSE) is a combination of exercise and technology intervention for fall problem, designed by considering the elderly's aspect of keeping their cultural, as well as the physical, cognitive, use of technology skill's limitation in mind. The TSE design details are elaborated on in the next sections. Figure 4. 1 shows a block diagram representation of the designed TSE.

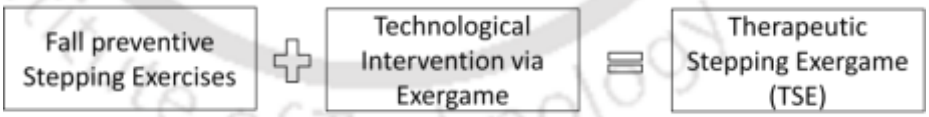
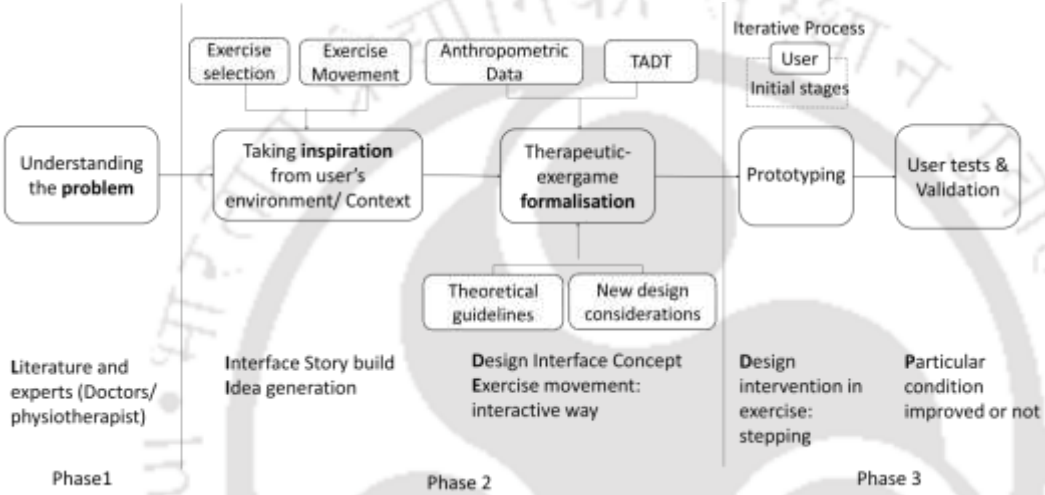


Figure 4. 1. TSE block diagram

The proposed TSE prototype is based on several layers of technological, exercise, and ergonomics concepts that have explicitly based on the HCD-approach. It is divided into 3 phases. The initial phase includes an understanding of the problem, i.e., in this research, the balance improvement in the elderly in India in a self-motivating way. The second phase consists of the idea generation with the exercises that will include in the form of the game and designing the interface, considering the exercises prescribed by the physicians; in this research, fall preventive exercise in

stepping is considered. The last phase is developing the prototype and testing it with the users, i.e., the Elderly population in India. Figure 4. 2 shows the pictorial representation of the design model used for Therapeutic Stepping Exergame (TSE). As shown in Figure 4. 2, prototyping in phase 3 is an iterative process (HCD- approach) that leads to taking a few new design considerations (phase 2) in the final TSE prototype. In the interface design process, to meet the user's need, Indian Anthropometric data along with Technology Acceptance Decision Tree (TADT) have been used. The detailed process is described in the following sections.



TADT- Technology Acceptance Decision Tree
Particular condition: Balance improvement, Balance confidence improvement, reduce in fear of falling

Figure 4. 2. Design Model for Therapeutic Stepping Exergame

4.2 Selection of exercise

In the initial studies, it is found that the elderly perform their exercises in a self-paced way (Pilot- I, II). Literature suggested that the implication of self-paced exercises for prescription exercise, sedentary adults, especially among overweight, who are most in need of interventions to improve adherence to exercise programs, and stepping exercises significantly impact balance improvement [89, 85, 33]. The ability of fast voluntary movement has been found to deteriorate with age [120]. So, in TSE, self-paced stepping exercises are selected as the abilities to initiate a quick voluntary step or to inhibit a well-structured stepping and footing position to avoid the instability that occurred due to an increase in age [105, 121]. Due to which the elderly will be more comfortable in a self-paced manner.

The exercise selection for TSE is made based on the initial pilot study- II. The exercises are self-paced, as mentioned above, and only four stepping exercises have been selected; those are:

- Stand with eye open- look front and stand
- Straight walkover
- Side walkover
- Figure 8

For straight walk over and sidewalk over, keeping two or more soft objects (space them out 12-16 inches apart) on the floor, and the person has to lift their leg to 6 inches while walking and step over the objects and should take a pause between each object [122]. However, lifting the leg can make the elderly feel knee pain; simple walking is prescribed to the elderly with knee pain (Pilot- II).

4.3 Design interface concepts selection

The conceptual phase is one of the essential characteristics of the design process. This phase is unpredictable, as the concepts that come up as a solution for the particular problem are may be creative, but it may not be feasible to execute in the field. Due to this, to lead to a successful novel product, TADT and Anthropometric data are considered in this stage.

4.3.1 Technology Acceptance Decision Tree (TADT)

The TSE will be a new technology among the elderly in India. It is found that the elderly could be motivated to use new technology if the system is well designed and the elderly are adequately trained [79]. Technology Acceptance Decision Tree (TADT) can assist in acquiring an understanding of the relevant issues that older adults consider before accepting new technology.

In this research, TADT is applied in the game interface development process. For the TSE interaction platform, various concepts and ideas are brainstormed. To see the feasibility of the ideas, TADT is used, as each of the shortlisted ideas has both advantages and disadvantages. The final shortlisted ideas are accepted and rejected according to their feasibility to outweigh the cons. The Technology Acceptance Decision Tree (TADT) is illustrated below (Figure 4. 3). The following ideas are shortlisted for the game interaction platform in the stepping game for TSE.

1. Inbuilt (mole to catch etc.) game activity on the Floor/ mat without a different screen interface

2. Use of led/ marker on the foot ware/ leg to detect movements
3. Use of Kinect
4. Software: S4A (Scratch for Arduino)
5. Gaming environment like DDR commercial (existing) exergames

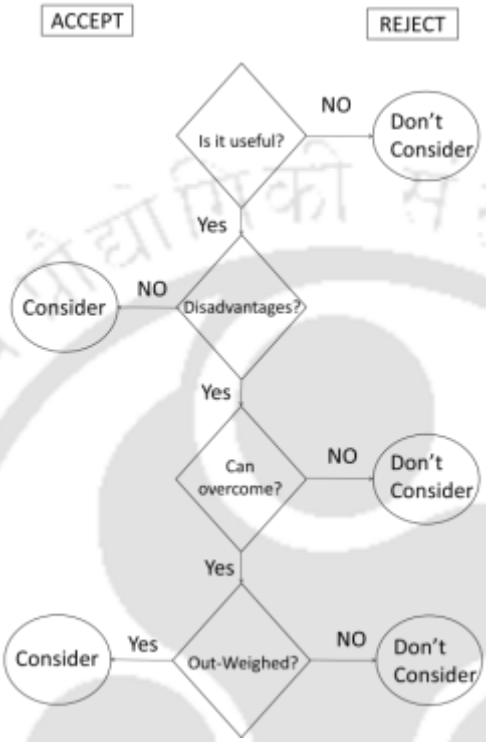


Figure 4. 3. Technology Acceptance Decision Tree (TADT) adopted [79]

One example is considered and explained in Figure 4. 4 to get a better understanding of the use of the TADT process in this thesis. Figure 4. 4 shows an example of the process, as shown below, using TADT with (1) Inbuilt game activity (mole to catch, etc.) on the Floor/ mat without a different screen interface.

As shown in Figure 4. 4, initially, it is checked whether considering this interface will be helpful to address the purpose of the TSE or not. If not, it will not be considered and rejected. As elaborated in Figure 4. 4 in detail about the first concept, if the disadvantage can be overcome using an attire as men, that is pants- shirt. The next important point is whether it outweighs the problem; if yes, the idea can be considered. In this case, in India, how much elderly females will be comfortable and willing to wear pants and shirts is another issue. So, this idea is rejected and proceed to the next ideas.

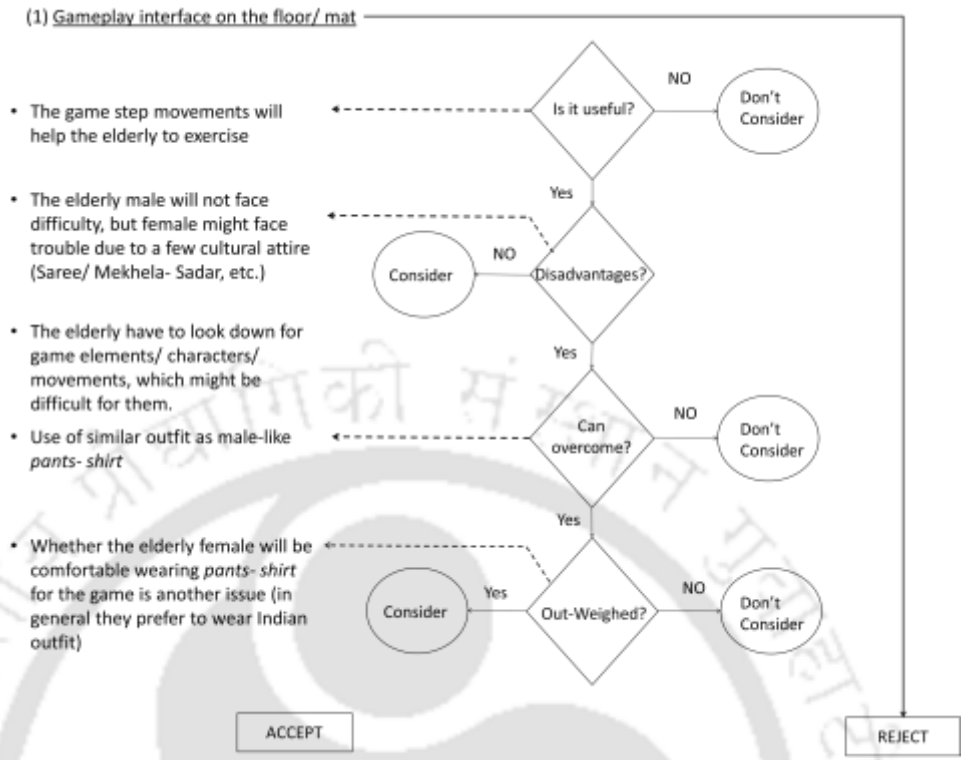


Figure 4. 4. Example TADT used in concept generation

Similarly, (2) Use of led/ marker on the foot ware/ leg to detect movements and (3) Use of Kinect had a similar issue as (1), as the camera unable to identify the lower limbs' movements while wearing Mekhela-Sadar/ Saree (as the legs are covered fully).

Software: S4A (Scratch for Arduino) is easy to install, and by using the engine, redundant connections can be removed. The software became very slow and took more time to load and open the game after developing one game with simple standing. Therefore, this option is rejected for the study.

Alternatively, the Scratch engine is used for development purposes. MIT developed the Scratch engine [123], and the S4A software is developed based on the Scratch engine. With Scratch, "Mackey Mackey" is used instead of Arduino. "Mackey Mackey" does not need external circuitry for compatibility with the operating systems, as it can act as an external switch while interfacing the game.

Can this disadvantage overcome, out-weighed? - Yes,

(5) Gaming environment like DDR commercial (existing) exergames, as stepping activity is involved, this game is selected. The problem found in the previous study (pilot V) can be outweighed using self-

paced movements, a more relatable game story, and environmental development to the elderly in India.

After using TADT, different elements of the design are merging. The process includes the outcomes, suggestions from the previous pilot studies, as well as from the findings of the literature review. The crucial points been taken care of in the design process are the use of cost-effective material, users should be able to carry it easily, and the elderly user can see their performance improvements through a quantitative feedback system (for example, the time duration that can be compared with each game completion time) along with the gameplay score/ time of finish.

In the stepping game design, all the points obtained from the pilot study-IV are considered (chapter 2). Participants will follow the instructions shown in front of the screen. The game screen also shows the score concerning the stepping action of the user (elderly). Another point considered in the TSE from the previous pilot study-I, IV, is the game scenario inspired by the observations, like their day-to-day life activity, living style, etc. Simple technical connections are included to avoid frustration among the elderly, easily installable. There are no complicated movements with self-paced movements.

4.3.2 Anthropometric consideration

The existing games are focused and developed based on Western countries; the body dimensions of the average Indian is different from them. So in the design of TSE, Indian anthropometric data is used.

The dimension of the stepping area (capacitive pressure sensor) of the mat for each is 30cm.×30 cm. The foot breadth of the 95th percentile of the male is 10.6 cm, and the foot length is 27.4 cm, and the female is 9.6 cm and 24.9 cm, respectively [124]. The stepping area (floor mat) is not made too large, providing space for ± 6cm length (considering dimensions of both male and female), as elderly step are short and slow (observation from previous studies (pilot I, II, III, V)) and involve sub-movements [125, 79].

4.4 The primary work for the Prototyping model of the exergame

The exergaming simulator for Stepping-exergame is created using the Scratch engine, version: 458.0.1 “Scratch 2 Offline Editor”. Later on, version: 460 is used for programming and editing purposes (Annexure D1).

"Makey Makey" is acting as a pressure switch. The scratch engine is also editable for character editing, as shown in Figure 4. 5.

Figure 4. 5. Example of the use of Scratch costume edit and initial interface design

4.4.1 Prototyping formalization: Interface design

A floor mat is used for interfacing, where capacitive pressure sensors are placed according to the stepping movements. The dimension of the mat is mentioned in the previous section 4.3.2.

In the initial testing TSE interface, a thick sheet and cloths are used. After taking proper measurements, the final sensor placement is done on a floor mat, designed explicitly with Indian anthropometric data. To make floor/ mat where the stepping activity, initially push-button switch is used with Arduino, but as the S4A software (Scratch for Arduino) is not correctly working, in later designs, it is replaced with the aluminium foil and Makey Makey. An aluminium foil can be used as a capacitive pressure sensor, and after connecting it with the "Makey Makey," it acts as a Capacitive Pressure Switch (Annexure D2). "Mackey Mackey" is an open-source code intervention device. Figure 4. 6 shows the initial interface testing stages of aluminum foil with Mackey Mackey.

Figure 4. 6. Testing the stepping concept with Makey Makey: testing with foil with a sheet, cloth and finally on the floor mat from left to right: interface mat (initially used for the trial purpose)

4.4.2 Prototyping formalization: Game story design consideration with exercise

Initial trials for the interface systems are done with the Simple Stand exercise. It is the basic exercise in the fall preventive balance exercise prescribed to the elderly by the physiotherapists (pilot study- II). Here the elderly are asked to stand with an open eye and closed eye. There is a difference in the COP (center of pressure) sways in the older adult when standing with open or closed eyes, unlike the younger ages [126]. In this research, only a two-leg stand with eye-open exercise has been considered.

At first, a relevant game story related to simple standing exercise is selected in the game story selection process. Both fishing and the stand-still (with the eye open) exercises, need a little patience to complete, and hence the name of the game as "Fish Catcher." In the game, fishes (Figure 4. 7 (a)), and tool "T" (Figure 4. 7 (b)) move in a predefined path. A few fishes are programmed to have a more extended motion near the fish catcher to increase the standing time of the elderly. Before the program's final execution, the initial tests are done with the inbuilt scratch costumes or the downloaded png image files Figure 4. 7 (c).

The movement of the fishes and "T" depends on the standing time of the user (on the correct position, sensor (mat)). As long as the user will stand on the mat, "T" moves to catch the fishes, as shown in Figure 4. 7 (b), and the game will continue till T finds all of the fishes. If the participant walks away from the selected portion of the mat (for this exercise, the participant has to stand still and look forward), the game will stop. Scores represent the number of fishes caught by the "T"; the maximum game score is 20. Once the 20^{th} fish is inside the bowl, the game will stop. In the initial user testing, the game end time is 20-25 s (survey with doctors/physiotherapy suggested that 10/20s are also tricky for elderly with knee pain).

If the participant finishes the game without a pause screen shown in Figure 4. 7 (c) will appear. If any user wants to leave the game before completing the same, there will be no negative feedback displayed on the screen. Further, there is a need to consider usability aspects of EXG not only in terms of merely projecting the game movements, as it has been a trend in most EXGs, but also in terms of adding features that can help conceptualize a finished and tailored EXG product for use in complex elderly fall-related problem in an Indian household environment.

After the experiment is over, the investigator requested the participants' feedback about their experience with the EXG. It is found from the user's

input that they relished the game-cartoon theme, and they have revealed their interest in Avatars in a traditional Indian attire instead of the elderly with western outfits (Figure 4. 7 (c)). The final prototype has designed keeping the finding of this study in mind.

Figure 4. 7. Initial TSE game interface game screen (inbuilt scratch costumes and downloaded png files): (a) fishes moving, (b) showing the container "T" moving to catch the fishes, (c) game avatar

4.4.3 Understanding the Elderly User's need: Pilot Study V

4.4.3.1 Introduction

Based on user research studies' findings and insights (pilot studies III, IV), a lightweight working prototype is designed as a proof-of-concept to observe the elderly's response towards it. This study mostly identifies the likings or problems with understanding the language, technology, or the game interface concept. The study is done in an iterative process, from the findings of 1st study re-modification, which is again tested with the elderly before moving to the prototype's final design.

4.4.3.2 Study Process

1st Pilot study: fish catcher.

After the initial design, two participants (1 female, 1 male; average age 62 yrs., SD= 0) participants are introduced to DDR and designed the game.

The first testing mat Figure 4. 8. The game process is described in the previous section, 4.4.2.

Figure 4. 8. Game interface mat used in the fish catcher at an initial stage

2nd pilot study (Modified game) - "Fish catcher" and "Plant a tree."

After the 1st iteration in the user testing, the participants' feedback helped make a few changes in TSE along with the general guidelines [89] for the 2nd iteration. The fish catcher game is designed in a similar process, as mentioned in the previous section.

In the 2nd pilot study, three elderly participants (1 female, 2 males; average age 63.2 yrs., SD= 1.15) are asked to play the game. The participants are asked to give their feedback after the experiment.

Figure 4. 9. Game interface showing (a) Assamese and English language option, (b) Interfacing mat, (c) shows the game avatar (d) game environment "Fish catcher," and (e) "Plant a tree" game theme

Figure 4. 9 shows the game detail of the study, along with the game screen interface for the 2nd user testing. The language selection option is included in the study (Figure 4. 9 (a)). The game avatars included are shown in Figure 4. 9 (c). Figure 4. 9 (d) shows the game theme for the simple stand exercise. In the game "Plant a tree," the elderly have to step on the mat side-

wise ten times (brown square area, in Figure 4. 9 (b)). With each step, the seed will grow into a tree (Figure 4. 9 (e)).

After the game is over final score is displayed on the screen through the "Score Board," shown in Figure 4. 10.

Figure 4. 10. Display the game's total time for each participant after each session

4.4.3.3 Findings

The study shows that there is a difference in the extent of the standing exercise with and without the EXG. The average time difference in a simple stand exercise (Fish- catcher) is +22.8 seconds than that of a manual one. The answers and observation suggested that when the participants are using EXG, they are more focused on the screen and not on the time extent. Few fishes are programmed to have a more extended motion near "T," although it is initially unclear whether this idea will work as expected without irritating them. It is observed and also mentioned that the elderly are eagerly waiting for those fish to catch by "T." It does increase the standing time of the elderly without discomfort. This is an essential aspect as the elderly are doing the exercise with self-motivation.

In the TSE, at the end of each game, the time of gameplay is displayed on the screen as a scoreboard (Figure 4. 10), saved automatically, and it is a crucial aspect in the design. Experts like doctors or physiotherapists use their experience and knowledge to assess elderly exercise improvement manually. With the display of the scoreboard, quantitative data can be accessed by the user as well as the experts later on. It will help the elderly keep track of each session and understand their exercise performance changes. Participants mentioned that they enjoyed the game; at the same time, they are not focused on time.

Minimum wire connections are considered in the design process to minimize the complexity of setting up the EXG, which is compatible with any laptop or desktop computer. The interface mat is designed as a portable product, which is lightweight and takes less space. The present estimated cost of the product is Rs. 6000, which will include different stepping exercises.

4.4.3.4 Discussion

The users' feedback unveiled a positive response with other factors like the game avatar, self–paced game movements, cost of the product, easy installation, compact size, self-motivation, etc. The next section will present a few new design considerations attempted to include in the tailored EXG- TSE design process.

4.5 TSE final design stage- new design considerations

4.5.1 Introduction

After the initial testing, the game is modified with different aspects of the game in the game interface design process. Theoretical design guidelines found from the previous pilot study's literature and findings are incorporated into the game.

In the design process, the physical and cognitive aspects of the elderly population are cautiously taken into consideration. Elements like their range of motion, ability to perform the task, memory recall, etc., are taken into account [127, 59]. The older people sustain the semantic memory, but their ability to retain episodic memories decreases with age, as to perform self-initiated processes, environment support can reduce these difficulties [59]. Such aspects are considered in designing the game story interface; visual feedback and instruction are provided, and the auditory appreciation from time to time.

The concepts of a user task, game interaction with the story display, and on-screen feedback mechanism overlaid as the prototype are started using techniques like conceptual scenarios and wireframe diagrams. Wireframes provided a blueprint to help layout essential user interaction elements on the TSE interface; see Figure 4. 11 and Figure 4. 12.

After having the wireframe of the user interface, a detailed implementation of the interface is carried out. The next sections will elaborate on the exercise, game story interfaces, and the TSE's hardware interfacing.

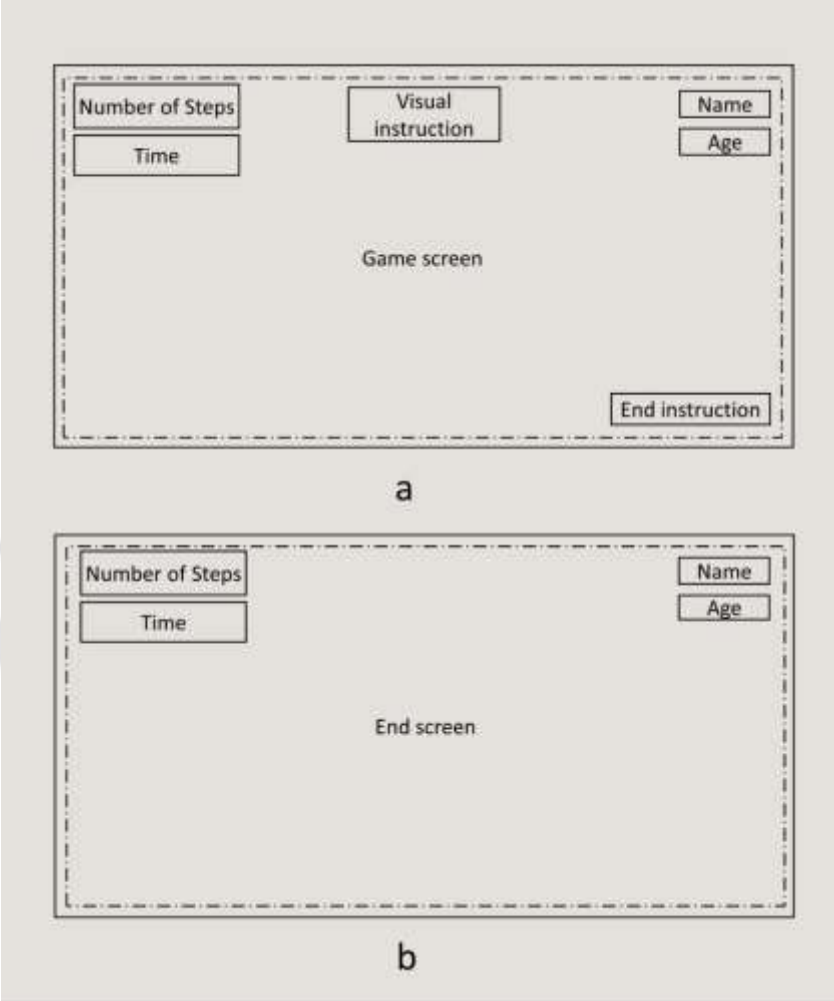


Figure 4. 11. Wireframe design (a) Game screen, (b) Game end screen

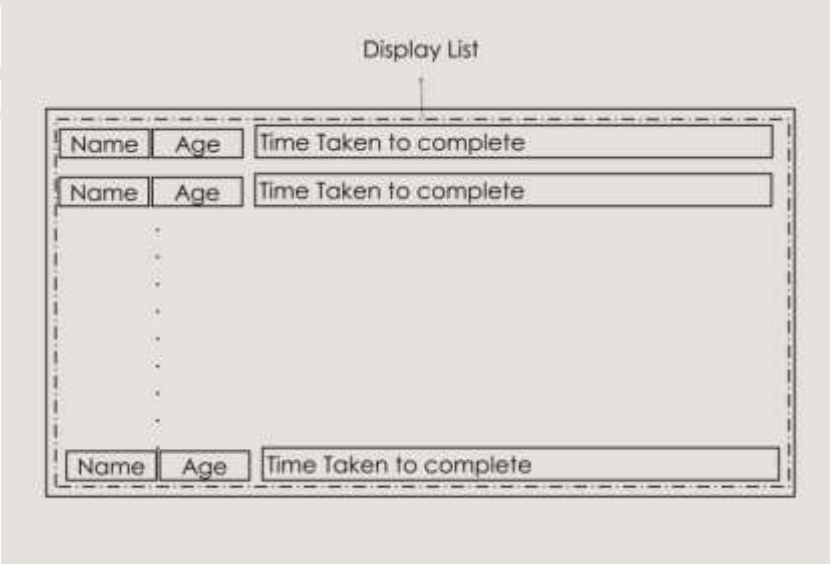


Figure 4. 12. Wireframe design scoreboard

4.5.2 Exercise and game story interface

In the final design, participants can play with five games for four exercises. The 1st exercise is "Simple Stand with eyes open" with one game. Two games for 2nd exercise, "Straight walkover," that is stepping frontward with an object in between and stepping back to the spot when it is started. one game for 3rd exercise "Sidestep over" that is stepping sidewise with an object in between (to and fro), and one game for 4th exercise is "Figure 8". The avatar is more related to the elderly in India. Each of the game stories selected for the respective exercise is inspired by the elderly's day-to-day life activities observed from the ethnographic study (pilot study I) (Annexure E). In the activities or locations where the elderly mentioned had a fall history or are afraid to do yet, these are the part of their daily requirement or hobby to pursue. The exercise and the inspiration of the game story and the concept of these stories are described below:

1. *Simple stand with eyes open*: In this exercise, the elderly have to stand still with their eyes open, mentioned in the previous section of this chapter 4.4.2. Figure 4. 13 shows the game theme of the exercise.

Figure 4. 13. Game theme screen display for simple stand with open eyes exercise (a) screen display after finishing the level 1 of the game, (b) real-time game screen during the exercise

The inspiration for the game is from the ethnographic study in rural India. The game story selected for this exercise is "Fish catcher." Fishing is an almost everyday activity in the rural area; many elderly mentioned they have even fallen near the river or pond area. In the final TSE prototype, two levels are introduced, and fishes move in a random path so that the game end time is not predictable.

The extended motion of the fish near "T" (Figure 4. 7) is incorporated only in level 2 of the game in one fish. The program randomly selects the fish, the fish path, and the number of rotations near "T."

2. *Straight walkover*: In this exercise, the game story selected for this exercise is "Build a House." The elderly have to walk on the brown areas, where the sensors are connected, and walking over the areas where sensors are not connected (as sown in Figure 4. 14 a, b).

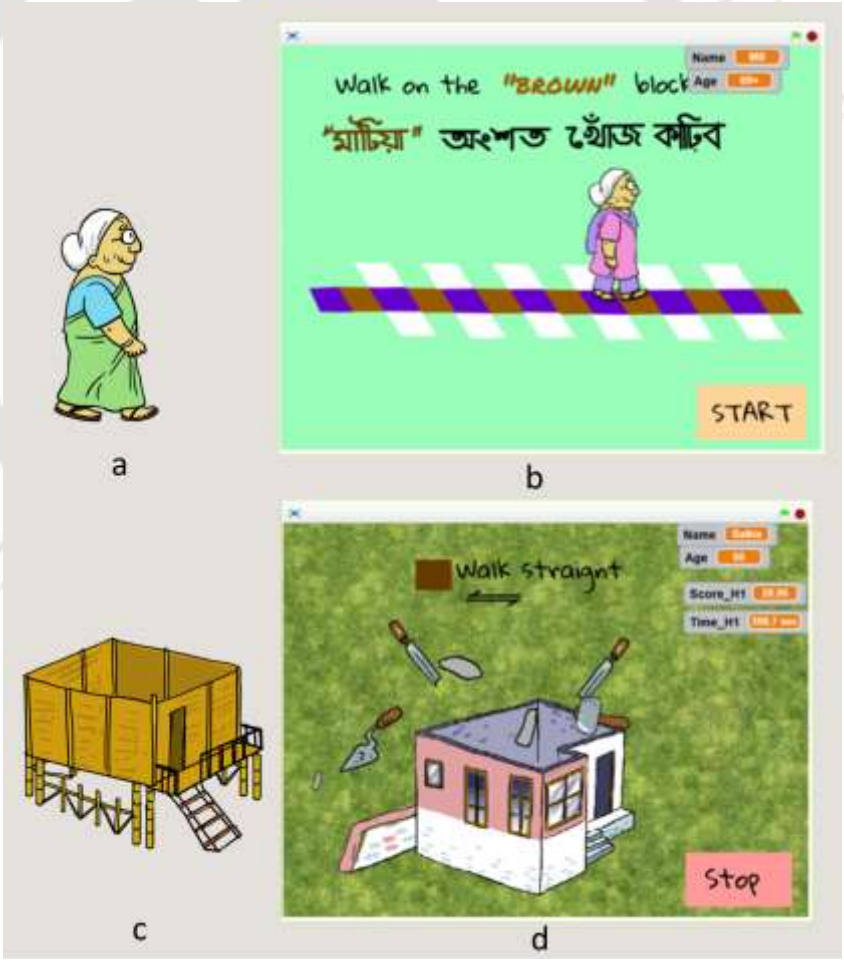


Figure 4. 14. Game story screen display for straight walkover exercise (a) avatar doing straight walkover, (b) on-screen demonstration of doing Straight walkover exercise on the interfacing mat, (c) Sang- Ghar, (d) example of the real-time game screen of building a brick house while doing the exercise

In this game story, two types of houses are introduced, (1) Sang- Ghar (traditional bamboo house found in Assam) shown in Figure 4. 14 (c); (2) Brick house, as shown in Figure 4. 14(d). The game has various stages of house building, from the initial base to the complete house, similar to the house building process.

The game stories in TSE are similar to the real-life of the elderly in India. The stories are tried to link one with another. So, after building the houses, a little gardening game is included in the TSE. Gardening is one of the activities the elderly mentioned enjoy doing. Thus, for the 3rd exercise, this activity is included.

3. *Sidestep over*

For this exercise, the gardening theme is selected; the game name is "Plant a Tree." The user has to step sidewise on the brown area, and on the screen, a seed will grow into a plant through various growth stages. There are three different plants included in this game. An example of the onscreen display of the exercise is sown in Figure 4. 15.

Figure 4. 15. Game story screen display for Sidestep over exercise (a) seed (b) grown plant

After the plantation of trees, the next activity included in TSE is marketing.

4. *Figure 8*: Marketing is a necessity in the household. In the field visit, the elderly mentioned that they slip or fall during rainy days due to slippery surfaces. On rainy days many areas, like open market areas in rural, suburbs, and even urban areas, bricks or other objects are placed at the water-covered grounds, as marked in Figure 4. 16. For the exercise "figure 8," the game story selected is marketing in flood; the name is "Monsoon Market."

Figure 4. 16. Monsoon market theme

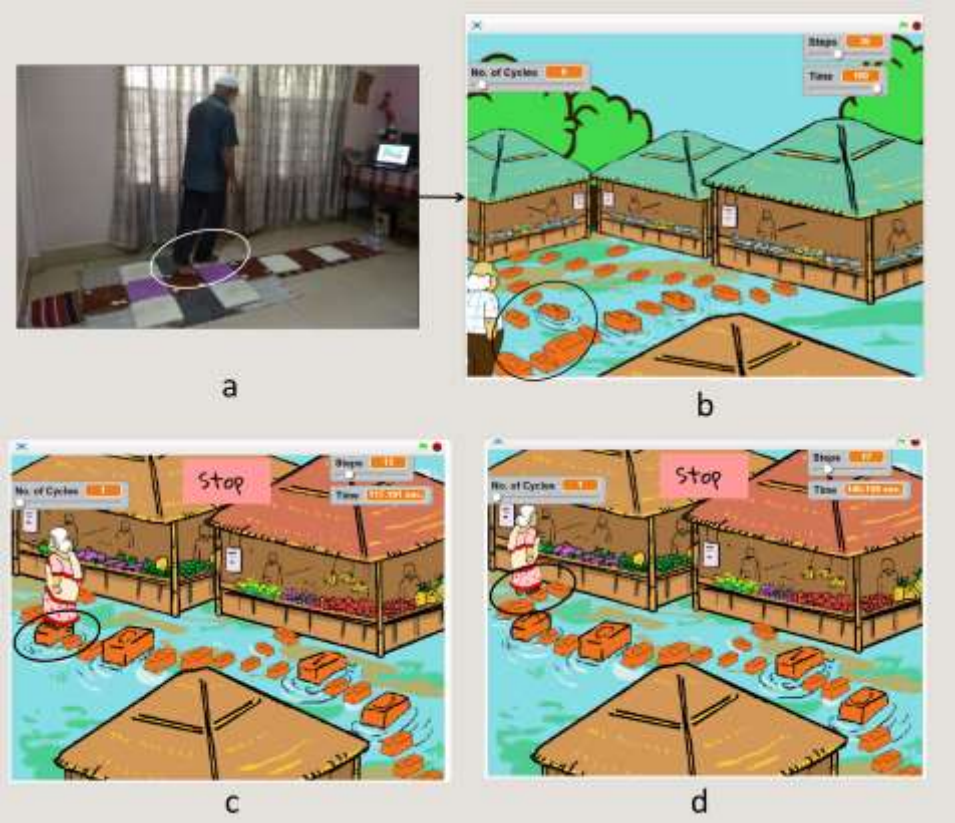


Figure 4. 17. Monsoon market theme to figure 8 exercise (a) elderly doing the task on the mat, (b), (c), and (d) the pathway to the respective market while doing the exercise

For this exercise, the monsoon market theme is selected as, at the time of the pilot study- II, it is observed that the elderly sometimes stumble while doing it. It is a little similar to the action of a person who tries to step from one brick to another during such a flooded area (field observation), as shown in Figure 4. 17. The game story is designed as much similar to real-life marketing scenarios.

During this "figure 8" exercise, there is a possibility of dizziness (filed observation and suggested by the experts, Pilot study-II). They are supposed to complete ten sets. To avoid any mishap, and a small gap is introduced as a game story. This gap is introduced in the form of a conversation between the buyer and seller, which is very common during marketing. An example of an on-screen display of the conversation is shown in Figure 4. 18.

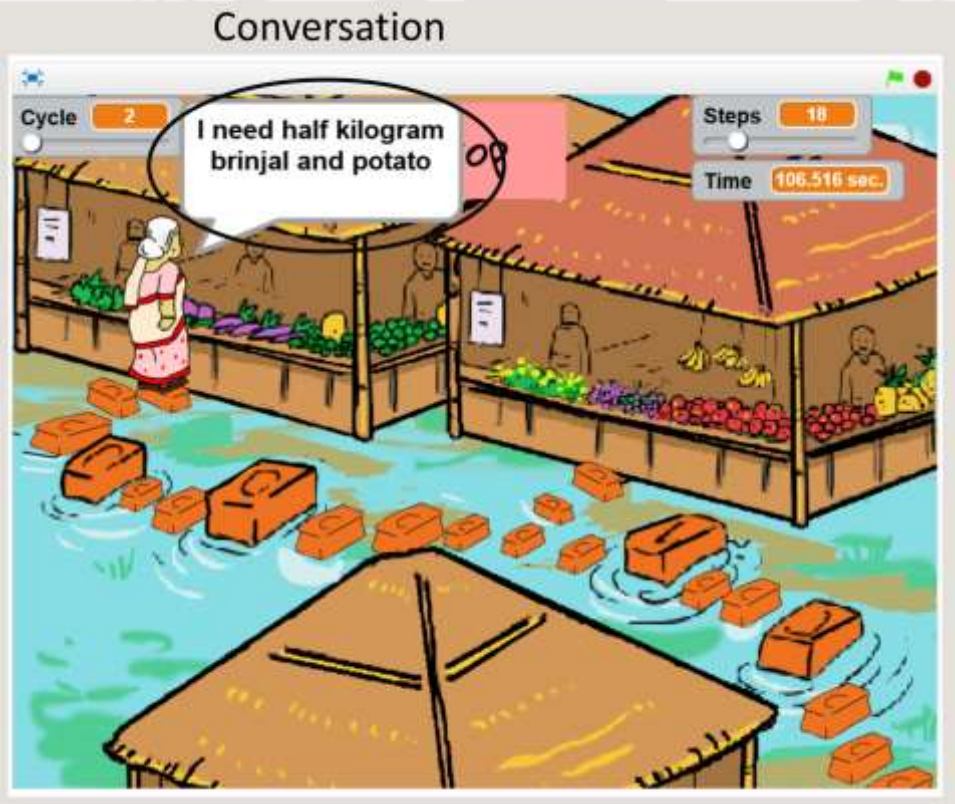


Figure 4. 18. The real-time game screen of the figure 8 exercise provides a little break to the elderly participant as a conversation

There are three different market places designed for this exercise, (1) Vegetable market, (2) Fruit market, and (3) Fish-market, see Figure 4. 19.

Figure 4. 19. Example of the game screen showing various targets (as a market place)

In these above-mentioned markets, 2- 3 shops (game target) (Figure 4. 19. Example of the game screen showing various targets (as a market place) are there in each market, among which the avatar is asked for some specific vegetable or fruit or fish, depending on availability, the avatar either purchases or move to the next shop. An example is illustrated in Figure 4. 20 (a), (c); 1, 2, 3 are different shops that are designed as a game goal "G" to complete the respective cycles of the exercise as prescribed by the expert.

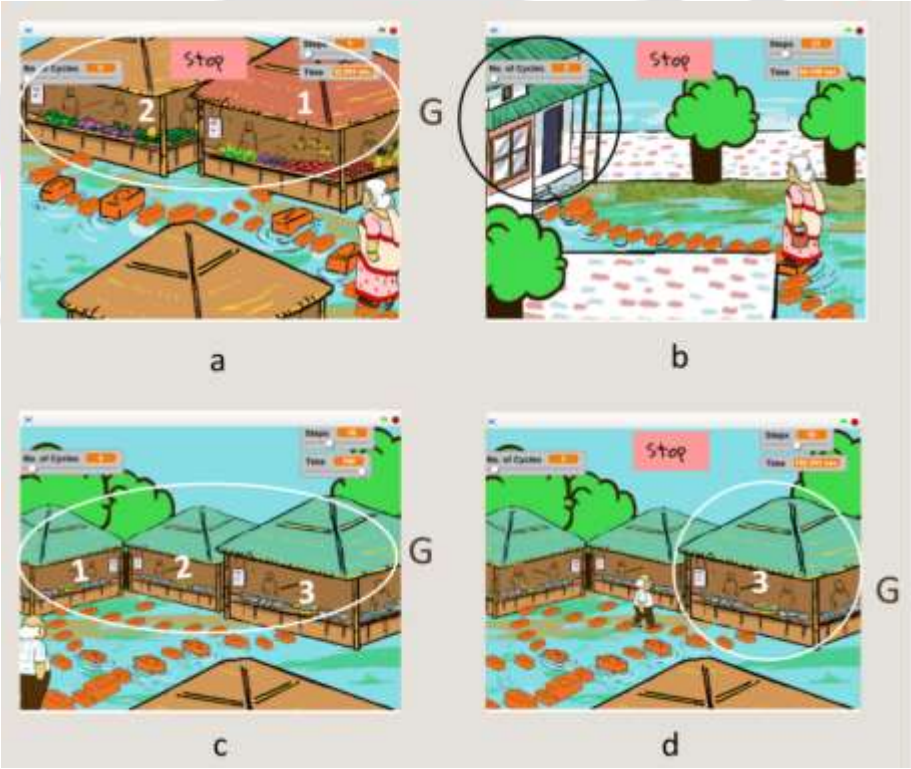


Figure 4. 20. Example of game goal "G" at various stages of the game "Monsoon Market" (a) Goals in the form of shops at the fruit market, (b) coming back to home from the market,

(c) various goals at the fish market, (d) from 2nd shop, the avatar is moving to 3rd shop at the fish market

The market pattern is so designed as in real-life shopping; the avatar is to complete 1 set of exercise while he proceeds from one shop to the other and goes back home after the shopping.

4.5.3 System Interface design

The final selection of the TSE interface is created based on TADT and Indian anthropometric data explained in section 4.3 of this chapter.

The elderly participants need to complete the sets of exercises that can improve their physical balance. For that purpose, the stepping input is collected using the pressure sensors. The sensors will respond to the elderly's steps and send electrical feedback to the system, and then the system will check whether the steps taken by the elderly are placed correctly or not, and then display the output on the screen. The user's correct stepping actions control the game movements. The TSE system architecture is shown in Figure 4. 21, and the system algorithm that controls the working process of TSE is shown in Figure 4. 24.

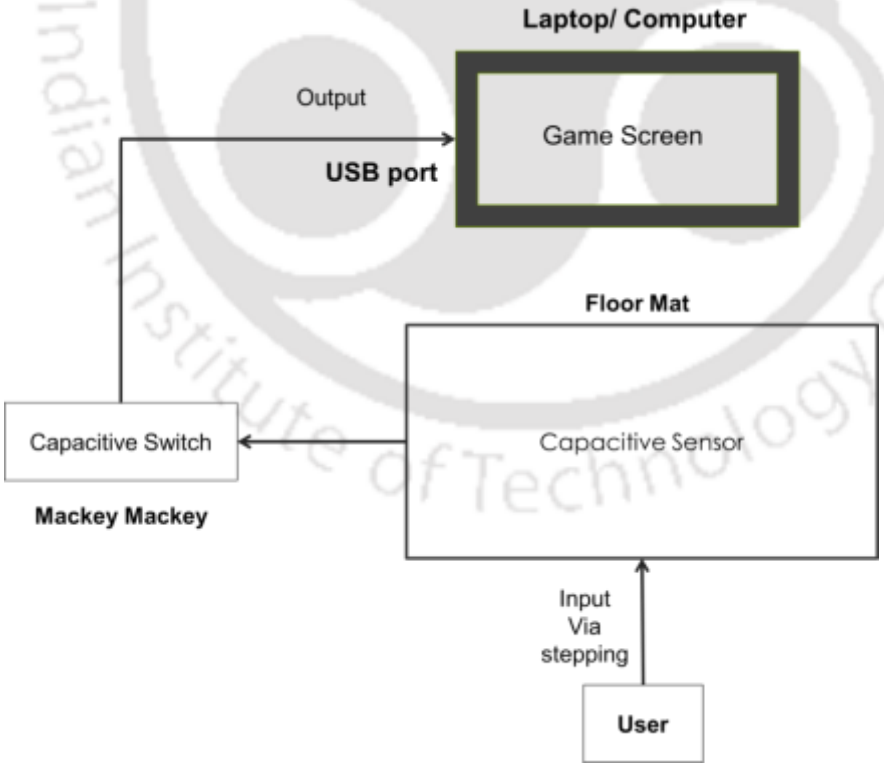


Figure 4. 21. TSE interface system architecture

As shown in Figure 4. 21, the user provides the input (step) on the brown areas of the floor mat, where sensors will identify the pressure (as sown in Figure 4. 22) and send the signal to the Macky Mackey, the Macky Mackey acts as a switch (Figure 4. 23) for on (when step on the sensor)- and off (when no step input is on the sensor); and sends the signal of step on information to the system (as shown in Figure 4. 21). Figure 4. 22 shows the final TSE mat used in the experiment, the dimension of the mat and the areas where the sensors are located.

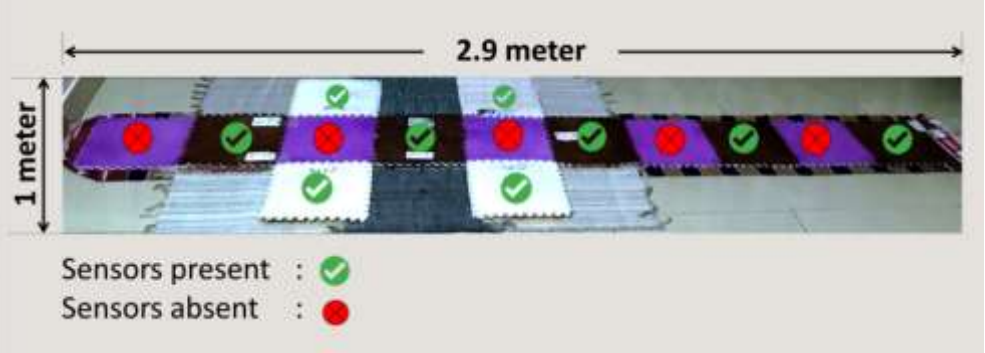


Figure 4. 22. Final TSE- interfaced TSE mat and areas where the sensors are present and absent along with the dimension of the mat

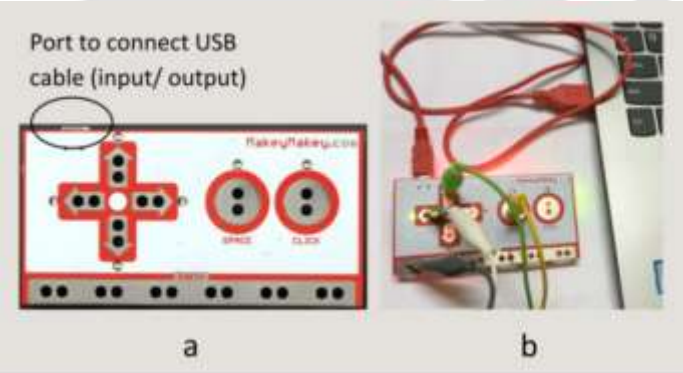


Figure 4. 23. Mackey Mackey: (a) Mackey Mackey circuit, (b) Mackey Mackey connected to the laptop through the USB port

An algorithm controls the mechanism of the TSE system, see Figure 4. 24, for each step input, the delay time has been provided in the programming section with respect to the sensors input and game avatar state. The game avatar changes the position once the user steps on the correct sensor. On the screen, there is the "Start" (Figure 4. 25 (a)) and "Quit" button (Figure 4. 25 (b)) or "Stop" (Figure 4. 25 (c)).

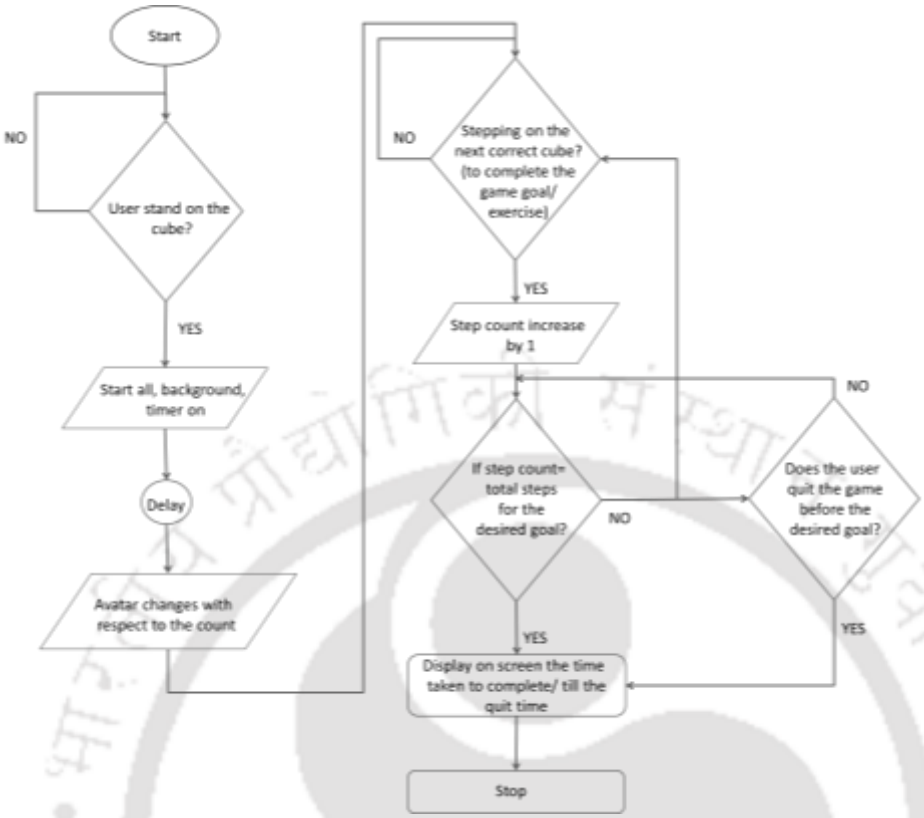


Figure 4. 24. TSE system algorithm

Once the user presses the "Start" and steps on the mat (brown area), "Time" will be displayed on the screen, which means it starts the timer, and their game time will be recorded in real-time. If the elderly move to another location on the carpet, where the sensor is not placed or for wrong exercise moves, then the game will stop until the user steps on the right position again (Annexure C). The more time the user will take to correct their exercise moves longer, the time duration of the game.

If the user wishes to quit the game in between, then they have to press the "Stop" or "Quit" are displayed on the screen. Once the game is stopped, the time is displayed as a "Scoreboard." For elderly time display will give them an idea of their performance improvements. There will be no negative feedback if the user wishes to quit the game. The scoreboard is also displayed once the user finishes the game along with "Clapping" (audial) and appreciation for the completion of the game (Figure 4. 25(d)).

Figure 4. 25. Example of an on-screen display of (a) "Start," (b) "Quit," (c)"Stop," and (d) feedback after completion of the game task (after successfully finishing the prescribed sets of exercise correctly)

Figure 4. 26 presents the architectural model of the control task of the TSE. The pictorial representation shows the systematic flow of the TSE that interacts with the user.

The final prototype of TSE is built on the knowledge gained from theories, research by previous pieces of literature, field observations, feedback, and initial user testing.

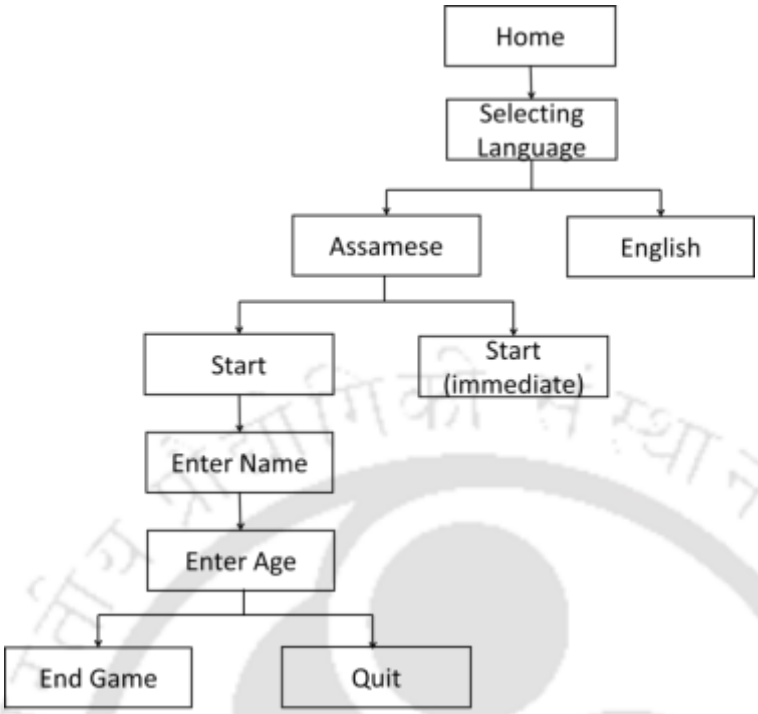


Figure 4. 26. Information Architecture: Control task

Chapter Summary

The TSE is made portable so that the elderly can carry it easily and use it according to their comfortable space. TSE includes only one regional language, "Assamese," along with "English." The process of TSE includes both theoretical and practical approaches. TSE is explicitly designed for the elderly population of India to improve their balance. The design considerations mentioned in this section are specific for TSE, including exercise and interface consideration used in the final prototype.

Table 4. 1 represents the design consideration that is integrated into the TSE; here, both theoretical (from literature review) and a few new design considerations are included that are observed as an essential factor from the initial pilot studies mention in chapter 2 and section 4.3, 4.4, 4.5.2 and 4.5.3 of this chapter 4.

The gap between the exercise intervention and the elderly population of India is tried to merge through TSE. The exergame designed in this research is to determine the outcome of TSE in terms of balance, balance confidence, and FOF in the elderly. The evaluation process includes a systematic approach in training the elderly participants with TSE and evaluating these three parameters using the statistical tool and subjective evaluation.

Table 4. 1. List of design consideration used in final TSE prototype

Theoretical Guidelines	• Real-life interaction mechanism • Elderly's physical condition, their range of motion • No sudden movements • Simple interactive mechanism • No negative feedback • No additional graphics/ annoying messages at an inappropriate time • Visual and auditive feedback
Design consideration	• Stepping exercise sets are converted into a game goal • Repeated movements to complete one goal • Game goals typically break into small parts to boost elderly interest • Relate exercise movement with game story • Language selection option • Instructions in a written form visible through the game • Give a little gap in the form of a game story: Exercise: Figure 8 to avoid dizziness
Design consideration (Exercise)	• Stand (open eye): random time to avoid repetition • Walk straight at an equal distance (30 cm)- walk exercises lifting the leg. • Straight walk: 2.9 m for≅ 210-520 steps with the game. • Sidewalk at an equal distance (30 cm) - walk over without lifting the leg. • Sidewalk: 2.9 m for ≅150 steps.
Design consideration (Story selection)	• Patience to stand still – Catch Fish • Builders home is one of the universal ways of living. • Small steps= Wooden house • More No. of steps= brick house • Idea: Relating the time w.r.t materials, as break house takes comparatively more time to build than the simple wooden house. • After building houses, it's time for a little gardening/ tree planting for the new house • Three different trees (Breaking the goal).

In the next chapter, a brief description of the evaluation process of TSE's effectiveness is presented.

Chapter 5. Design Evaluation of TSE for Elderly Balance Improvement, Balance Confidence, and FOF

5.1 Introduction

The research study described in the thesis investigates TSE's effect on balance, balance confidence, and FOF of the elderly in India. It is essential to conduct such an investigation because fall is a critical problem that leads to various health hazards like fractures, traumatic brain injuries, and even death in the elderly [128]. Along with these, fall leads to fear of falling (FOF), which is also called post-fall syndrome [129]. FOF causes a curtailment of activities in the elderly [23, 130]. It further leads to reduced mobility, and the avoidance of activity may also lead to restricted mobility, loss of functional independence, or reduced functional capabilities and gait speed, reduced independence, causes poor health and poor quality of life, depressed mood, increased spontaneous sway, decreased one-leg stance time and balance performance, and further increases in fall risk [23, 130]. Individuals with FOF and quiet standing and walking measures are linked to balance confidence in the elderly [21]. The elderly with high levels of FOF has a higher risk of future falls, but the elderly with low levels can be protective for falling, irrespective of the presence of balance impairments [25]. The balance (ability to keep the body's center of mass within the limit of the base of support) is the fundamental component of all functional movements [1]. As mentioned in the previous chapters, the negative aging stereotypes, attitudes of the elderly influence the exercise domain, which is related to elders' self-perceptions, such as youthful bias and physical self-worth, etc., [28, 30], therefore, a self-paced step-balance exercises are introduced in the EXG termed TSE.

The effectiveness of the TSE is measured using a screening tool that can detect and evaluate the old person's dynamic balance, which is the primary focus of this investigation. The other most significant focus of the studies is evaluating its effect on balance confidence and FOF.

This chapter presents a statistical analysis of the data collected during the experimental study. The three hypotheses and research questions 1-3 of the thesis have been stated again, and results are discussed in the light of the hypothesis.

Restating the hypothesis:

H1. The use of TSE will improve balance in the Indian elderly.
H2. The use of TSE will improve balance confidence in the Indian elderly.

H3. The use of TSE will reduce the fear of falling in the Indian elderly.

Restating the research questions (1-3)

1. *If a design intervention in the Indian context is infused in the traditional way of doing balance exercise (like stepping), will it improve the balance in the elderly in India?*
2. *Whether using Therapeutic Stepping Exergame (TSE) can improve balance confidence in them?*
3. *What will be the effect of TSE on the fear of falling in the elderly in India?*

5.2 Experiment Design

The hypothesis of the research is tested using the following experiment process Figure 5. 1. Elderly participants are introduced to TSE, and TSE-session is continuous for four weeks, each day 30 minutes. Each participant's balance, FOF, and balance confidence is evaluated using the Y- Balance Test (YBT), Short Fall Efficacy Scale (FES), and The Activities-specific Balance Confidence (ABC) Scale, respectively. The details of these tests are described in the following section of this chapter. The data are taken from the same participants at two different times, before and after the use of intervention- TSE. Data are analyzed using version 20 of the Statistical Package for the Social Sciences (SPSS) software package. The experimental process is shown in Figure 5. 1.

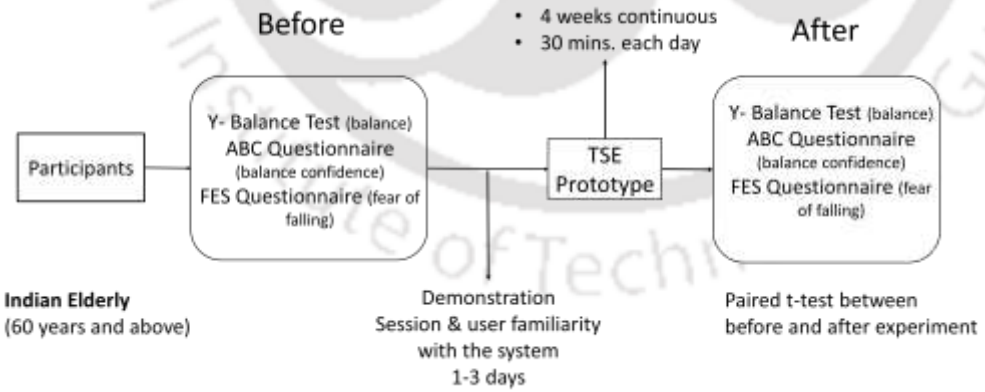


Figure 5. 1. Block diagram showing the experiment process

5.2.1 Variables in the study

The research intends to evaluate TSE's effect on a group of participants having no earlier experience of using EXG. The following Table 5. 1.

Variables in the studythe dependent and independent variables considered for the study.

Table 5. 1. Variables in the study

Research Questions (Tool)	Dependent Variables	Independent Variable
TSE's effect on the balance among elderly in India? (YBT)	Balance	Exergame intervention
TSE's effect on balance confidence among elderly in India? (ABC)	Balance confidence	
TSE's effect on the fear of falling among elderly in India? (FES)	Fear of falling	

5.2.2 Procedure

A researcher has informed all the participants about the details and the process of the experiment. They signed informed consent forms before entry into the study. At first, the facilitator has shown the TSE how to operate and complete the game task. The elderly participants are free to ask questions, doubts about the TSE – if any. To get familiar with the TSE, two to three days (as per the participant's comfort) was given before taking the experiment's video recordings. The test facilitator stood near the participants for their safety in case of balance loss when playing TSE. An observation method was used to understand their problems- if any, to follow the instructions on- screen.

Once the participants are familiar with TSE, the elderly can follow the TSE without any help. The facilitator has assessed the YBT, FES, and ABC Scale. The TSE has clear instructions that are displayed on the screen during playtime. The participants or sometimes the facilitator selected the order of the game selection. They were guided with assistance (query, physical support, refreshments, etc.) when required during gameplay. After playing each game, participants can see the duration and score each time for the particular game, and if they failed to finish the goal, there was no negative feedback included.

Finally, after completing the 4weeks TSE session, the facilitator has assessed the YBT, FES, and ABC Scale, respectively, again.

5.2.3 Participants and selection criteria of the study

For the experiment, the sample size is calculated using the following formula [131]:

$$n = \frac{Z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2} \quad \rightarrow \quad \text{Equation 1}$$

Where, n is the sample size, z is the z score, ε is the margin of error and $\hat{p}$ is the population proportion.

For the research a confidence level of 95% is considered. The z score for 95% confidence level is 1.96; population proportion is considered as 50 % and margin of error is considered as 0.2.

Thus, putting the values in Equation 1, we have,

$$n = \frac{1.96^2 \times 0.5(1-0.5)}{0.2^2}$$

$$\Rightarrow n = \frac{0.9604}{0.04} = 24.01$$

This means 25 or more measurements or surveys are needed to have a confidence level of 95% that the real value is within ±20% of the measured value.

The study is carried out with twenty-seven participants (N=27, ten female and seventeen male). Participants are fit elderly participants in a commonplace in Guwahati, Assam, of India, of age 60- 80 years old (mean= 66.64 years, std. deviation= 5.85 years). The individuals who are aged 60 years or above defined as "Elderly" or "Senior citizen" of India [4]. The term fit includes elderly that are freely ambulant and living independently without significant hepatic, respiratory, cardiac, renal, or metabolic disorder on either clinical examination or laboratory investigation. Although there are biological alterations, they do not take consistent prescribed medication such as reductions in liver mass and glomerular filtration rate, which are the natural trait of aging [8]. All participants are senior citizens of India, and they have voluntarily participated in the experiment; and all of the participants signed informed consent forms before entry into the study and examined by expert medical personnel. All the participants can stand and walk independently. The characteristics of the participants are shown below in Table 5. 2 (A) and (B).

Table 5. 2. Characteristic of the participants

(A)

Variables	Mean ± Std. Deviation

Age (years)	66.44 ± 5.84
Leg Length (cm)	
Left Leg	90.39 ± 4.82
Right Leg	90.46 ± 4.74

(B)

Characteristic	No. of Participants/ Total no. N (%) (N =27)
Total Participant Started	30
Completed	27
Dropout	3
Female Sex	10/ 27 (37)
Age:	
60-69 yr.	20/27 (74.1)
70-79 yr.	6/27 (22.2)
80-90 yr.	1/27 (3.7)
Education:	
Less than high school	2/27 (7.4)
Less than graduation	6/27 (22.2)
Graduate degree	16/27 (59.3)
Postgraduate degree/ Higher	3/27 (11.1)
Occupation/ Ex- service	
Business	3/27 (11.1)
Civil Service	1/27 (3.7)
Home Maker	6/27 (22.2)
Public/ Government Sector	14/27 (51.9)
Private Sector	1/27 (3.7)
Teaching	2/27 (7.4)

5.3 Y- Balance Test (YBT)

The Y- Balance Test (YBT), also termed as the "modified Star Excursion Balance Test (mSEBT)," was used in the study to evaluate the dynamic balance improvement in the participants. The mSEBT is a widely used screening tool among physical therapists to assess dynamic balance improvement and identify the dynamic balance deficits in individuals after following a preventive training program [110, 132]. YBT is a tool to evaluate the dynamic balance. The three reach lines in YBT labeled concerning the stance leg as anterior (A), posteromedial (PM), and posterolateral (PL) directions, as shown in Figure 5. 2. Angles between the A and PM line and between the A and PL line are 135° and between the PM and PL line is the angle of 90°(Figure 5. 2). The lines are created with the help of black tape and standard tape measures on a white chart study (Figure 5. 3- 1). YBT involves a unilateral stance while attempting to reach the maximum distance by the opposite leg's big toe in 3 different directions: A, PL, and PM for both lower extremities (LE). The following figures give the measurements of the Y- Balance Test, and the example of doing it using the Y- Balance Test, reference is shown in Figure 5. 2, and Figure 5. 3. Example of participants doing Y- Balance Test about left/ right stance leg before and after the intervention in 3 directions: A, PM, PL, respectively.

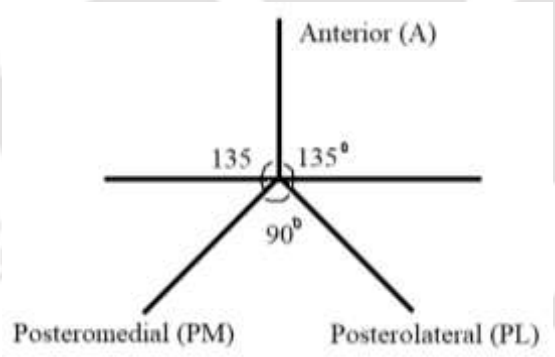


Figure 5. 2. Y- Balance Test Reference

The participant has to keep their hands on the hips in the test, and they are barefooted. There are three trials for each LE in all directions. The trial has to discard if the stance LE is lifted or moved, or weight is transferred to the reaching foot, and the balance is lost, or hands are removed from hips. In these cases, the participant has to repeat the trial. For the anterior direction, a participant has to stand on one LE with the most distal part of the big toe at the cross of the Y at the beginning of the anterior tape measure (Figure 5. 3).

With the other LE, the participant has to reach the maximum comfortable distance with the most distal part of the big toe along the A-line a light touch keeping the balance (Figure 5. 3- 2). In the two-posterior reach (PL and PM) directions, the participant has to stand with the most posterior part of the heel at the cross of the Y at the beginning of the PL, and PL tape measures to reach as far as possible along each of the three reach lines. After each trial participant has to bring the leg back to the center while maintaining a single-leg stance with the other leg, each participant gets ten seconds of rest in between the different trials of one reach direction (Figure 5. 3- 3,4). The recorded scores of each trial in each reach direction are in centimeters. All of the trials are taken before and after the TSE is introduced to the participants. Throughout the data analysis, SPSS (Statistical Packages for Social Sciences) is used as a statistical tool.

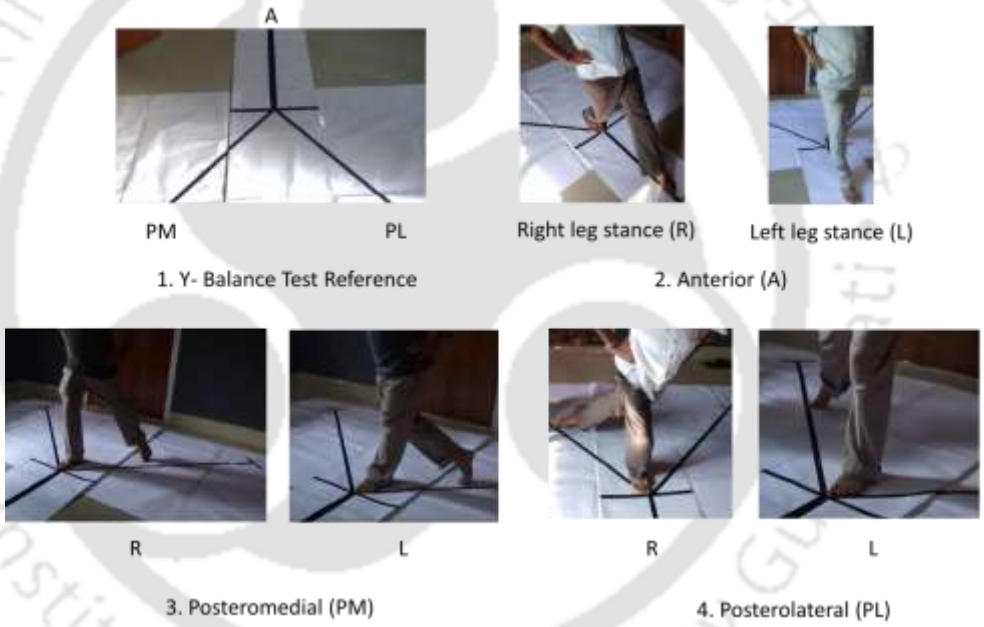


Figure 5. 3. Example of participants doing Y- Balance Test about left/ right stance leg before and after the intervention in 3 directions: A, PM, PL

5.4 The Activities-specific Balance Confidence (ABC) Scale

The ABC [112] (Annexure B1) can be self-administered or administered via personal or telephone interviews, and regardless of the method of administration, each respondent should be queried concerning their understanding of instructions and probed regarding difficulty answering specific items. The level of concern is measured on the percentage points on the scale from 0% to 100%.

5.5 Short Fall Efficacy Scale (FES)

The Short Falls Efficacy Scale-International (FES) (Annexure B2) is a short, easy to administer tool that measures the level of concern about falling during physical and social activities inside and outside the home whether or not the person does the activity. The level of concern is measured on a four-point Likert scale (1=not at all concerned to 4=very concerned) [23]. For this study, the Short FES- I is used as it is more feasible in settings and needs less time for the assessment as respondents are less able to fill in longer questionnaires [133].

5.6 Data analysis and Hypothesis testing

5.6.1 Study of TSE effect on the balance among the elderly in India

The following hypothesis (H1) has been tested to understand the impact of TSE on elderly balance performance.
H1. The use of TSE will improve balance in the elderly in India.

To test the hypothesis, H1, YBT is done. To analyze the YBT data, the Relative (normalized) distance in each direction (%) (that is, the average distance in each direction/leg length × 100) is obtained for both LE. To analyze the effect of the intervention- TSE, a paired t-test is done, as the assumption of normally distributed difference score is less than the maximum allowable values for *t*-test (i.e., skew < |2.0| and kurtosis < |9.0| [134]). The statistical result is significant at $p \leq 0.05$. Indicating there is a significant difference between the pre-intervention and post-intervention results for each LE in all three directions for both of the LE shown in Table 5. 3. Therefore, TSE has improved the balance of the elderly in India. Thus, the null hypothesis H01is failed to accept, and H1 is accepted. The results are evaluated, keeping 95% CI.

Table 5. 3. Reference values for the Y- Balance Test (expressed as a percentage of the leg length (%LL)

Variables (cm) Direction- stance leg	Pre- Post use of TSE Mean± Std. Deviation	Paired Differences 95% Confidence Interval (CI)	P-value
A- Left Leg	16.95 ± 7.2	14.1 -19.8	<.00001
PL- Left Leg	21.6 ± 9.99	17.6 - 25.5	<.00001
PM- Left Leg	19.27 ± 9.46	15.5 -23	<.00001

A- Right Leg	17.8735 ± 7.26	15 - 20.7	<.00001
PL- Right Leg	18.9005 ± 9.66	15 - 22.7	<.00001
PM- Right Leg	21.3334 ± 9	17.8 - 24.9	<.00001

Overall, from H1, it can be seen that TSE has improved the balance in the Indian elderly in both LE in all the three directions, that is A, PM, and PL.

5.6.2 TSE effect on the balance confidence and fear of falling (FOF) among the elderly in India

The following hypothesis H2 deals with testing the influence of TSE on the elderly balance confidence among the elderly in India.
H2. The use of TSE will improve balance confidence in the elderly in India.

The evaluation of the impact of TSE on elderly balance confidence is done using a paired *t*-test between the pre-and post-intervention data. For balance confidence, the assumption is satisfied as to the estimated skewness, and kurtosis levels are estimated at 0.683 and 1.164, respectively, which is less than the maximum allowable values for *t*-test (i.e., skew < |2.0| and kurtosis < |9.0|) [134]. The descriptive statistics for the balance confidence in the elderly participants, pre-intervention (mean, M= 56.31, std. deviation, SD= 11.83) and post-intervention (M= 72.69, SD= 12.11). The statistical result shows that t (26) = -18.528, p<.05, indicating that the post-intervention balance confidence score is statistically significant and higher than the pre-intervention.

Table 5. 4. shows the paired *t*-test score for FOF and balance confidence in the participants.

Table 5. 4. Paired t-test value for FOF and balance confidence

	Paired Differences		t	Sig. (2-tailed)
	M	SD		
FOF	9.11	3.77	12.57	.000
Balance Confidence	-16.38	4.59	-18.53	.000

The hypothesis H3 deals with the impact of TSE on FOF among the elderly in India. Restating the hypothesis H3:
H3. The use of TSE will reduce the fear of falling in the elderly in India.

For FOF, the descriptive statistics shows, pre-intervention (mean, M= 19.67, std. deviation, SD= 4.54) and post-intervention (M= 10.56, SD= 2.39). The evaluation of the impact of TSE on elderly balance confidence is done using a paired *t*-test between the pre- and post-intervention data. Before conducting the analysis, the assumption of normally distributed difference scores is examined. The premise is satisfied as to the estimated skewness and kurtosis levels assessed at -0.061 and -0.075, respectively, which is less than the maximum allowable values for *t*-test (i.e., skew < |2.0| and kurtosis < |9.0| [134]. The statistical analysis shows that t (26) = 12.573, p<.05 (Table 5.3)

The results indicate TSE has significantly reduced the FOF in the elderly in India, as the post-intervention FOF score is significantly lower than the pre-intervention in the participants. Thus, the null hypothesis i.e., TSE does not affect FOF is failed to be accepted, therefore, accepting the alternative hypothesis H3.

Overall, from the experiment results, we failed to accept the null hypothesis H01, H02, H03, thus accepting the working hypotheses H1, H2, H3 of the thesis.

This chapter addresses the first three research objectives and answers the initial three research questions of the thesis.

Table 5. 5 gives the summary of the experiments in terms of research objectives and research questions.

Table 5. 5. Summary of the experiments in terms of research objectives and research questions

Sl. No.	Research Objectives	Research Question	Comment
1	To assess the effectiveness of the stepping exercise design intervention in terms of balance in the Indian elderly.	If a design intervention in the Indian context is infused in the traditional way of doing balance exercise (like stepping), will it improve the balance in the Indian elderly?	To assess the effectiveness of TSE in terms of balance YBT is used, and results showed statistically significant improvement in the balance in the elderly in India.

2	To assess the effectiveness of the designed stepping exercise intervention in terms of balance confidence in the Indian elderly.	Whether using the designed intervention termed as Therapeutic Stepping Exergame (TSE) can improve balance confidence in them?	The effectiveness of TSE in terms of balance confidence is assessed using the ABC scale. The results indicate there is a statistically significant improvement in the balance confidence in the elderly in India from pre- to post-intervention data.
3	To assess the effectiveness of the design intervention in stepping exercise, in terms of fear of falling in the Indian elderly.	What is the effect of TSE in fear of falling in the Indian elderly?	The effectiveness of TSE in terms of fear of falling is assessed using the FES-I scale. The TSE decreases the fear of falling in the elderly in India at a statistically significant level.

5.6.3 TSE effect and the correlation of balance confidence and fear of falling (FOF) among the elderly in India

The previous section elaborates on the impact of TSE on dynamic balance, balance confidence, and fear of falling. In this section, the correlation between the balance confidence and fear of falling is evaluated before- and after using TSE. To assess the relationship between FOF and balance confidence using TSE, the Pearson correlation is performed. Before conducting the analysis, a normally distributed difference score has examined. The assumption is satisfied. The list of correlation value is presented in Table 5. 6, and a scatter plot of balance confidence (ABC scale) and fear of falling (FES) in Figure 5. 4.

Table 5. 6. Correlation for balance confidence (N= 27)

	ABC	Fear of Falling (FOF)
Activity of Balance Confidence (ABC)	1	-0.682**

Note. **Correlation is statistically significant at the 0.01 level (2-tailed).

The Pearson correlation results show the Fear of falling is negatively related to balance confidence, r (26) = -.682, p< 0.01, and with long term training, it can influence more strongly. These findings indicated that Balance confidence increases with a decrease in fear of falling.

The scatter plot in Figure 5. 4 shows that the increase in the balance confidence in elderly FOF will decrease. The effect size for balance confidence (r^2= 0.466) indicates that the balance confidence in participants accounted for a portion (46.6%) of the variability in fear of falling. Thus, this study suggests that TSE has reduced the FOF and increases the balance confidence in the elderly population in India. The result also indicates the negative relationship between the FOF and balance confidence using TSE.

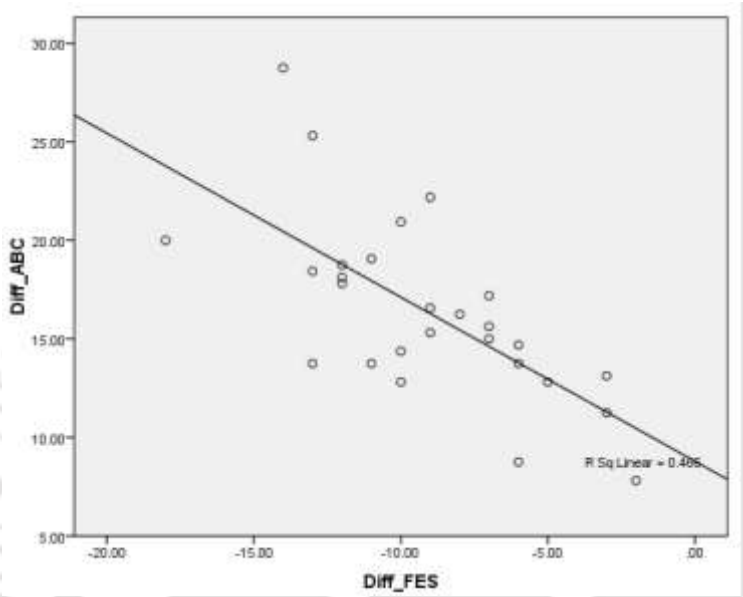
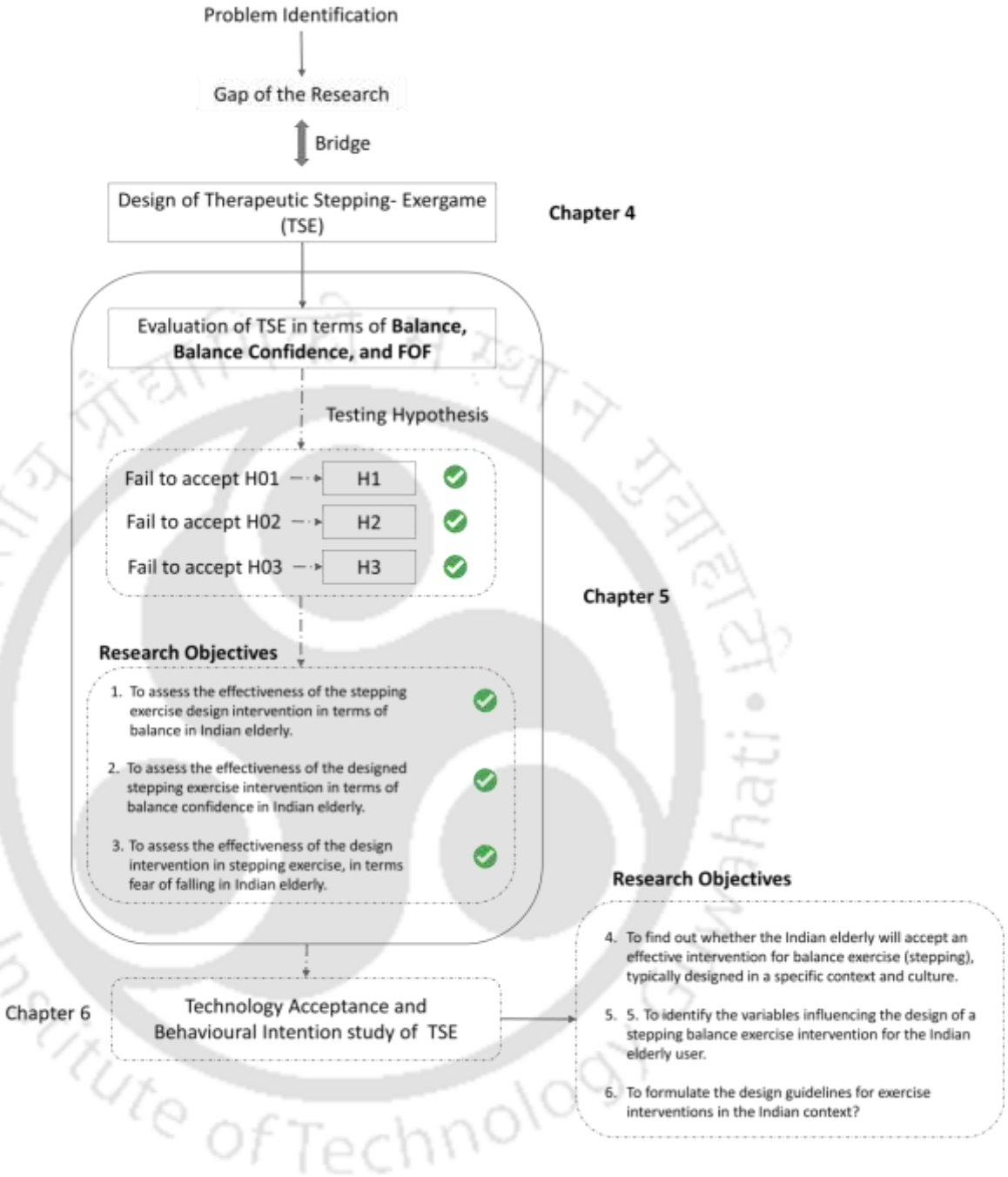


Figure 5. 4. Scatter plot FOF and balance confidence

Chapter summary

The chapter presents the results of the experiment conducted with the tailored EXG-TSE with the elderly participants in India. The results indicate that the TSE influences the improvement in balance, balance confidence and reduces the fear of falling. In the next Chapter 6, we present further experiments conducted to test our prototype and user acceptance.



Chapter 6. Validation of Inferential Guidelines through Technology Acceptance and Behavioural Intention study of TSE

6.1 Introduction

The design strategy is to come up with a creative solution, addressing the elderly fall issue. In the chapter4, a design strategy is adopted to address the elderly fall-related issue in terms of exercise intervention that is TSE. In the previous chapter, it is already established that TSE is an exercise intervention that has improved the balance and balance confidence in the elderly while reducing the FOF in them. If the TSE is well accepted by the elderly in India, the strategy used in TSE's design process can be considered an acceptable tool for future designers.

The use of technology is a prospective way of reducing elderly inhibition towards exercise. Exergame (EXG) can change the elderly's attitudes towards health, endorse their healthy behavior, and improve balance [31, 114]. EXG can interlink the exercise (alleged as unpleasant and dull [29]) with body movements to progress within a game (perceived as pleasant and entertaining [83]). Studies have measured EXG usability and acceptability, where acceptability is measured as a general aspect of usability using the Technology Acceptance Model (TAM) [135]. Unified Theory of Acceptance and Use of Technology (UTAUT) model has been applied and tested extensively to predict system usage and make mobile health, technology-adoption- and technology-usage-related decisions in various fields such as interactive whiteboards, home telehealth services, net banking etc. [136, 137, 138]. Such technology acceptance models or theories are used in studies aiming to predict and explain individual behaviors towards the acceptance and usage of new technologies. Studies used EXG like Wii, Silverfit, etc., which are Westernized and does not consider Indian context in the design process. In the Indian context, almost no attempt has been made to study its (EXG) acceptance or its effectiveness as an elderly fall intervention. One of the critical challenges faced by researchers is developing a new technological product that can effectively benefit the elderly population of India.

The product must also meet the requirement of the cultural, context-specific need of the elderly, like their attire, traditional belief system, the feasibility of the availability of the materials or product installation requirements, and mitigate age-related declines in physical and cognitive aspects. In technology research, the user acceptance of technology is considered as the

key factor for successful implementation [79]. From the literature review, as discussed in Chapter 2, it has been identified that the information regarding such type of technology is not widely aware of among the elderly in India. In the Indian context, whether the elderly population will accept such new technology requires a broader user's perspective. If they do- what are the individual constructs influencing their intention to use it. The Indian elderly's acceptance with EXG has been insufficiently reconnoitered so far. To fill this void, a tailored EXG TSE is developed. An experimental study is designed with the elderly in India to influence the elderly to do exercise positively and understand the Indian elderly's response towards EXG.

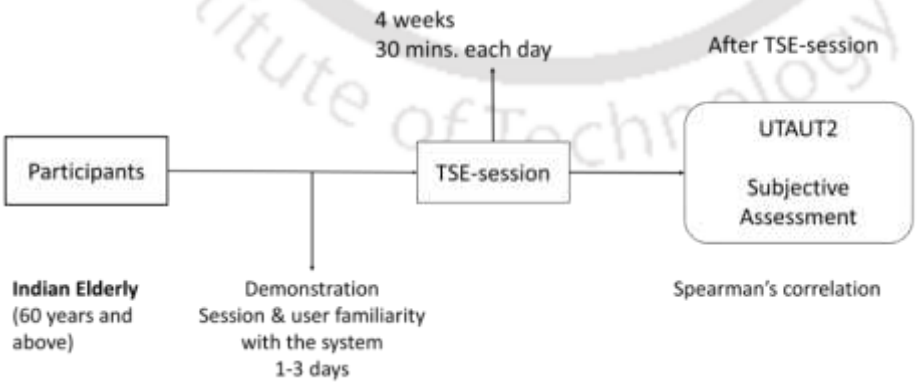
In this experiment, the focus is on the acceptability of TSE. It helps to evaluate the acceptance and constructs that lead to the intention of the use of technology in a consumer context, using the Unified Theory of Acceptance and Use of Technology (UTAUT2). The experiment helps to answer the research questions 4 and 5 of the thesis.

Restating Research Questions (4,5)

4. *Whether TSE will be accepted by the elderly in India?*
5. *What are the key constructs considered by the end-users to use TSE?*

6.2 Experiment design

The experiment is described in 5.2 chapter 5, and after completion of a 4weeks continuous TSE session, participants are requested to fill the UTAUT2 questionnaire (Annexure B3, adopted a validated questionnaire (Siow, 2016)).



UTAUT2= Unified Theory of Acceptance and Use of Technology

Figure 6. 1. Block diagram showing the experiment process

After the TSE-session is completed, the facilitator also conducted a semi-structured interview based on the technology acceptance model's constructs to assess more users' insight into their likeliness in the particular EXG. Figure 6. 1. Block diagram showing the experiment process.

6.3 UTAUT2- Unified Theory of Acceptance and Use of Technology2

UTAUT2 is a unified model for technology acceptance and use of technology developed by Venkatesh 2003, which assimilates eight models (previously developed) into one comprehensive model [114]. It has contingencies and critical factors related to the prediction of behavioral intention to use technology. UTAUT2 has served as a baseline model for new technologies and has been valuable in understanding technology adoption. The UTAUT2 model is shown in Figure 6. 2.

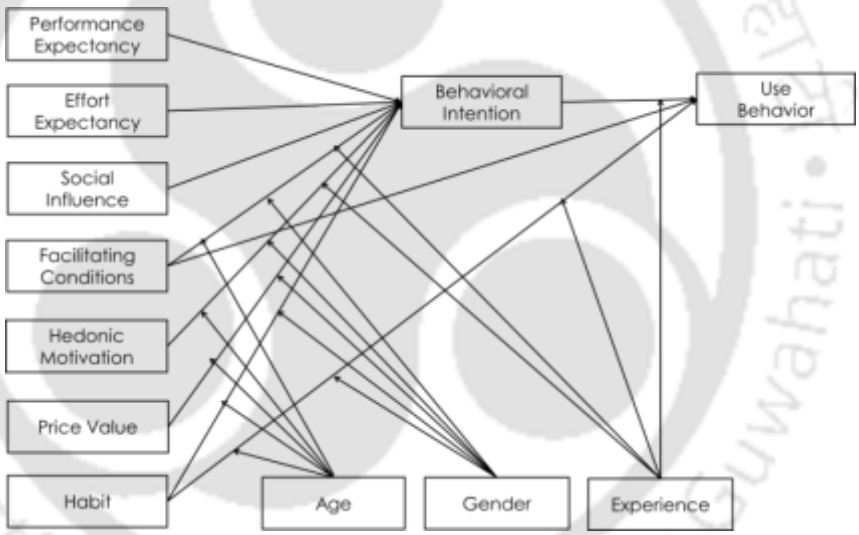


Figure 6. 2. Research Model: UTAUT2 (Venkatesh, 2012)

UTAUT2 key constructs are Perform Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), Hedonistic Motivation (HM), Price Value (PV), Habit (H), and Behavioral Intention (BI) to use technology. Individual differences are age, gender, and experience.

However, this study using UTAUT2 employed only the understanding of tailored EXG and elderly Indian response towards it and the key constructs that they consider towards technology use. The age range is considered 60 years and above, and all participants have no earlier experience on EXG; gender correlation is not analyzed for this study. Literature suggests that

the acceptance and use of technology differ across age, gender, and experience [11].

6.4 Data analysis procedures

For the quantitative analysis of acceptance of TSE, a validated questionnaire [139], for EXG with the elderly is used. The study's dependent variables are elderly performance in the game, as well as behavioral intention (BI) from the Unified Theory of Acceptance and Use of Technology (UTAUT2) model as the intention to use such EXG in the future. All variables are surveyed in 5-point Likert scales. The Cronbach's alpha values of all constructs are 0.8, indicating the instrument has a high degree of reliability, and the results could be considered very stable. Later the data are analyzed using inferential statistics and observatory methods.

Spearman's correlation analysis is used to determine which constructs are the most influential to use the intervention TSE, as the premise is not satisfied with the normality test and had outliers in the response data. In this study, in the response data, the estimated skewness and kurtosis levels assessed are more than the maximum allowable values for Parametric analysis (i.e., skew < |2.0| and kurtosis < |9.0| [134]).

6.5 Results and analysis

6.5.1 Inferences for newly design TSE technology acceptance

The study results (Table 6. 1) show a positive response from the participants. The descriptive statistics show that the scores for each construct (UTAUT2) to use the EXG are high. The average scores from the respondents' for Performance Expectancy (PE) ranged from 4.95± .099. In Effort Expectancy (EE), the score ranged from 4.94± 0.144, which is high. The score of Social Influence (SI) is ranged from 4.91± 0.149, indicating that the family and friends are highly supportive of the elderly to use it. The score for Facilitating Conditions (FC), Hedonistic Motivation (HM), Price Value (PV), and Habit (H) are 4.93± 0.167, 4.93± 0.169, 4.81± 0.447, and 4.81± 0.313, respectively, which shows a high scale for these constructs. The score for behavioral intention (BI) to use is 4.96± 0.107. These results mean that the behavioral intention level of the Indian elderly to use the tailored EXG is excellent, and they accept EXG. The mean BI of the elderly male and female are 4.9± 0.03 and 5± 0.00. Elderly female participants showed a higher interest than the male.

Table 6. 1. Descriptive Statistics for individual items in the UTAUT2-model (N= 27).

Table 6. 1. Descriptive Statistics for individual items in the UTAUT2- model (N= 27)

	Mean (M)	Std. Deviation (SD)
Performance Expectancy (PE)	4.95	.099
Effort Expectancy (EE)	4.94	.144
Social Influence (SI)	4.91	.149
Facilitating Conditions (FC)	4.93	.167
Hedonistic Motivation (HM)	4.93	.169
Price Value (PV)	4.81	.447
Habit (H)	4.81	.313
Behavioral Intention (BI)	4.96	.107

The results imply that the elderly in India have accepted the TSE. In the next section, research question 5 is attempted to answer.

6.5.2 Inferences for Behavioural Intention to use the TSE technology

As the elderly have accepted the TSE, to determine the key constructs that play an essential role in influencing the behavioral intention of the use of TSE, Spearman's correlation is used. The analysis shows (

Table 6. 2, Figure 6. 3) the most strong significant positive relationship is in between HM to BI, which is 0.791 at $p<.01$ level, followed by PE, FC, and EE, which are 0.742, 0.738, and 0.693 at $p<.01$. There is a moderately strong correlation between PV and H to BI to use of exergaming in the Indian elderly, that is, 0.568 and 0.544, respectively, at $p<.01$.

The SI was found to be insignificantly correlated in terms of predicting the behavioral intention of the EXG use. In this study, Hedonic motivation (HM) shows the maximum (0.791 at $p<.01$) role in the intention to use. It is defined as the pleasure or fun derived from using technology, and it has been previously found as an essential role player in determining technology acceptance and use [11]. The result means the elderly found TSE fun and entertaining, and TSE positively helps the Indian elderly to complete their exercise.

Performance expectancy (PE) is defined as the degree to which an individual believes that using the system will help them to attain gains in job performance [115]. PE is found as the second most crucial construct (0.742 at $p< .01$) in the use of TSE. The elderly realized using TSE, their balance and balance confidence will improve and reduce their fear of falling into day-to-day activities.

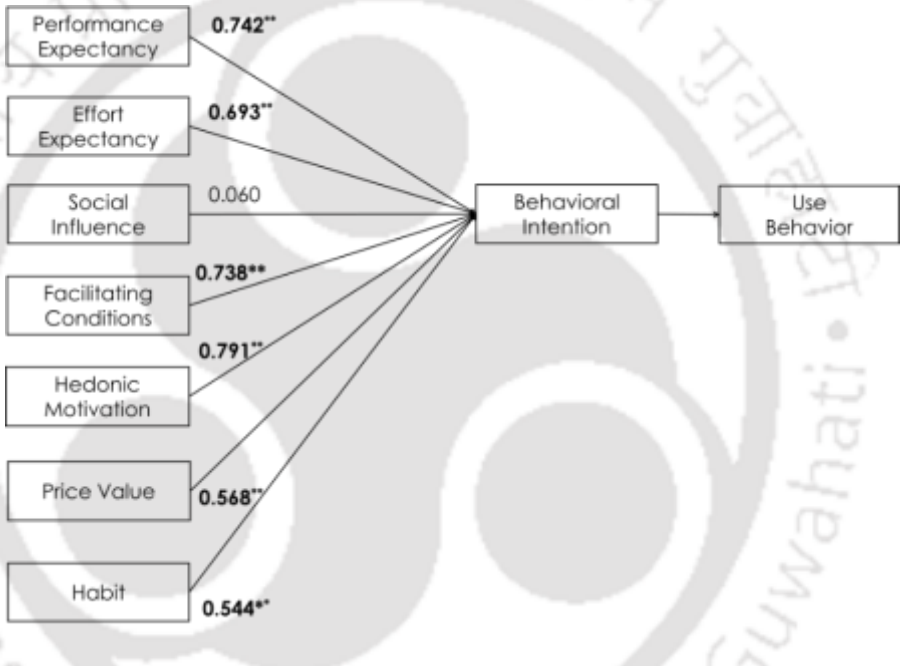
Facilitating Conditions (FC) is the degree of support that an individual believes in getting from an organizational and technical infrastructure available towards the use of the system [115]. This study captures the concepts of resources, knowledge to use, compatibility with other required systems, and supportive help to use the TSE. After the use of TSE, the elderly considered TSE's FC satisfies and plays an important construct (0.738 at $p< .01$) to use TSE. Figure 6. 3. Correlation: UTAUT2 model for this study.

Effort Expectancy (EF) is the easiness that an individual thinks of when using the system [114]. EF of TSE is appreciated by the Indian elderly. It comes out as the fourth most crucial construct (0.693 at $p< .01$) in this study to use TSE.

Price value (PV) is defined as consumers' cognitive trade-off between the system's perceived benefits and the monetary charge for using them [11]. PV is moderately (0.598 at $p< .01$) associated with using the TSE. The elderly felt that with a few more game- exercise TSE is a value-for-money product.

Habit (H) is the extent to which users automatically perform behaviors because of learning [11]. In this study, H is moderately correlated (0.544 at $p < .01$) with BI. The elderly used the TSE and intend to use it in the future as they felt habituated using it while doing the exercise.

Social influence (SI) is defined as the extent to which consumers perceive it to be important to family and friends and believe they should use a particular technology [11]. In the previous study by Venkatesh 20012; the effects of SI on BI are all moderated by individual characteristics like different combinations of age, gender, and experiences. However, the study is not statistically correlated with the future intention to use the TSE.



**p < 0.01; other correlation is insignificant.

Figure 6. 3. Correlation: UTAUT2 model for this study

Overall, the results answer the 5th research question of this thesis. The finding suggests that HM, PE, FC, EE, PV, and H are the key constructs for accepting the TSE by the elderly in India. HM is the most influential construct that influences the elderly's intention to use TSE, as shown in table 6.2.

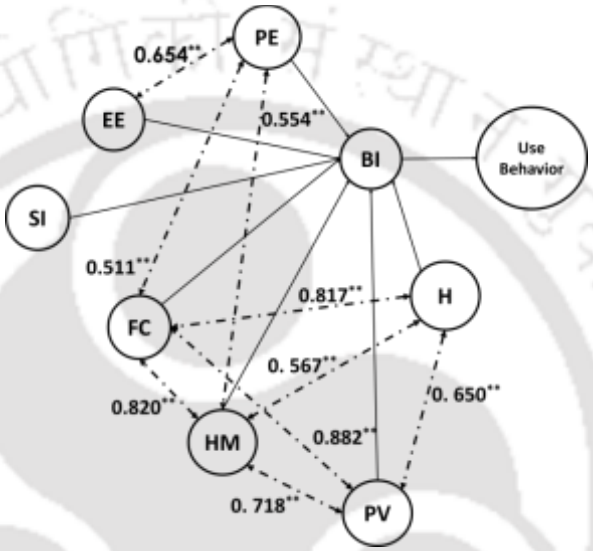
Table 6. 2. Spearman's Rho Correlation for UTAUT2 (N= 27)

	PE	EE	SI	FC	HM	PV	H	BI
Perform Expectancy (PE)	1.000							
Effort Expectancy (EE)	**.654****	1.000						
Social Influence (SI)	.153	.215	1.000					
Facilitating Conditions (FC)	**.511****	.321	-.010	1.000				
Hedonistic Motivation (HM)	**.554****	.351	-.094	**.820****	1.000			
Price Value (PV)	.379	.033	-.186	**.882****	**.718****	1.000		
Habit (H)	.232	.284	.245	**.817****	**.567****	**. 650****	1.000	
Behavioral Intention (BI)	**.742****	**.693****	.060	**.738****	**.791****	**.568****	**.544****	1.000

Note: **. Correlation is significant at the 0.01 level (2-tailed).

6.5.3 Inter-correlation between the UTAUT2 constructs

To understand how the constructs are related to one another, spearman correlation is used. Figure 6. 4 shows the interrelation between the critical constructs found in the study that affects the future intention to use the TSE by the dotted lines.



**p < 0.01; other correlation is insignificant.

Figure 6. 4. Inter-correlation between the constructs in the UTAUT2 model

The HM is very strongly positively correlated with the FC and PV of the TSE, that is, 0.820 and 0.718 respectively at p<.01. HM is also moderate, positively correlated with PE and H, 0.554, and 0.567 at p<.01, whereas it is not correlated with the EE and SI in the present study. PE is also moderately positively correlated with FC, 0.511 at p<.01. It is not correlated with other constructs like PV, H, EE, and SI. EE is not correlated with any constructs in the use of TSE.

Along with HM, PE; FC is also very strongly positively correlated with PV and H, 0.882 and 0.817 respectively at p<.01. Other constructs EE and SI are not significantly correlated with it. PV is positively correlated with the H, 0.650 at p<.01. The results show other than constructs FC, HM, and H; it is not significantly correlated with others.

This indicates that the exergame-prototyped solution, TSE, will positively influence elderly fall research in India. To understand the elderly's

perspective on TSE, a qualitative study with subjective assessment is carried out.

6.5.4 Inferences of subjective assessment

The participants are requested to share their valuable feedback on their experiences after using the TSE prototype. An open-ended questionnaire is used, and their responses are transcribed thoroughly. To analyze the data content analysis method is used. The researcher coded the transcribed data and categorized it into five categories, namely (i) Perceived Usefulness, (ii) Ease of Use, (iii) Relative Advantage, (iv) Extrinsic Motivation, (vi) TSE learning experience, (vii) Facilitating Conditions, (viii) Family factor, and (ix) Cost factor.

Participants reported that the introduction of TSE would help to improve their balance and motivate them towards exercise. Relative advantages they feel are that TSE helps them reduce fear in doing day-to-day activities and feeling active. Keywords identified from the transcribed data that described TSE's usability aspect are – 'easy,' 'understandable,' 'would like to continue' - which shows their willingness to continue usage.' Elderly participants used adjectives like 'good,' 'helpful,' 'interesting,' and 'fun' to describe their learning experience with TSE. Participants described the instruction concerning the system that is available to them and easily compatible with their system (computer/ laptop). The elderly reported their family members/ friends are supportive of using TSE. Moreover, they realize they are drawing the benefit out of it, and they can convince their family to use such technology. Lastly, the cost of the TSE is somewhat of a concern to them (if the TSE is designed as an individual-based intervention). Table 6. 3 presents a few elderly' responses on exercise and regarding the use of TSE. From the answers and direct observation, it is found that the elderly game experience is positive, and they perceived it to be an effective solution for doing exercise, and it is easy to use.

Table 6. 3. Indian elderly' few responses regarding exercise and experience on the use of TSE

General responses on Exercise	Response on TSE
"I want to mention that although we know exercises benefit me, I feel impossible to continue it regularly as it is dull …"	"TSE is going to be very helpful, and it is very promising. With a few upgrades, it will become an essential part of the exercise."

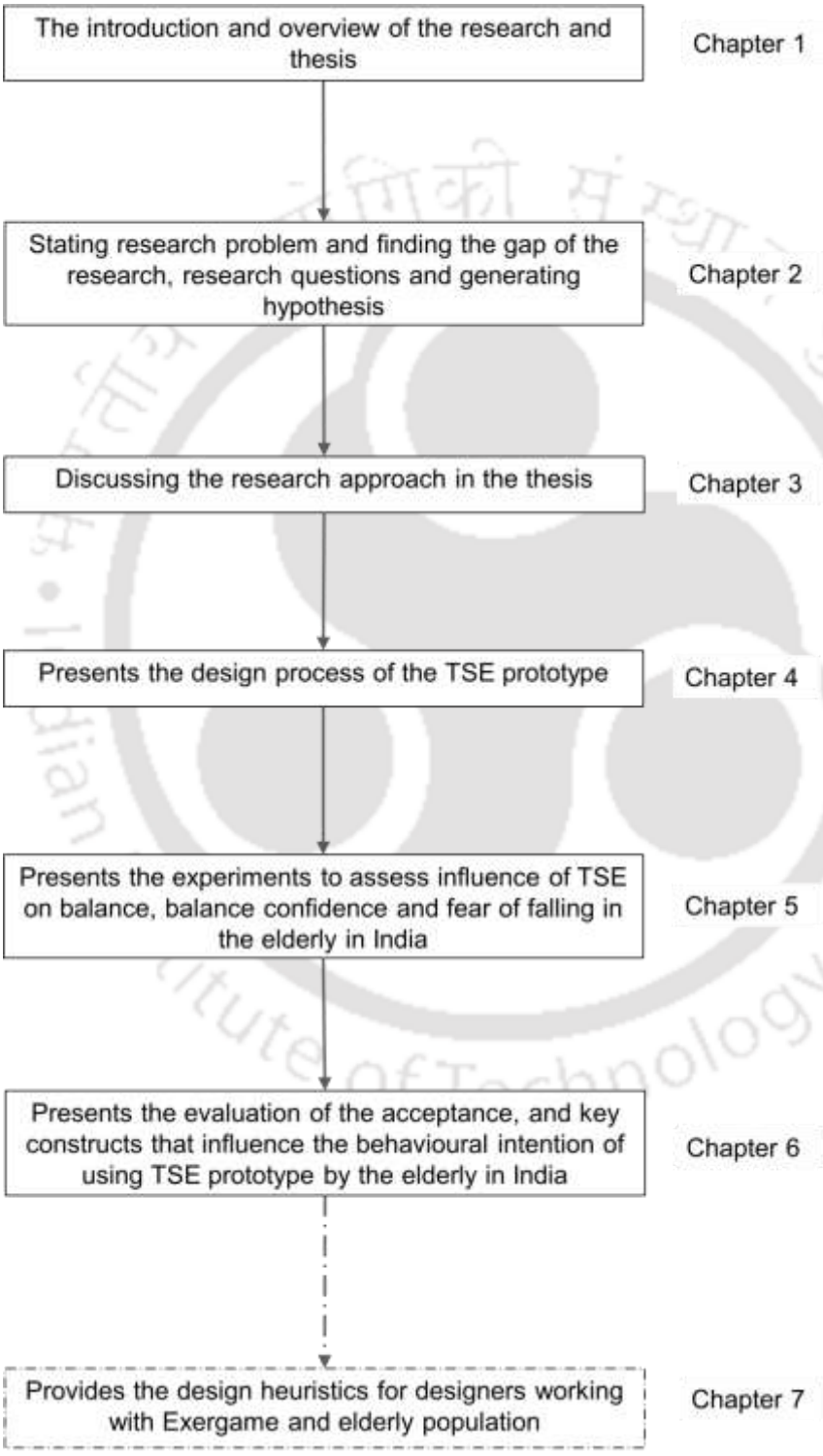
"At least after the exercise, we must get some hint about our progress…"	"TSE provides us the most appropriate motivation, seeing the scores at the end, giving motivation and interest to continue."
"Feel to skip every day..."	"It is a perfect experience because it showed us the avatars moving with us and completing interesting tasks."
"Often doing exercises, we want somehow to skip or leave early, etc.…"	"It will be beneficial to exercise efficiently rather than dull and boring. Learning a new game becomes easier, and we won't have to worry about not finishing the set of exercises as it is taking care of it automatically."
___	"I can feel it reduces my back pain, knee pain, and helping me walk more confidently."
___	"Easily understandable story-line, the concept of games, and it is relatable and enjoyable."
___	"Easy to start, and do exercise, understandable instructions. I love the fact that it is written in Assamese, along with English. I can help anyone to use it, as it is lightweight."

The subjective assessment findings indicate that the proposed TSE prototype has positively influenced the elderly to do their exercises, and they are feeling more motivated towards exercising. Their positive feedback, along with observation, indicates elderly are eager to use TSE; moreover, they mentioned that, after each session, they look forward to the next day to using TSE. These subjective assessment findings support our statistical analysis results, indicating that the elderly has accepted the TSE.

Chapter summary

This set of TSE is designed to integrate physical exercise through technology for the health promotion of the Indian elderly. Initially, it is speculated that the results might show differing degrees of acceptance and impact among the elderly. This chapter proves that the elderly indicates acceptance of new technology like TSE. The analysis suggests that EXG is a novel way to motivate the elderly to do exercise in India. Based on the insights gathered from the prototype development process and experimental investigations, including the subjective assessment reported in this thesis, design implications, and heuristics towards developing an

EXG for stepping exercise have been derived and stated in the following chapter7.



Chapter 7. Design implication and Heuristics towards designing Exergame (EXG) for Elderly

7.1 Introduction

In the field of exergame, there are a few theoretical guidelines available, which have been discussed in chapter 2 of the thesis. The design activities may vary depending upon the state of the creative process [140], and the process needs to fulfill the context-specific problem. In the literature, the researchers mentioned the need for research on the actual development of EXGs and how the gathered knowledge and understanding of user behavior can be transformed into design decisions when developing such EXGs [141]. The thesis attempts to state the possibility of interweaving various fields such as – exergame, elderly fall, and exercise interventions into a holistic system to enrich the elderly's experience of doing balance improvement exercises.

Heuristics are a set of fairly broad usability principles [142], aiming to prevent the user's problem that has come up before [143]. Exergame is a combination of video games and exercise [144], so from a usability aspect, it should provide the user the benefit of the respective exercise and playability of the game. Based on the insights gathered from experimental investigations and prototype development process reported in this thesis, design implications and heuristics towards developing an EXG based on stepping exercise for the elderly have been derived and stated in the following Section 7.2. These heuristics will be helpful for the Human Factors Ergonomics researchers, elderly researchers, Interaction Designers, user experience (UX), and Human-Computer Interaction (HCI) researchers working on EXG in their effort to develop an effective interactive tool for the elderly to exercise. Further investigations to test and validate these heuristics can be carried out as future work for the elderly EXG in the different exercise contexts.

7.2 Design Heuristics for Exergame in elderly

Heuristics are design guidelines that serve as a useful evaluation tool for both product designers and usability professionals [145]. To develop heuristics, domain-specific understanding is much needed. By creating heuristics that are specific to EXGs for the elderly, it will help identify issues that are common amongst EXGs that can be overlooked by using

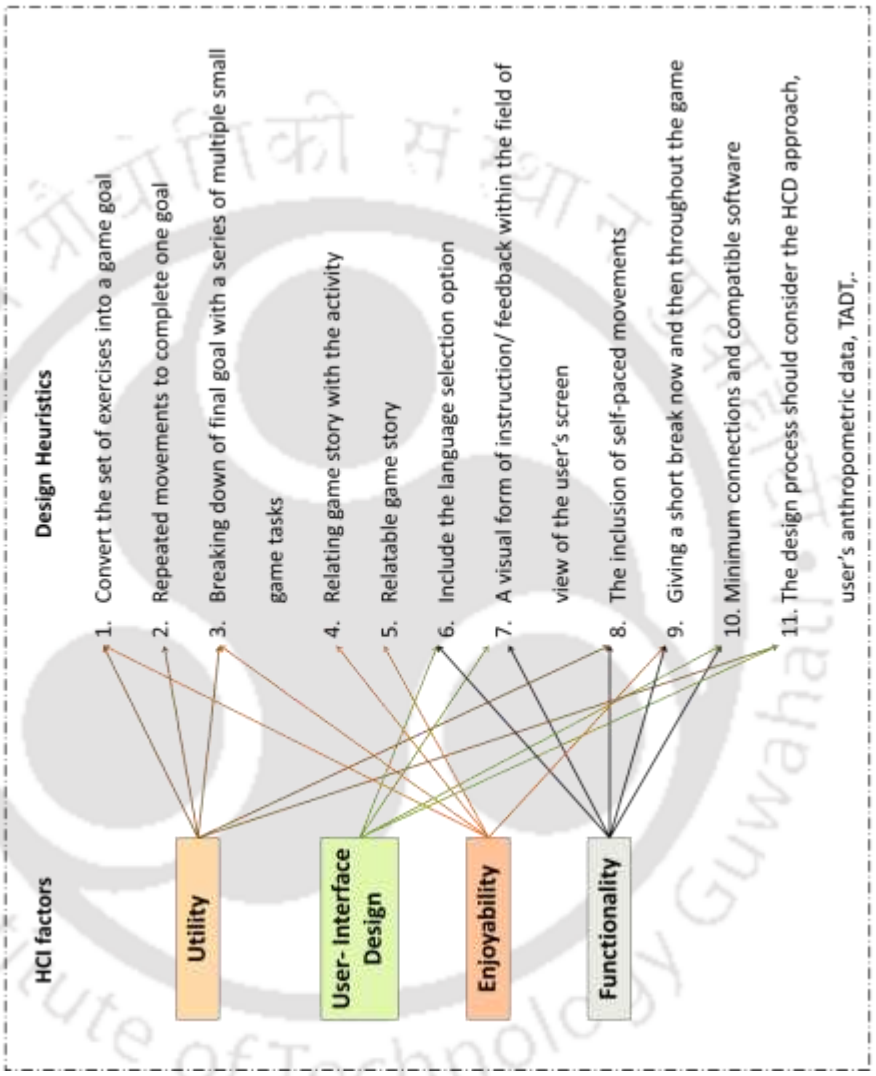
general heuristics. This development will allow for future researchers/ developers to understand the elderly-specific EXG. It will help them create more EXG that can apply to a broader user range, especially for the elderly. In EXG design, one of the essential factors is to make the game attractive to players and, at the same time, effective as an exercise [144]. Literature suggested domain-specific heuristics probably work better, which needs to have a right balance between specificity while maintaining generality [146].

The design of EXG technology (TSE in this thesis) in the context of the elderly fall preventive exercise measure requires understanding about the following four heuristics: (i) Physically appropriate game structure to encourage continuously, recurring play; (ii) Motivational game concepts to promote physical activity; (iii) Gameplay movements that mimic the prescribed exercise for the elderly users; iv) Gameplay movements safe for the users.

Figure 7. 1 portrays these HCI factors and their relation to the derived heuristics in terms of EXG technology for elderly users. These design heuristics have been derived from user research studies, field observations, and prototype development. Gerontologists and interface designers can use it to develop EXG for exercises in the elderly. These heuristics fall under broad HCI factors of Utility, User-Interface (UI) design, Enjoyability, and Functionality and lead towards overall usability and usefulness of the EXG technology. Utility refers to aesthetics & feedback and efficiency in terms of HCI [147] whereas, in the domain of EXG, motivation, attractiveness is most similar to the concept of utility value 'in the field of economics' (person's satisfaction from consuming a good or service) [148]. Here, utility refers to the tools that should be embedded in the EXG and will be useful for users in completing the exercise. The UI design means the EXG interface with which the users interact during the game for exercising. Enjoyability refers to the degrees to which the game content created for EXG is entertaining and pleasurable for the user to lead towards playful engagement in completing the exercise. Functionality means the technical features that should be incorporated while developing the EXG for elderly users.

- **Convert the set of exercises into a game goal**

The game activities should help the elderly to complete the set of exercises prescribed by the physiotherapist. To do the exercises in a pleasurable and fun way, each prescribed exercise set should be converted into a game goal.



TADT- Technology Acceptance Decision Tree
HCD- Human-Centric Design

Figure 7. 1. Broad HCI factors of derived design heuristics for elderly Exergame

- **Repeated movements to complete one goal**

To avoid the complex movements that the elderly might forget, incorporating repeated movement to accomplish one game target will minimize cognitive load in elderly users.

- **Breaking down of final goal with a series of multiple small game tasks**

The final goal of the EXG is designed as per the prescribed sets of exercises that the elderly have to complete, as explained in section 4.5.2 in chapter 4 of the thesis.

To maintain the interest, the game goals should be typically broken into small parts (multiple small achievements) so that it boosts elderly interest to complete the sets of exercise. Figure 7. 2 shows an example of using short objectives (seed to grown plant) to achieve a bigger goal (plat a tree) in the present experiment.

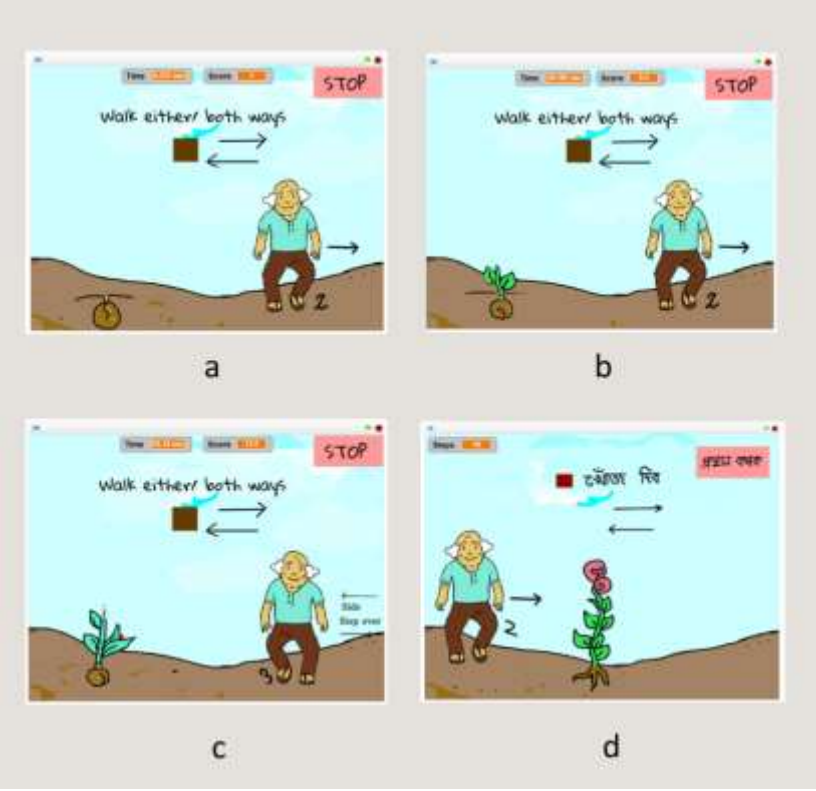


Figure 7. 2. Example of small goals (seed to plant) to complete ten cycles of Side- Step over exercise (a) seed, (b) grew into leaves, (c) intermediate state from seed to grown plant, (d) grown plant

- **Relating game story with the activity**

The game story plays a vital role in the gameplay, and the movements, which are the Exercise movement that should be relatable with the story in a subtle way. For example, while doing exercise "figure 8" in this study,

the elderly might stumble in between, so in this game, "Monsoon Market" is selected as a game story. During flood/ water-covered ground, a person stumbles during walking on the sidewalks or brick/ similar object placed to cross the waterlogged area. Figure 4. 17 (a), in chapter 4, shows the participant is doing "figure 8", which mimics the way the avatar is moving in the game.

- **Relatable game story**

Make the Exergame (EXG) a continuous story so that it relates the elderly's everyday activities (describing real-life scenario), as referred to in section 4.5.2 chapter 4 (Figure 4. 13, Figure 4. 14, Figure 4. 15, Figure 4. 17).

- **Include the language selection option**

The EXG interaction design should consider the depth of the user's perception. The language of the game narration plays a vital role in communicating with the users. To play the game language selection option should be included. Understanding the language used in the game is an essential element that needs to be taken into consideration along with the other aspects like the game story or movement control for better interaction between user and content. The items should also be placed within the field of view of the user's screen. Users find it difficult to navigate content if that is displayed outside the screen area or their comfortable visual field. Figure 7. 3 shows the example of the on-screen display of the language selection option in the TSE.

Figure 7. 3. Example of showing language selection option in the field of view of the user along with written instruction

- **A visual form of instruction/ feedback**

To design an EXG for the elderly, one must consider their cognitive ability, as the working memory declined with age [127], and that might cause a problem in following and remembering the instructions. So, in TSE, a written form Instructions (in visual) is included through the game, as shown in Figure 7. 4. After finishing the game task, users are provided feedback, as shown in Figure 4. 25(d) and scoreboard, to give quantitative feedback of their performance, shown in Figure 4. 10 in chapter 4. Users must not find it difficult to navigate content, so visual instructions or feedback should be within the screen area or a visual field of view, as shown in Figure 7. 4 and Figure 4. 10 (chapter 4).

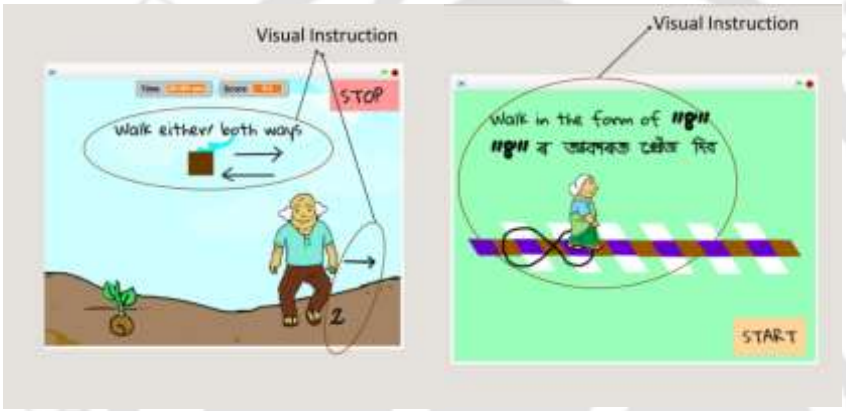


Figure 7. 4. Example of showing visual instruction and feedback in the field of view of the user along with written instruction

- **The inclusion of self-paced movements**

The integration of self-paced movements to complete the game task avoids the frustration of fast/slow movements. Finish time should be dependent on the user's performance.

- **Giving a short break now and then throughout the game**

Give a little gap where necessary in the form of a game story to avoid dizziness. Figure 4. 18 shows one of the on-screen examples for the overlay during the experiment of TSE, proving break as a storyline, nicely described in chapter 4, section 4.5.2.

- **Minimum connections and compatible software**

The elderly should able to install EXG easily with minimum connections and compatible with all operating systems in laptops or computers. Easy

installation and lesser complex connections will encourage the elderly to use new technology more efficiently. The details of the interface are described in section 4.5.3 of chapter 4, which refers to Figure 4. 21.

- **The design process should consider the HCD approach, user's anthropometric data, and TADT**

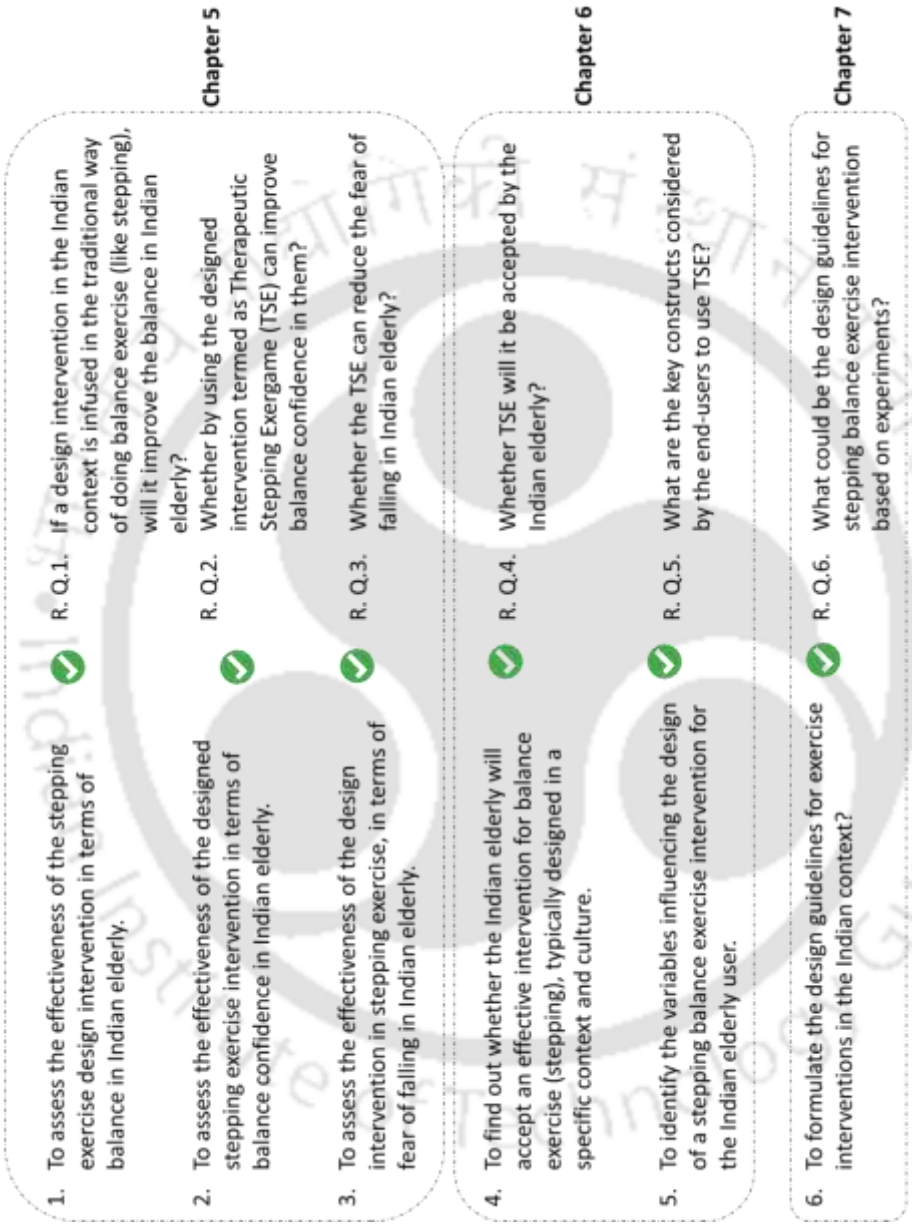
The design process must include the HCD approach while designing new technology for the elderly (section 3.4 of chapter 3). TADT helps to identify the possibility of acceptance of new technology, discussed briefly in section 4.3 of chapter 4. The design should consider the specific anthropometric data of the target user (in this research, elderly in India).

The tailored EXG will be definitely helpful for the elderly in the context of the specific health benefits.

Chapter summary

This chapter presents the design implications and heuristics derived from experimental investigations reported in this thesis. These heuristics hold practical use for designers, gerontechnology, and HCI researchers working towards the elderly with a specific focus on possible fall preventive interventions.

A glance of the summary of the chapters that address the research objectives and answers the research questions of this thesis



Chapter 8. Discussions, Contributions, Limitations, and Future Study of the thesis

8.1 Discussion

This research work briefly discussed the elderly balance exercise and EXG technologies and their applications in fall prevention, a motivator in exercising, and various design-related fields. It also discussed the benefits of the EXG into balance improvement, balance confidence improvement as well as reducing the fear of falling in the elderly in India. This thesis would help designers develop EXG realistically, which addresses the complex elderly problem like falls and considers the necessary measures in the computer-aided product design process. A method has been formulated to create an EXG system. In the thesis, the procedure regarding the experimental setup, data collection, data analysis, and interpretation results related to the tailored EXG- TSE and its usability for balance improvement in the elderly and its acceptance among the users are briefly discussed.

This research investigation is started with a few contradictory findings and multiple questions that remained unanswered in the literature. As grasped from the state-of-the-art literature review discussed in Chapter 2, significant research gaps are identified that indicate a lack of insights in an exploration of traditional exercise for balance training and elderly motivation to do it. These gaps suggest that there are not many novel technologies designed to address users' human-centric needs in balance training and cater to motivation in the specific context of the elderly in India. This thesis attempts to bridge these gaps by developing a system of devices knit together by new hardware, new design consideration, and stepping-inputs from the elderly (user).

The findings from the literature show mixed responses in terms of the potential of EXG in the promotion of physical activity; a few have found no such evidence or have been inconclusive in nature, whereas some studies have shown evidence to support this statement [141, 75, 76, 149, 150]. As reported in the literature, no study used efficiency measures to evaluate EXG [135]. It is also observed from the existing research on EXG that these are dominated by device-centric perspective focusing on the games and gaming devices themselves instead of a more user-centric perspective that focuses on the end-users or their behavior, and issues such as why users play such games [141]. These aspects are essential while creating EXG for

the elderly. There is a severe shortcoming, as understanding these issues can be considered necessary, especially for developers and marketers of EXG in terms of the games they want to use and adapt.

On top of that, the literature on EXG, which is readily available, is focused on developed countries, but in the Indian context, there is a vast lacuna that exists, and as per our knowledge, extensive research in this area is unavailable [86]. India has a significant interregional and interstate demographic diversity [39], a similar approach as the developed nations may not be suitable and sufficient in India. The current experimental study attempted to integrate such research with the elderly in India, taking an EXG that has been designed considering an Indian scenario in mind [86], which is one of the first few attempts to evaluate the effect of EXG (explicitly designed for the elderly) on balance, FOF and balance confidence of the elderly in India. This research can help future designers and researchers design and develop EXG that positively gives health benefits and motivates physical activities in the elderly and the elderly fall research field.

The subjective assessment and descriptive analysis suggest that EXG can be a novel way to motivate the elderly to do exercise in India. Along with the subjective evaluation, an experiment set up with four weeks' time span (TSE- session) was conducted with the tailored EXG- TSE to test its effect on the elderly balance, balance confidence, and FOF and their acceptance towards the use of TSE. To sum up the overall research, statistical analysis is conducted using the data obtained from the same participants for the balance, balance confidence, and FOF before and after the TSE- session. To understand the effect of TSE before and after the intervention, a paired t-test is used. The summary of the results is shown below in Table 8. 1.

Table 8. 1. Summary of the hypothesis of the thesis

Hypothesis	Comments (Paired t-test)
H_1: The use of TSE will improve balance in the elderly in India.	To assess the effectiveness of TSE in terms of balance, YBT is used, and results showed statistically significant improvement in the balance in the elderly in India. Significant at $p < 0.05$.

H_2: The use of TSE will improve balance confidence in the elderly in India.	The balance confidence is assessed using the ABC scale. The results indicate a statistically significant improvement in the balance confidence in the elderly in India. Significant at $p < 0.05$.
H_3: The use of TSE will reduce the fear of falling in the elderly in India.	The effectiveness of TSE in terms of fear of falling is assessed using the FES-I scale. The TSE decreases the fear of falling in the elderly in India at a statistically significant level. Significant at $p < 0.05$.

To study their acceptance level of the elderly towards TSE UTAUT2, inferential statistics are used. The current study illustrates the targeted user population is inclined to adopt and use such new systems, as the mean score for Behavioral Intention (BI) to use EXG is higher, which is 4.96± 0.106.

The elderly's feedback suggests that they think exergaming could improve their balance and keep them active. Their positive feedback, along with observation, support our statistical analysis results, indicates elderly are eager to use TSE; moreover, they mentioned that, after each session, they look forward to the next day to use TSE. Thus, the Indian elderly accepted TSE-an EXG for balance training, which is developed explicitly for seniors.

The statistical result suggests that Hedonistic Motivation (HM) is the most important construct to use the EXG in the future by the elderly in India, which indicates the elderly are motivated to do the exercise using the TSE, i.e., EXG technology.

In India, where 30% of the elderly are below the poverty line [151], and up to 65% of the elderly are economically dependent on others, especially widowed women [27], then the cost will be a crucial factor to consider for any product. Considering the Indian context where consumers have to be careful, or they have to bear the costs associated with the purchase of technology, devices or services, etc. TSE is designed mainly as an organizational solution, e.g., hospitals or nursing centers for the elderly, old age homes. This study indicates the Price Value (PV) has a positive impact on the future intention of use by the elderly. If the user-perceived that the benefits of using the EXG- technology are higher than its monetary cost,

they would intend to use it irrespective of the price. Between the constructs, Facilitating Conditions (FC) and PV showed a very strong positive (highest) correlation for TSE.

The literature suggested that Social Influence (SI) is a fundamental construct in the intention of using new technology [152, 11]. In the descriptive statistics, results show that family members and friends are also quite supportive of using TSE by the elderly, as SI for TSE has a higher mean value of 4.91± 0.148. However, in this study, it is found that SI does not correlate with the other constructs. It also has no significant correlation in the future intention of using such technology. This may happen due to the elderly's interest in using EXG in a pleasant way, as well as its benefits in improving balance. In India, where for taking care of the elderly, family members play an essential role (both financially and as a caregiver) in this study. This factor can be further researched in the future. The effect of gender on the acceptance of TSE and its correlation with other constructs are not studied. In the future, this aspect can be researched further.

In Chapter 6, section 6.5.4, participants reported that TSE would help improve their balance and motivate them towards exercise and help them reduce fear in doing day-to-day activities and feeling active. Whereas in the traditional way of doing exercise, they lack motivation and purpose. TSE motivates and helps them complete the balance training with positive performance feedback in the form of score and completion time.

The TSE is made portable so that the elderly can carry it easily and use it according to their comfortable space. TSE includes only one regional language- the Assamese, along with English. The use of local language is a significant factor in Effort Expectancy (EE). The TSE is well accepted by the Indian elderly. Thus, future designers can consider the constructs in mind while designing for the elderly for Indian or similar contexts.

The designed TSE is different from the existing EXG like DDR or Wii. In TSE, aspects like, (i) Perceived Usefulness, (ii) Ease of Use, (iii) User interaction, (iv) Self-motivator, (vi) Self-paced EXG experience, (vii) Facilitating Conditions, (viii) Cost factor are considered. The following Table 8.2 listed out the hypothetical comparison of the TSE, other EXG, and traditional way of exercise. This comparison is made based on the systematic literature review, field surveys, and knowledge, and results from the pilot studies.

Table 8. 2. A hypothetical comparison between TSE and other EXG

Therapeutic Stepping Exergame (TSE)	• Designed explicitly for the elderly • Self- paced movements • Simple game movements • Repeated movements so that the elderly people do not forget the movements and reduce additional cognitive load • Visual and audial feedback and instruction • Designs are made context-specific, that is, considering the real-living scenario of the elderly of India • Based on the HCD approach, TADT, and Indian Anthropometric data • Game Avatars are relatable to the end-users (the elderly in India) • Languages selection is available- the Assamese along with English. • Portable • Compatible with all the operating systems • It does not require an additional game console • Can use irrespective of the cultural attire • The elderly do not have to look continuously on the screen to play
Other EXG (Dance Dance Revolution (DDR), Wii)	• EXGs like Wii, DDR are not designed for the elderly • DDR, games are fast- pace activity troubles the elderly to do the task • Wii balance board is smaller, which makes the elderly more prone to fall • Wii sports is difficult • Wii has an upper limit • Needs additional game console box to play • Designs are Westernized • A typical EXG needs proper infrastructure, facilities, and resource addresses around them, like a place to put cameras, Kinect, internet • No quantitative output for completion of prescribed sets of exercise • Do not consider any model that tells the acceptance of the game among the elderly in India • Game avatar is not relatable to the elderly in India • Continuously look on the screen to play
Traditional Exercise	• Finds it is dull • Not aware of the improvement themselves • Skip and do not complete the prescribed sets • Lack of motivation to do exercise • Boredom • No newness

TADT: Technology Acceptance Decision Tree
HCD: Human-Centric Design

Brox highlighted that Wii is too fast or gives too negative feedback [76], as TSE is a self-paced game without proving any negative feedback to the user; it addresses the issue stated in the paper. The literature highlights that the available EXGs are not designed for the elderly [86, 31], and in India, new technology is not accessible as in the developed nations [22, 72]. This thesis addresses these issues and provides evidence that the tailored EXG is effective and accepted in elderly fall research in India. It considered its context-specific need in a Human-centric Design approach, TADT, Indian anthropometric data while developing. The statistics show TSE intervention's impact on improving balance, balance confidence, and reducing FOF. It is expected that these aspects will improve the quality of elderly adults' life and helps to remain active.

Age-related changes in cognitive, sensory, and psychomotor ability affect balance control mechanisms and postural reflexes, etc., causing the risk of tripping, and the elderly become more prone to fall [12]. The utmost critical risk factors for elderly fall are gait and balance and muscle weakness [14, 13]. Fall often contributes to fear of falling, or FOF can develop in the absence of a fall [21]. FOF causes a curtailment of activities in the elderly and further leads to restricted mobility, reduced functional capabilities and gait speed, increased spontaneous sway, decreased one-leg stance time and balance performance, etc., and further increases fall risk [23, 130]. Individuals with FOF and quiet standing and walking measures are linked to balance confidence in the elderly [21]. The elderly with high levels of FOF has a higher risk of future falls, but the elderly with low levels can be protective for falling, irrespective of the presence of balance impairments [25]. The experiment results showed TSE has significantly improved the balance, balance confidence and reduced the FOF in the elderly, which are the crucial factors elderly fall. It suffices to say TSE will help the elderly as a fall preventive tool. However, further in-depth research in this aspect is required.

The research gaps regarding exercise intervention, which required a newness, like helping the elderly understand the improvement in balance, and motivation to exercise, are addressed in this thesis. The existing EXG is not related to the real-life scenario (an essential aspect in theoretical guidelines) of the elderly in India [99, 89, 76, 102, 85, 84]. The research has addressed this issue along with issues like existing EXGs are not designed for the elderly [76, 75, 107, 89] by tailoring an EXG-TSE designed explicitly with prescribed fall preventive stepping exercises. The

research has helped gain more insight into how to use exergames for older adults as an exercise and rehabilitation tool and address the gap mentioned by Maroni, 2016 [109]. This research shows supportive evidence, to the study by Laufer, that EXG can improve the balance in the elderly [93].

In the Indian context, a few studies on intervention like balance training, fall detection technology are conducted [18, 78]. The literature highlighted the difficulties in using assistive technology, technology malfunction, lack of competence or training, lack of financial resources, privacy disquiet, fall detectors with wearable sensors, portability, and cost-effectiveness acceptance of such technology, etc. and the need of redefining the technologies used for fall intervention [22, 72, 79]. This research bridges the elderly's inhibition towards technology-based products in India without compromising their privacy while addressing the fall problem. TSE is designed carefully considering and addressing these issues and also, keeping in mind issues like fast pace or narrow board of the existing exergame (DDR, Wii) [76, 86]. The TSE is designed as a self-paced, floor mat-based exergame intervention. The elderly do not have to look continuously on the screen or get conscious about the pace during the game session, as there are no such obligations for the user to look into the screen while playing the game or completing it. Hence, the hedonic motivation is not compromised, which is a crucial factor in determining the acceptance of new technology. The cultural attire aspect is also addressed in this research so that elderly females can play the game without compromising their comfort of wearing their traditional or regular attire (Saree/ Mekhela-Sadar or similar attire) [86]. TSE includes the physician's fall preventive stepping exercise and is designed as an institute-based intervention (hospital/ old-age home, etc.). The elderly may also consider TSE home-based intervention since many elderly may prefer exercises delivered at home with some professional guidance [7]. The TSE is a solution to improve the elderly's balance in a self-motivated way, delivering quantitative output data that can help physiotherapists/doctors to view and analyze in the future if required. The design heuristics drawn from this research will provide an understanding of how emerging technologies – balance exercise (fall preventive) be utilized and explicitly designed for the elderly in India.

8.2 Contribution

This research contributes to the form of both knowledge and product. It bridges the identified research gaps by introducing game movements inspired by the traditional stepping exercises (fall preventive) and a new hardware interface with a game story relatable to the user through developing a tailored exergame, termed as Therapeutic Stepping Exergame (TSE), as an interactive exercise tool (fall- preventive). This thesis contributes in terms of formulating a possible 'design methodology' (chapter 4) for developing 'EXG products' based on the emphasis of TADT and the human-centered design approach. As adopted in this thesis, it suggests a viable method (as validated by user testing) for designing functionally useful products to ease human work and assist better in exercising that emerging technology can afford.

The thesis has both theoretical and practical implications of the findings. The experiment results are observed from the perspectives of the literature; it is found that EXG can provide the health benefits [83] in the elderly in a motivating way; in this thesis, it is for balance improvement

Another critical view is the need for users' acceptance [11], and the results of the thesis indicate for TSE, Hedonistic Motivation (HM) is one of the most significant constructs (chapter 6). The results show that the EXG also hits the benefits of exercise [25] in terms of balance confidence and FOF in the elderly.

The practical implications of the findings of the current research are, like, the design heuristics for designers and researchers to use EXG as a new product or tool for fall intervention in the elderly in India. For healthcare providers could suggest the EXG as an intervention strategy to treat FOF and promote balance confidence among older adults in India.

The significant contribution of the thesis listed below:

- The thesis presents a novel way to interweave technology, gaming, and exercise intervention with special reference to balance, stepping exercise. This eventually will help the complex health issue like elderly fall.

- The thesis presents the possibility of doing exercise by the elderly in a self-motivated way with the use of an interactive exercise tool- Therapeutic Stepping Exergame (TSE) in India.

- The thesis examines and states the potential of TSE with balance improvement, increase in balance confidence, and reduce FOF.
- The thesis also presents the present situation of the older adults' perception of fall and fall intervention in India and the interventions that are aware and practiced.
- Another contribution is the design heuristics for an interactive exercise tool like TSE for the elderly in India or similar cultural and social arrangements.
- The main contribution is in terms of providing a novel approach in the exercise intervention system for the elderly in India to improve balance in a self-motivated way.

8.3 Limitations

This study incurs a few limitations, first, given the constraints in the number of stepping exercises incorporated in TSE. The small number of exercises may lead to a weak statistical power in UTAUT2 data, especially in terms of the significance of Social Influence (SI) in behavioral intention. Hence, results obtained in this study need to be interpreted with caution. A significant limitation of the thesis is that the TSE prototype is developed at an experimental level due to limited resources, and it is not a fully functional prototype to conduct a large-scale user usability study. However, more trials should be assessed and taken into account when attempting to help the elderly optimize their quality of life. The effect of this prototype is not tested with the frail Indian elderly. A comparative study based on gender that is the effect of TSE on male vs. female elderly is not under the purview. Due to this limitation, the work reported in the thesis does not verify the impact of the proposed TSE on a different (both healthy and frail) geriatric population of India. Therefore, we relied on both qualitative and quantitative methods – as practiced in Design Science.

8.4 Future study

In the present study, it is found that Social Influence (SI) is not correlated with any of the constructs in the UTAUT model. The results revealed a contradictory fact that although the descriptive statistics have shown that SI for TSE has an excellent score (4.91± 0.148). So, the question arises- why is SI not significant in the Indian elderly's use of exergaming? The

effect of Social Influence (SI) on exergame use and the correlation between SI and other constructs in the UTAUT2 model can be researched in the future. In the future, researchers can also conduct studies incorporating the effect of age variation in the UTAUT2 model for their future intention to use TSE or other EXG use. Future studies can also include how different EXG use experience levels of the elderly user can influence the future intention of using such technology. Studies can include user groups like inexperienced, moderately experienced, and fully experienced EXG elderly users. Researchers can also dive for more information like how one construct affects the other in UTAUT2.

In the future, more stepping exercises can be incorporated and can design a fully functional prototype with larger sample size, including frail and elderly with visual and auditory disabilities, in different locations of India. TSE's effect on back pain, thigh pain can also be studied. The study can address a question like- whether it can be used for more health care benefits? Many participants claimed that their back pain and thigh pain are being relieved after using TSE in the present study. The previous research indicates EXG for the elderly also led to improvements in the perceived level of pain [149]. However, in the present study, no quantitative research is done in this aspect. The present study has not studied the preference of TSE with respect to different genders. The effect of TSE or exergame on males vs. females can be pursued further.

The design model used in the thesis (Figure 4. 2) is for TSE or may be applicable for similar EXG. Future studies may perform differently in the case of people who do other kinds of physical exercise in exergaming.

Another potential path of future research could be to compare the performance of the users of the context-specific EXG- TSE to the performance of other EXG or traditional exercises.

Future research may include more exercises and refine the prototype to improve balance confidence and reduce FOF and provide a fit and better picture of the influencing mechanism of exercise platform among the elderly in India. This study contributes to the existing field of work in the EXG's effects as an influential fall intervention and sheds light on the future use of EXG in the treatment of fall-related issues. Furthermore, these findings may aid in developing more effective rehabilitation EXG for individuals with low balance or elderly in Indian or similar socio-economic contexts.

In the future, EXG can include gender selection options, with an advanced technical setup (in hospitals or community hall) that consists of a facial recognition system to mimic the user as the game avatar. It can be integrated with VR (Virtual Reality), with proper measures needed with the elderly in India.

Another emerging future path is to create EXG with exoskeleton specific for elderly users, as in the latest research for children with CP (Cerebral Palsy), such work is becoming a new rehabilitation paradigm [153]. Such kind of approach might be a breakthrough in not only the elderly fall research but also different specially-abled user groups.

8.5 Conclusions

From the research work, it is found that the integration of exercise and technology (that allows the user to exercise in a pleasurable way) to evaluate the usability in terms of balance-related measures with the elderly is one of the perfect solutions. Moreover, this is proved through experimentation, data collection, and data analysis. Therefore, proper use of TSE or similar EXG may help improve the balance, balance confidence, and reduce the FOF. The heuristics of such product design and development are stated based on the experience gathered from repeated physical prototyping, user- testing, field survey, and knowledge from previous researches. In addition to this, participants are confident as the system implementation may increase their motivation towards exercise and reduce FOF. The TSE designed with the HCD approach can also be used to reduce pain in the back, as many participants have mentioned during the experiment. However, this needs further prolonged quantitative analysis.

Annexure A

Annexure A1

All the participants are informed verbally about the entire process of the experiment and the details of the study. Participants are free to choose their time to join the experiment. If they have any queries regarding the research or the consent form, they are guided by the invigilator with the information they are looking for until they are satisfied. The consent form used in this thesis is adopted from the literature [35].

Consent Form

Title: Therapeutic Stepping- Exergame (TSE) Date:

TSE: "Exergame" is an interactive game. The game movements are associated with the fall preventive "Stepping exercises." To improve balance and complete the recommended set of exercises (by doctors/physiotherapists) in the elderly in Indian, this **TSE** has been designed.

The objective of the study:

1. To find the effect of TSE on balance, balance confidence, and the fear of falling in the elderly.
2. To find out whether using the TSE can help the Indian elderly to complete the prescribed set of exercises as compared to the traditional way of stepping exercise.

Name of the Researcher: Nilakshi Yein

Declarations **(Please read carefully and tick the box)**

☐ **1.** I confirm that I have read and understood the information provided above. I have had the opportunity to consider the information, ask questions, and had these answered satisfactorily.

☐ **2.** I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without any consequences for me.

☐ **3.** I have been informed that the experiment will be recorded/ photographed, and I give my consent for this to be made.

☐ **4.** I understand that all the information I provide will be treated as confidential and will be anonymized.

☐ **5.** I agree with the use of anonymized direct quotes from my interview in publications and presentations arising from the study.

☐ **6.** I agree to take part in the above study.

_____	_____	_____
Name of Participant	Signature	Date
_____	_____	_____
Researcher	Signature	Date

Annexure A2

Semi-structure interview script (PRQ1)

At first, it is made sure that the physical environment of the interview location is comfortable, private, and quiet. The interview place is their home or their chosen site. After a formal introduction, the interview started by introducing the participants to the research. The participants are then asked to shred their experience of falls. Family members are also asked a few questions when needed. In India, family members are the one who acts as a caregiver to the elderly. So, their opinion on the elderly falling matter is considered as an essential perspective.

1. How do you like to spend your free time? What activities do you involve the most?
2. Would you like to share your experience before and after your retirement (if any)?
3. How many members are there in your family? How many of them are elderly and children?
4. Do you like to play with your friends or grandchildren? What are activities that bring joy to you?
5. What is the work- profile of your earning member in your family? How they like to spend time while not working?
6. How often you visit neighbors or extended family or vise versa?
7. Have you undergone any clinical surgery for the last two years? Are there any? Are you under any regular prescribed medication?
8. How often you or someone you know experience fall?
9. Have you experienced a fall? Have you experienced it for the last two years?
10. What is your view on the elderly fall?
11. Tell me about the circumstances that lead to falling and how you/ someone manages to get help?
12. What are the places where fall occurred, and what activities lead to it?
13. What are the first things you did when you experienced it?
14. How your previous fall experiences have influenced your course of life?
15. How do you overcome these difficulties? Any specific measure that you use?
16. How often you rely on informal measures of fall you used? What type of help do you usually take from them?
17. What do you think about available elderly fall interventions?
18. Do you use any aid or help while walking on mud or slippery floor?
19. How you parent/ grandparent or elderly neighbor feel about taking your help while walking?
20. How often do you exercise? How do you feel about it?
21. What are the circumstances that you skipped exercise?
22. What if, you can realize your health improvement (like muscle strength, balance, or balance confidence) after exercising, will you do it regularly?
23. If exercising can be made fun for you, will you consider doing it?
24. How do you feel about changing a few architectural arrangements at your house?
25. Are you aware of any technology-related intervention o fall? Tell me your opinion on new technology, are you interested in them?
26. If you have a chance the use of technological measures for fall (fall monitoring system, fall detector, exergame, etc.), are you interested in using it?
27. What do you think about a technological aid that you can operate freely and easily?

28. Is there anything you would like to share about your significant experience with fall? Any suggestions on how such a problem and interventions can be made available to you so that you use it without any hesitation?

End of the interview session.

A few images and videos are shown to make the elderly and family members understand about technological solutions. Example of images used in the study are shown below:

Figure A2. 1. Examples of Technological measures for elderly fall

Image (jpg) Sources:

a. http://www.liveagethrive.com/fall-detection-systems/753
b. https://www.google.com/imgres?imgurl=https%3A%2F%2Fdmtyylqvwgyxw.cloudfront.net%2Finstances%2F132%2Fuploads%2Fimages%2Fphoto%2Fimage%2F49395%2Flarge_ffb55889-5fde-49db-b0f9-04e0f875ae4c.png%3Fv%3D1538494768&imgrefurl=https%3A%2F%2Fdevmesh.intel.com%2Fprojects%2Fimproved-elderly-fall-detection-system-wireless-and-compact&docid=sd3NUJBumpR3dM&tbnid=2HWCyRMBc_07QM%3A&vet=1&w=1280&h=960&bih=722&biw=1536&ved=2ahUKEwjuoqLN5uflAhVIr48KHUEbAfMQxiAoBnoECAEQIw&iact=c&ictx=1
c. https://www.ranker.com/review/dance-dance-revolution-solo-2000/9844071?ref=wiki_282723
d. https://www.google.com/url?sa=i&source=images&cd=&ved=2ahUKEwjuzt-k7eflAhVKL48KHXJnCAIQjRx6BAgBEAQ&url=https%3A%2F%2Fwww.hardcoregamer.com%2F2013%2F11%2F02%2Fwii-fit-u-full-demo-released%2F60680%2F&psig=AOvVaw1SSjTws69-vEFuBPNnHQrE&ust=1573757305743986

Annexure A3

Semi-structure interview script (PRQ2 and PRQ3)

The ethnographic study helped to understand the insight scenario of the elderly in India, and helped to understand various aspects of the available fall interventions. Before further proceed in this area, it is essential to know the experts' opinions on this matter. To gather the information, a field survey is conducted, as mentioned in chapter 2 of this thesis.

The interview starts with introducing the research, and various findings from ethnographic study and literature are discussed with experts.

A total of seven doctors (Physiotherapist, Orthopaedics) from different hospitals of different hospitals are randomly selected for the survey. The interview is conducted at a pre-fixed time as comfortable by the physicians. Doctors allowed the researcher to observe elderly patients while doing the exercises.

Hospital Name	No. of Experts
Downtown Hospital	1
GNRC	2
Satribari Hospital	1
IIT Guwahati Hospital	2
Guwahati Medical College	1

1. What are the primary causes of elderly falls?
2. What kind of suggestions are provided to patients to prevent further fall?
3. What are the interventions elderly experts prescribed to the elderly? On what basis the elderly are suggested the prescribed intervention?
4. What type of intervention do you think will be suitable for elderly Indian fall?
5. Are there any products that you have recommended using to prevent falls/minimize fall injury? Are you aware of products like: "Hip protectors," "Real-time monitoring system," "Human airbag system for fall," "Alarm system" that are available in the international market (online)?
6. What causes the elderly to avoid prescribed sets of exercise? And why they skip coming to the chamber?
7. What do you suggest to make the elderly to inclined towards exercising?
8. What are the exercises do you prescribe the elderly patients?
9. How long do you advise to continue the steeping exercises?
10. What are the fall preventive balance exercises (FPBE)?
11. What are the stepping FPBE?
12. Any suggestions that can help to make the traditional exercise for fun and productive?

Interview script (PRQ4)

The interview started by introducing the participants to this research. Participants are then asked to share their experience on falls. Target population: INDIAN ELDERLY Population (Excluding any disabilities), age: ≥60 years. The questionnaire is administered both personally as well as via e-mail to the elderly.

Purpose of the questionnaire: To find out the opinion about possible technology-oriented solutions to reduce fall impact among the healthy elderly population in India.

1. To explore the attitude of the elderly in India towards the use of fall preventive technological aid.
2. What are the criteria that Indian elderly/ family members consider before accepting any technological solution for fall?

Participants' details will be entirely confidential.

Part I

Filled up by **Elderly/ Family member/ Caregiver/Others**
***If filled up by other than an elderly person**
*Education qualification:
*Job background:
*Address/Locality/district:

Personal Details (Elderly person)

1. Name:
2. Age:
3. Gender:
4. Address/Locality/district:

5. Education qualification:
6. Job background:
7. Occupation of earning member/s of the family:

8. Where do you live:
   House :
   Flats (apartments):

9. Type of family:
   Nuclear Family:
   Joint Family:
   Extended Family:

10. Total members of family members:

11. Family Income (rupees per month)

<4000	4000-5000	5000- 10000	10000-50000	>500000

Part II

Questionnaire **Tick (√)**
*If filled up by other person than elderly person: Part 'A' questions 2-6 is about elderly person's details

A. Fall history

1. Do you think fall among elderly is a major problem?
   ○ **Strongly agree** ○**Agree** ○**Disagree** ○**Strongly disagree**
   ○ **Don't know**
2. Have you ever experienced fall for last 2 years? (Or someone else: husband/ wife/ relative/ neighbor/ others/ both)
   ○ **Yes** ○ **No**
3. When did you fall last time?
   ○ **≤6 months** ○ **6 months- 1 year** ○ **1-2 years** ○ **>2years**
4. How many times you have suffered accidental fall in last 2 years?
   ○ **0 time** ○ **1-2 times** ○ **3-5 times**
   ○ **>5 times**
5. Where did you fall?
   ○ **Out- door** ○ **In- door**
   Specify_____
   _____
   _____
   _____
6. What is the reason for your fall?
   ○ **Slippery floor** ○ **Balance problem** ○ **Trip** ○ **Others**

Specify others
_____
_____
_____

B. About Technological aid (In 5, 6 you can Tick (√) more than one option if you want)

1. Are you aware of any gadget/ technological assistance related to fall? (For example fall prevention aid/fall detectors/elderly monitoring system, mobile apps, serious games, etc.)
   ○ **Yes** ○ **No**
2. Do you think a fall preventive technological aid can actually reduce negative impact due to fall/ prevent fall?
   ○ **Yes** ○ **No** ○ **May be**
   If **May be**/**no**, what is the reason?
   _____
   _____
   _____
   _____
3. If you come to know that technological aid can reduce the negative impact due to fall/ prevent fall, will you use it?
   ○ **Yes** ○ **No** ○ **May be**
   If **Maybe/ no**, what is the reason?

_____
_____
_____
_____
_____

4. For your safety purpose, will you accept a fall preventive wearable device even if it is visible to others?
   ○ **Yes** ○ **No** ○ **May be**
5. What are the factors you would consider before using a wearable fall preventive technological aid?
   a. Usefulness.
   b. Easy to carry.
   c. Easy to understand: how it operates, and it can be worn without any help.
   d. How it looks, it's color and form.
   e. Cost-effective.
   f. All of the above
   g. None of the above.
   Comment_____
   _____
   _____
6. If you need to consider only one factor before using a wearable fall preventive technological aid, what would that be?
   a. Usefulness.
   b. Easy to carry.
   c. Easy to understand: how it operates, and it can be worn without any help.
   d. How it looks, it's color and form.
   e. Cost-effective.
7. What is your attitude towards (the acceptance of) any kind of technological aid that can prevent falls?
   a. The technological aid would make life safer by reducing the impact of fall.
   b. It is a good idea to use technological aids without effecting everyday activity.
   c. It will be beneficial to make some technological aid that can help to prevent falls.
   d. All of the above
   e. None of the above.
   Comment_____
   _____
   _____
   _____
8. What do you think about the following comments?
   a. If I use technological aid, I would be afraid to make an error with it and not easy to restore.
   ○ **Yes** ○ **No** ○ **Maybe**

b. I think I can use technological aid when I have a user-friendly manual/ instruction.

○ **Yes** ○ **No** ○**Maybe**

Suggestions/ comments (If any?)

_____

_____

Interview script (PRQ5)

This annexure depicts the open-ended questionnaire that contributes to section 2.6 in chapter 2 to understand the end-users need in EXG. They are free to quit at any time during the interview or interaction with the EXG.
Participants are explained with the research and asked a few basic questions (1-7) and later introduced to the EXG- Dance Dance Revolution (DDR) and its working mechanism. A sufficient amount of time is provided to the participants to get familiar with the DDR. After finishing the session, relevant questions are asked to understand their views on DDR and EXG.

1. Have you undergone any clinical surgery for the last two years? Are there any? Are you under any regular prescribed medication?
2. What is the work- profile of the earning member in your family?
3. Would you like to share your experience before and after your retirement (if any)?
4. How do you like to spend your free time? What activities do you involve the most?
5. How many members are there in your family? How many of them are elderly and children?
6. Do you like to play with your friends or grandchildren? What are the activities that bring joy to you?
7. Have you or any person you known heard of exergame? Would you like to use it?
8. Do you have any discomfort while playing?
9. Tell me about your experience with DDR. What are the interesting and problematic points, according to you?
10. Why do you think it is not for the elderly?
11. Are you clear about the interaction with the game?
12. Can you explain the task and your movement coordination of DDR?
13. Are you able to play it without any help? Do you think after more practice you can guide other people with it?
14. How fast or slow do you think the game is?
15. Are you satisfied with the visuals of it?
16. Do you think it can help the elderly in exercising?
17. If yes, what kind of scenario will you prefer in a similar EXG?
18. If an EXG is tailored, considering the elderly in India, will you be interested in using it?
19. Is there anything you would like to share about the EXG that you think will be beneficial for you or others? Any suggestions on how such EXG is supposed to be?

End of interview.

A few images and videos are shown to make the elderly and family members understand about exergame. Images used are shown below:

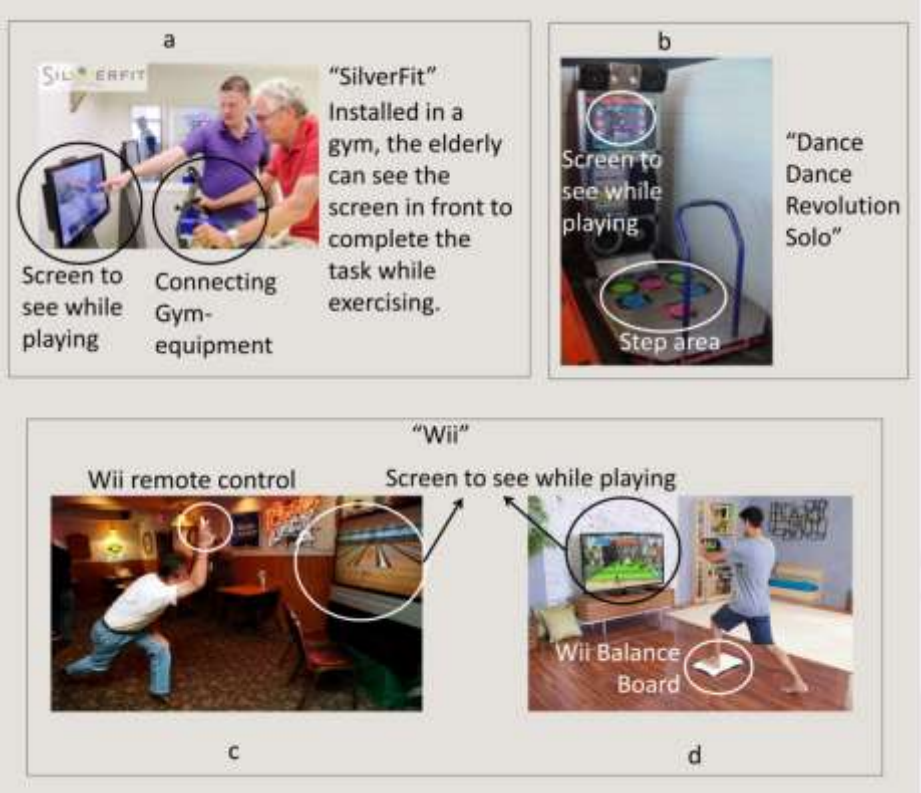


Figure A5. 1. Example of images of Exergame

Image original sources:

a)https://www.google.co.in/search?q=SilverFit&source=lnms&tbm=isch&sa=X&ved=0ahUKEwid24zMjqXUAhXEG5QKHVURABEQ_AUICCgD&biw=1517&bih=735#imgrc=F9kkWU0-B654EM

b) https://www.ranker.com/review/dance-dance-revolution-solo-2000/9844071?ref=wiki_282723

c) https://static01.nyt.com/images/2009/04/21/science/21wii-600.jpg

d) https://www.google.com/url?sa=i&source=images&cd=&ved=2ahUKEwjuzt-k7eflAhVKL48KHXJnCAIQjRx6BAgBEAQ&url=https%3A%2F%2Fwww.hardcoregamer.com%2F2013%2F11%2F02%2Fwii-fit-u-full-demo-released%2F60680%2F&psig=AOvVaw1SSjTws69-vEFuBPNnHQrE&ust=1573757305743986

Annexure B

Title: Therapeutic Stepping- exergame (TSE) for the elderly in India.

Therapeutic Stepping- exergame/ Stepping- Exergame (TSE) summary:
"Exergame" is an interactive game. The game movements are associated with the fall preventive "Stepping exercises." To improve balance and complete the recommended set of exercises (by doctors/physiotherapists) in the elderly in Indian, this TSE has been designed.

The objective of the study:

1. To find whether the Stepping- exergame can help the elderly to improve balance.
2. To find out whether using the Stepping- exergame can help them to complete the prescribed set of exercises (in a more interesting way) as compared to the traditional way of stepping exercise.

Name of the Researcher: **Nilakshi Yein**

***Personal details will be completely confidential.**

Participant's personal Details*

Name: **Address:**

Age:

Gender: ☐ **Male** ☐ **Female** ☐ **Other**

Education: ☐ **None** ☐ **Under 10th** ☐ **12th** ☐ **Graduate / above**

Number of falls in the last 2years:

☐ **0 times** ☐ **1-2 times** ☐ **3-4 times** ☐ **5 times/ more**

Participant Signature: _____ Date: _____

Signature: _____ **Signature: _____**
Doctor/ Therapist **Researcher**

Part I

Annexure B1

The interview started by introducing the participants to this research. Participants are then asked to shred their experience on falls along with the form (Part I). This annexure contributes to section 5.6.2 in chapter 5.

Participants are given the questionnaire to fill before and after the TSE- session. The balance confidence is measured using The Activities-specific Balance Confidence (ABC) Scale [112].

ABC questionnaire (RQ2)

Patient Name: _____ Date: _____

*The Activities-specific Balance Confidence (ABC) Scale**

Instructions to Participants: For each of the following activities, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale from 0% to 100%. If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as if you were using these supports.

0% 10 20 30 40 50 60 70 80 90 100%

No Confidence Completely Confident

How confident are you that you will not lose your balance or become unsteady when you…?

1. … walk around the house?	%
2. …walk up or downstairs?	%
3. …bend over and pick up a slipper from the front of a closet floor?	%
4. …reach for a small can off a shelf at eye level?	%
5. …stand on your tiptoes and reach for something above your head?	%
6. …stand on a chair and reach for something?	%
7. …sweep the floor?	%
8. …walk outside the house to a car parked in the driveway?	%
9. …get into or out of a car?	%
10. …walk across a parking lot to the mall?	%
11. …walk up or down a ramp?	%

12. …walk in a crowded mall where people rapidly walk past you?	%
13. …are bumped into by people as you walk through the mall?	%
14. …step onto or off of an escalator while you are holding onto a railing?	%
15. …step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing?	%
16. …walk outside on icy sidewalks?	%

*Powell LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. Journal of Gerontology Med Sci 1995; 50(1): M28-34.

Total ABC Score: _____Scoring: _____/ 16 = _____% of self confidence

Total ABC Score ☐

Patient Signature: _____ Date: _____

Signature: _____ _____

Doctor/ Therapist Researcher

The fear of falling is analyzed using FES - Short Falls Efficacy Scale [133, 23].

FES questionnaire (RQ3)

Patient Name: _____ Date: _____

FES - Short Falls Efficacy Scale*

Below are some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (for example, if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity.

For each of the following activities, please check the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

	Not at all concerned 1	Somewhat concerned 2	Fairly concerned 3	Very concerned 4
1. Getting dressed or undressed				
2. Taking a bath or shower				
3. Getting in or out of a chair				
4. Going up or downstairs				
5. Reaching for something above your head or on the ground				
6. Walking up or down a slope				
7. Going out to a social event (for example, religious service, family gathering, or club meeting)				
TOTAL SCORE =				

*Adapted from the Prevention of Falls Network Europe, Falls Efficacy Scale International Kempen GIJM, Yardley L, Haastregt JCM van, Zijlstra GAR, Beyer N., Hauer K, Todd C.

Participant Signature: _____ Date: _____

Signature: _____ _ _____

Doctor/ Therapist Researcher

Annexure B3

This annexure shows the questionnaire for User Study (Chapter 6) to answer the research questions 3 and 4. Participants are to fill up the UTAUT2-Unified Theory of Acceptance and Use of Technology 2 questionnaire [139] after the TSE- session is completed successfully.

Assistant

Based on your experience with the game, please read the following sentences and rate on a scale.

TSE: Therapeutic Stepping- exergame

	Strongly Disagree **1**	Somewhat Disagree **2**	Neither Agree Nor Disagree **3**	Somewhat Agree **4**	Strongly Agree **5**
1. Using the TSE motivates me to do the set of TSE.					
2. I find TSE useful in balance improvement.					
3. Using TSE helps me reducing my fear of falling.					
4. Using TSE helps me in increasing balance confidence.					
5. Learning how to use TSE is easy for me.					
6. My interaction with TSE is clear and understandable.					
7. I find TSE is easy to use.					
8. It is easy for me to become skillful at using TSE.					
9. People who are important to me think that I should use TSE.					
10. People who influence my behavior think that I should use TSE.					
11. People whose opinions that I value prefer that I use TSE.					

12. I have the resources necessary to use TSE.					
13. I have the knowledge necessary to use the TSE.					
14. TSE is compatible with other technologies I use.					
15. I can get help from others when I have difficulties using TSE.					
16. Using TSE is fun.					
17. Using TSE is enjoyable.					
18. Using TSE is very entertaining.					
19. TSE is reasonably priced*.					
20. The TSE is a good value for the money*.					
21. At the current price, TSE provides a good value*.					
22. The use of TSE has become a habit for me for exercise.					
23. I am addicted to using the game to exercise.					
24. I must use TSE.					
25. Using TSE has become natural to me.					
26. I intend to continue using TSE in the future					
27. I will always try to use TSE in my daily life.					
28. I plan to continue to use the game frequently.					

***Price ≈ Rs. 6000 (Hospital / Physiotherapy / Community based)**

Perform Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, Hedonistic Motivation, Price Value, Habit, Behavioral intention are the key constructs of UTAUT2. In the above shown questionnaire, these constructs have questions that are listed below:

Constructs	**Corresponding question numbers**
Performance expectancy	1-4
Effort expectancy	5- 8
Social influence	9- 11
Facilitating conditions	12- 15
Hedonistic motivation	16- 18
Price value	19- 21
Habit	22- 25
Behavioral intention	26- 28

Annexure C

Annexure C1

This annexure is a contribution to the prototype design from chapter 4; it shows the task and interaction flow of TSE- for the exercise "Simple stand"- "Fish Catcher."

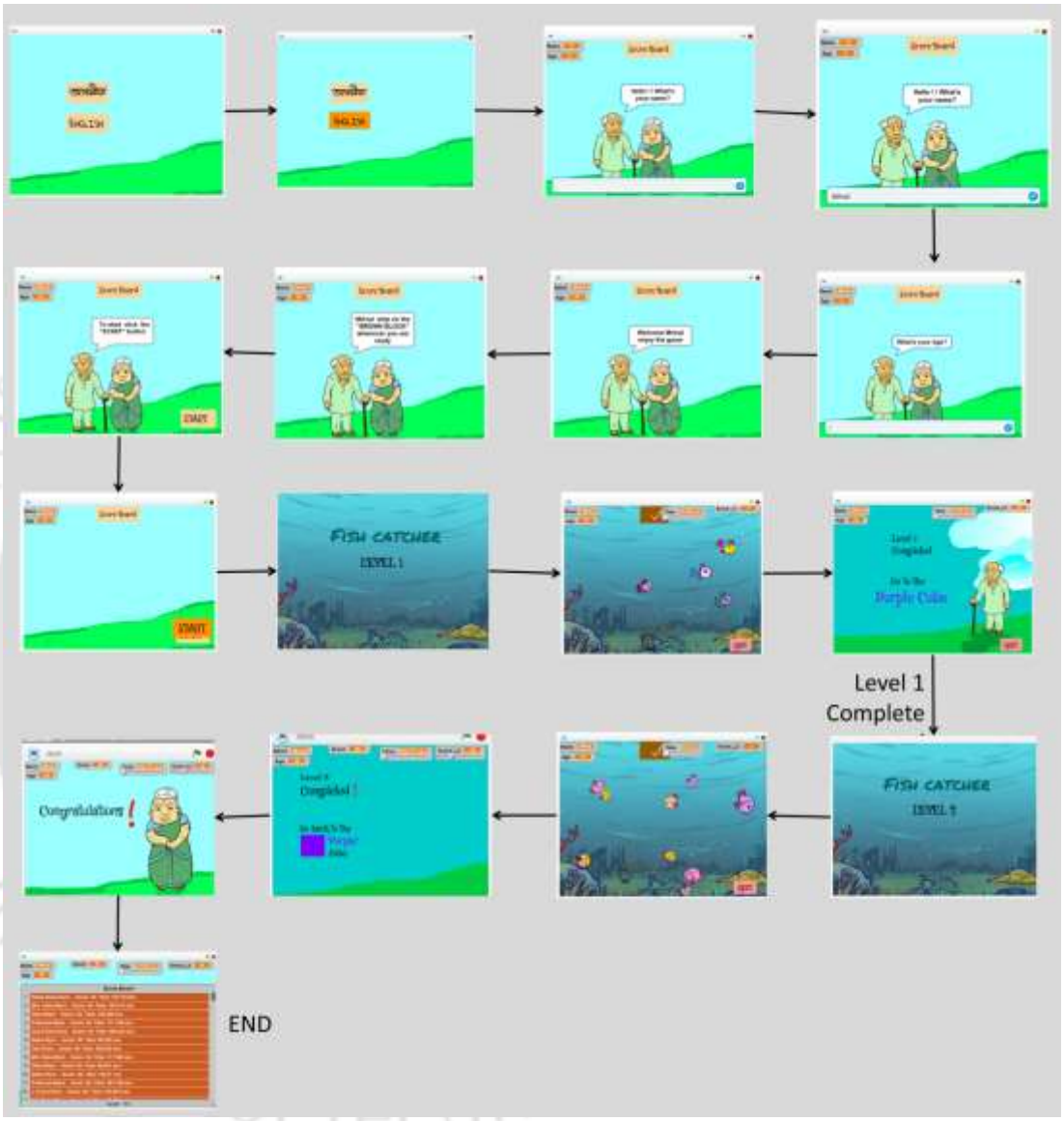
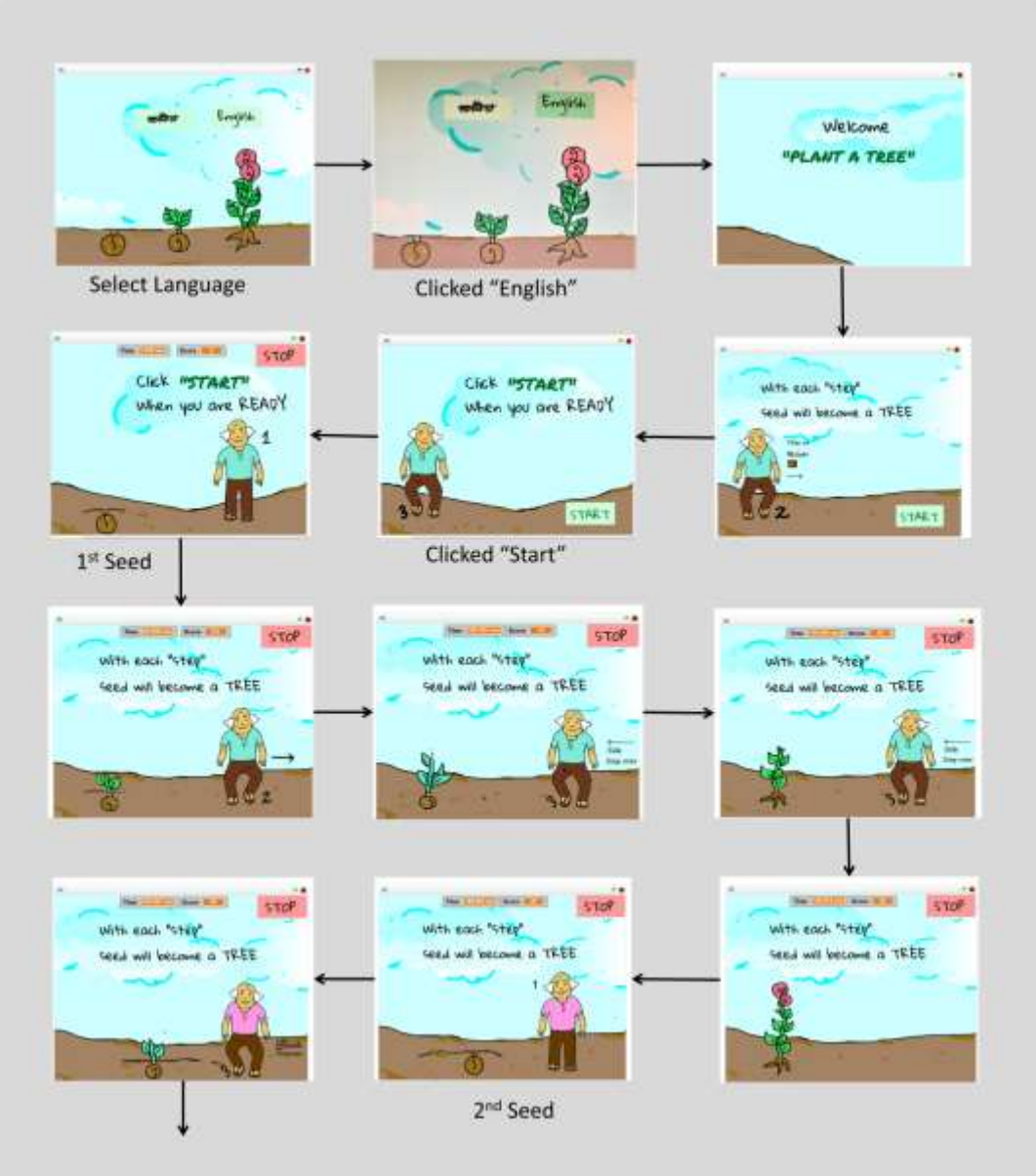


Figure C1. 1. "Fish Catcher" at various stages

As discussed in chapter 4, this annexure depicts the interaction flow and the exergame story of TSE- for the exercise "Side Step over"- "Plant a Tree."



Contd.

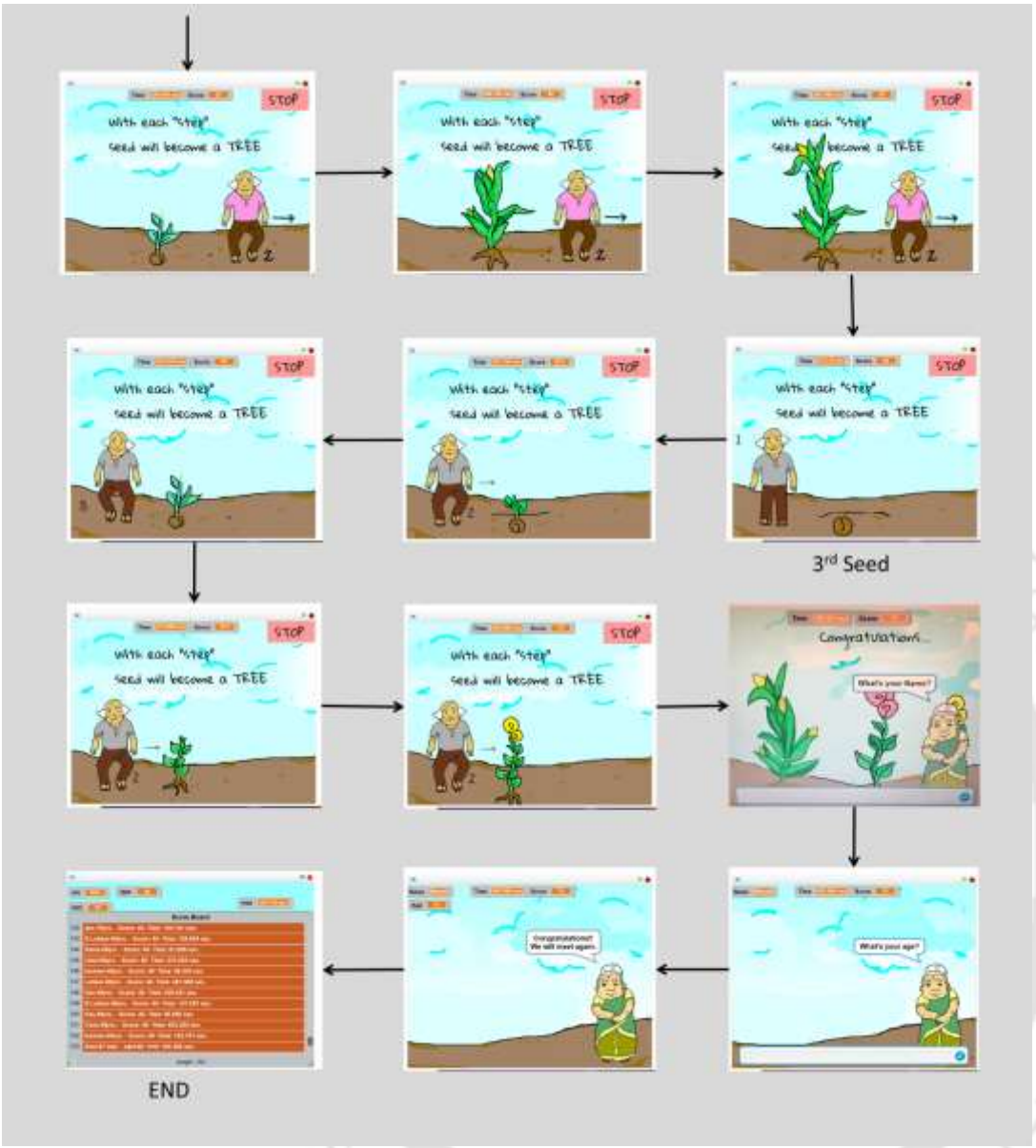


Figure C2. 1. "Plant a Tree" - at various stages

Annexure C3

As discussed in chapter 4, this annexure depicts the interaction flow and TSE's exergame story- for the exercise “Straight walkover”- “Bild a house.”

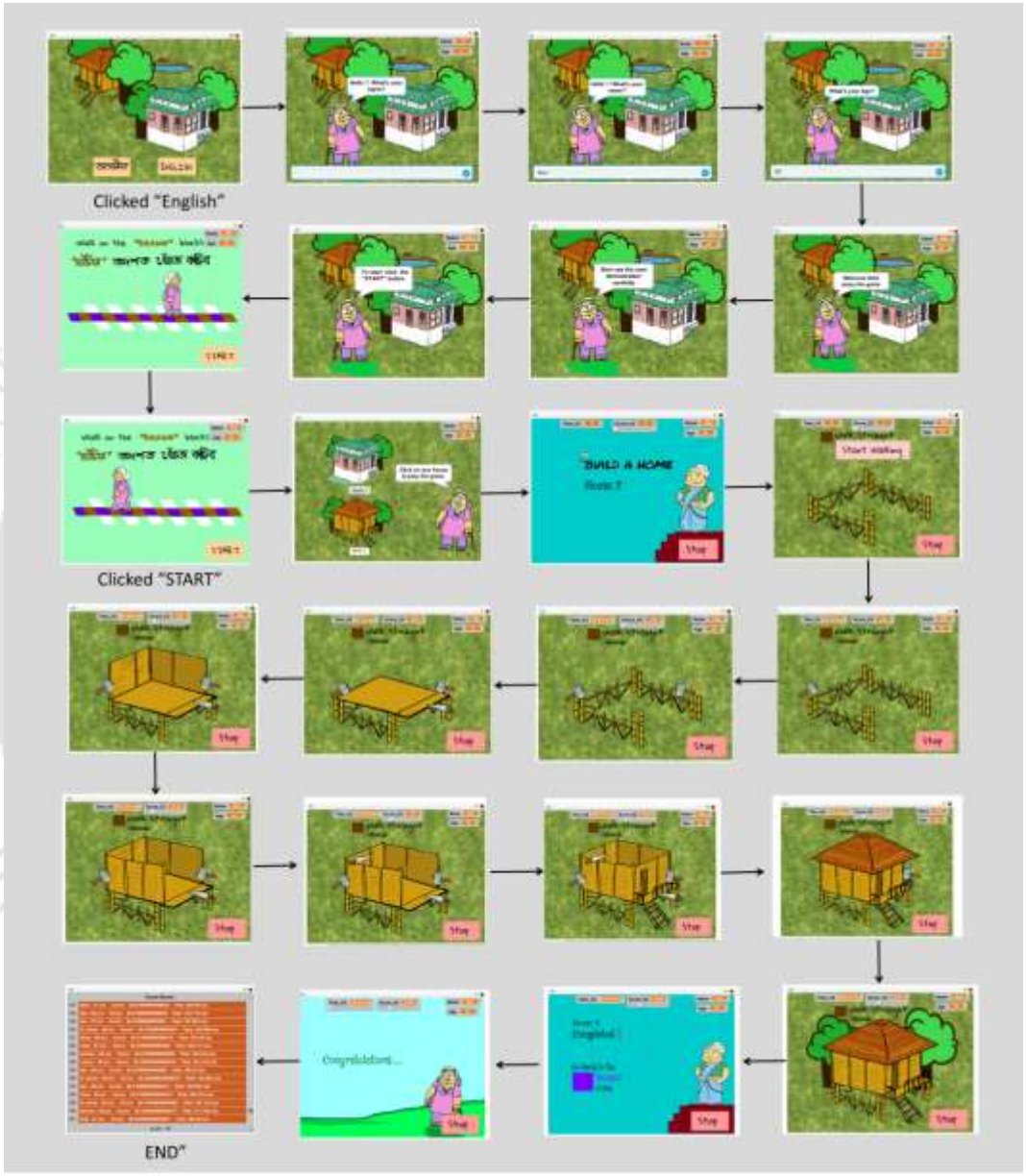


Figure C3. 1.: Build a House: at various stages

Annexure D

This annexure shows the detail of the Scratch engine used in the TSE development process for the programming and game design process.

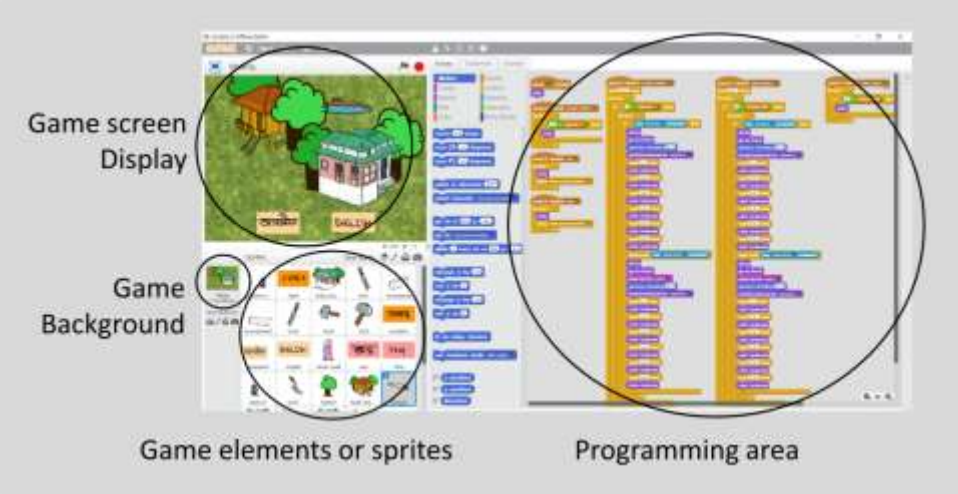


Figure D1. 1. Space assigned in Scratch Engine for game design

For each exercise, a set of instructions are written. It can control the sprites' movement in the game, and the step inputs from the elderly are assigned to specific each sprite.

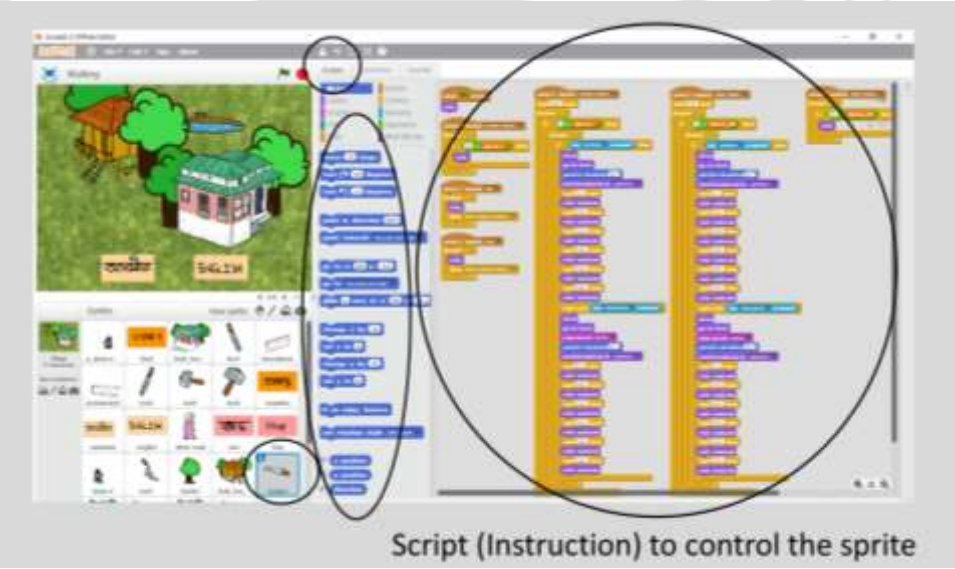


Figure D1. 2. Example of a Script to control the Sprite

Scratch has its own image creating space as well as audio recording and editing space.

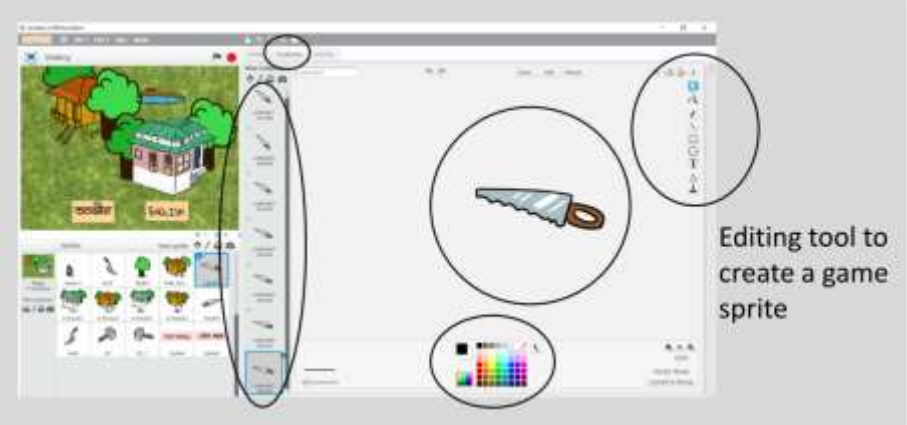


Figure D1. 3. Scratch picture creating space

Figure D1. 4. Example of sound recording in Scratch

This annexure is a contribution to section 4.4 in chapter 4. It shows the development process in making the TSE- interface. The capacitive pressure sensor used in the prototype is Alluminuum Foil, connected, as shown in the figure below, which is placed under the Mat of the TSE.

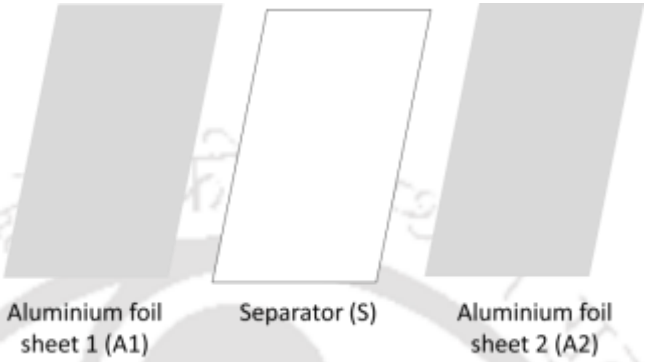


Figure D2. 1. Example of using Alluminum foil

Two sheets of Alluminium foils A1 and A2 are used as positive and negative points, separated by S. The positive end (A1) is connected to the designed keystroke on the MAkey MAkey as programmed, and the negative end (A2) is connected to the ground as shown in the following two figures.

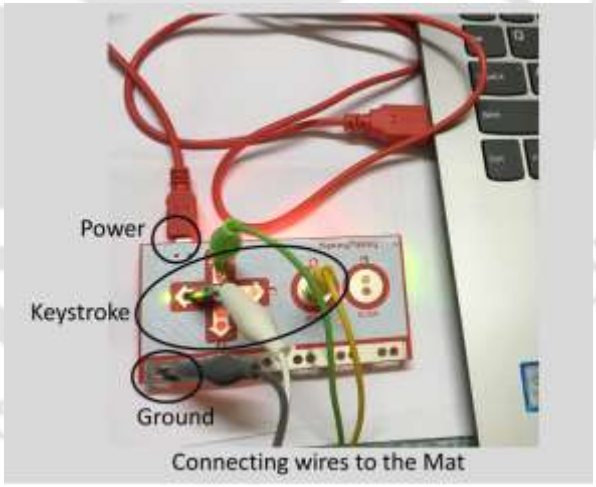


Figure D2. 2. Connections of Mackey Mackey in TSE

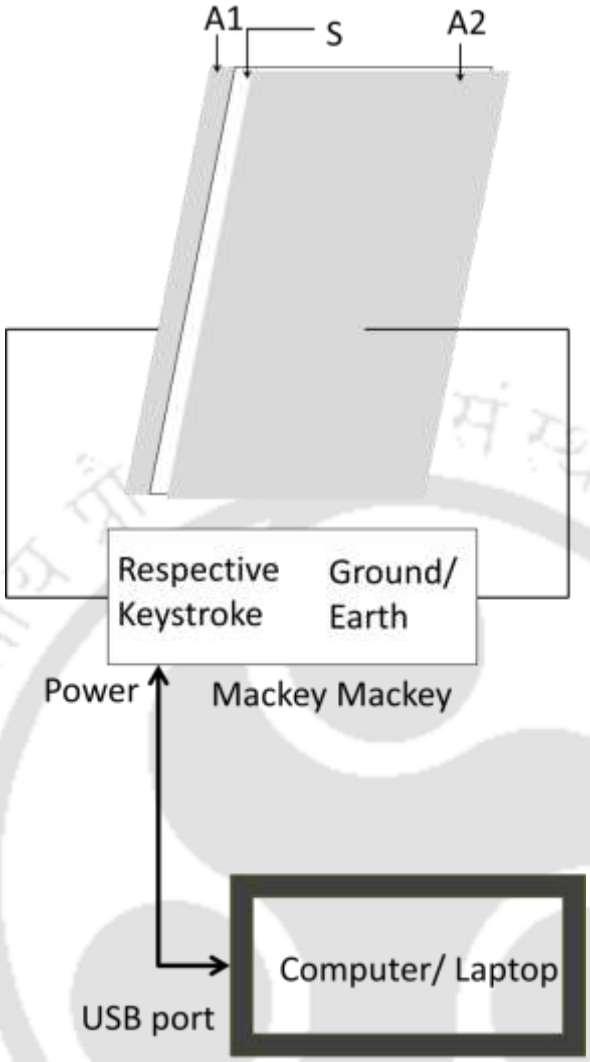


Figure D2. 3. Pictorial representation of the Hardware Connection in TSE

Annexure E

Annexure E

Examples of conceptual mapping and brainstorming to generate the TSE design concept.

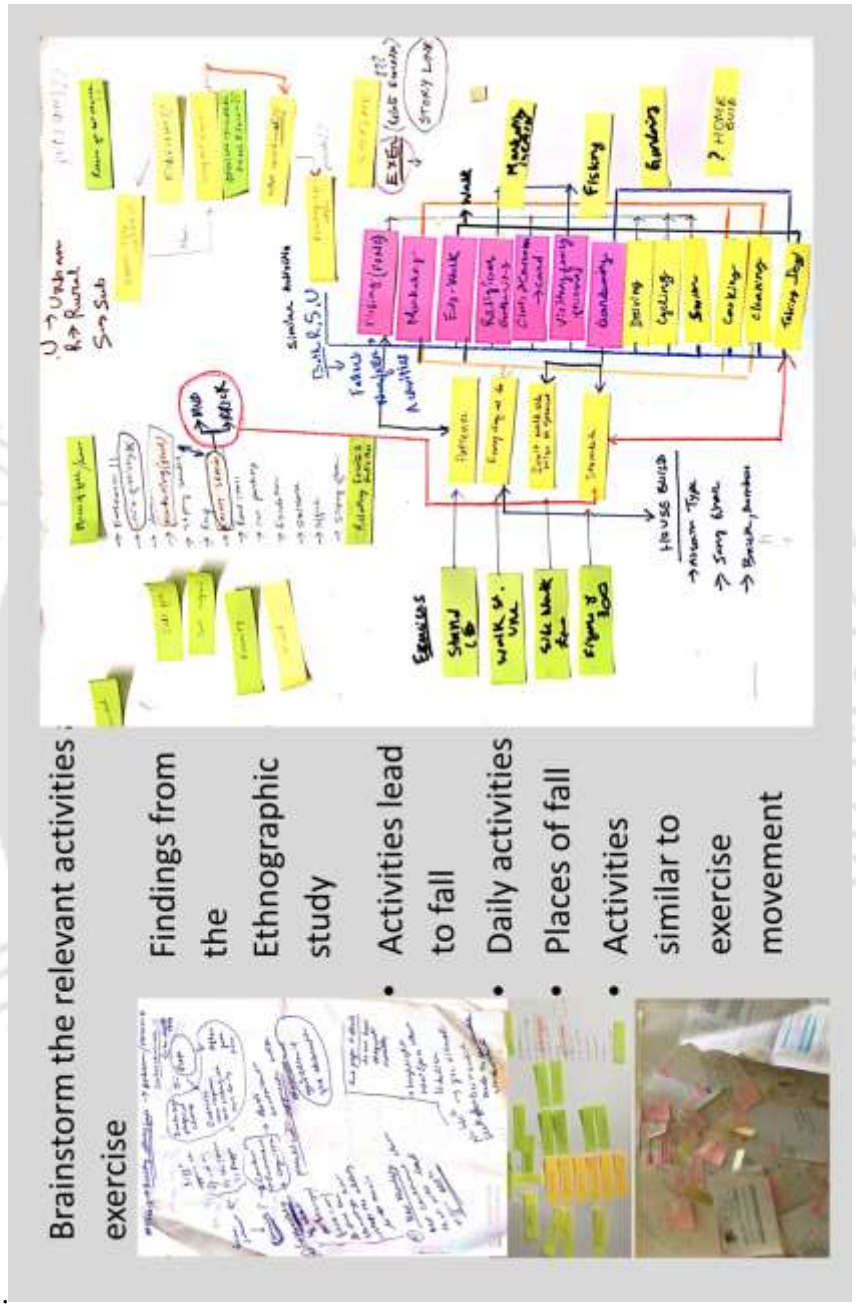


Figure E 1. Examples of conceptual mapping and brainstorming

Publications associated with the research output of this thesis

Publications with the research output of this thesis

1. Yein N., Pal S. (2020). Design Interventions of an Exergame for Fall Problem in Indian Older Adults. In: Rebelo F., Soares M. (eds) Advances in Ergonomics in Design. AHFE 2019. Advances in Intelligent Systems and Computing, vol 955. Springer, Cham.
2. Yein N., Pal S. (2018). Qualitative Study on Salient Factors Influencing Indian Elderly's Perception on Fall and Its Related Interventions. In: Di Bucchianico G., Kercher P. (eds) Advances in Design for Inclusion. AHFE 2017. Advances in Intelligent Systems and Computing, vol 587. Springer, Cham.
3. Yein N., Pal S. (2017) Technological Assistance for Fall Among Aging Population: A Review. In: Chakrabarti A., Chakrabarti D. (eds) Research into Design for Communities, Volume 1. ICoRD 2017. Smart Innovation, Systems and Technologies, vol 65. Springer, Singapore.
4. Yein, N. & Pal, S. (2015). A Review on Preventive Interventions for Elderly Fall Problems related to Balance. Conference Proceedings International Conference on Humanizing Work & Work Environment 2015 & Community Nutrition & Health: A Social Responsibility. 7-9th Dec 2015, Mumbai, India, pp. 82-87. ISBN: 978-93-5258-836-7.
5. Yein, N., & Pal, S. (2014). Analysis of Indoor Design and related different risk factors for elderly: A review. International Ergonomics Conference HWWE 2014, Dec. 3-5,2014. Mc Graw Hill Education, Delhi, India, pp.276-81. ISBN: 978-93-392-1970-3.
6. Pal, S., Kundu, A., Rana, N., & Yein, N. Study of forearm muscle activity with regard to hand grip strength for different elbow-wrist posture. ISBN: 978-93-5258-836-7.

Journal communication:

Accepted

- Yein N., Pal S. "Analysis of the User Acceptance of Exergaming (Fall-preventive measure)- Tailored for Indian Elderly using Unified Theory of Acceptance and Use of Technology (UTAUT2) model
  —Entertainment Computing – Elsevier

Under process

- Yein N., Pal S. Evaluation of user-centered design of Therapeutic Stepping Exergame for balance improvement of elderly
  —Design for Health- under major revision (Taylor and Francis)

- Yein N., Pal S. Evaluation of Therapeutic Stepping Exergame (TSE)- a tailored Exergame for Fear of Falling and Balance Confidence for Elderly in India
  – JMIR Serious Games – Under review

Invited- MethodsX (Under process)

Method article for the research article -Entertainment Computing

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