A FRAMEWORK DEVELOPED USING ERGONOMIC PRINCIPLES AND MODIFIED PRE-DETERMINED MOTION TIME SYSTEMS (PMTS) TO INCREASE THE OPPORTUNITIES FOR PHYSICALLY DISABLED POPULATION TO WORK IN INDUSTRY

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Declaration

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Date:

Abstract

One billion of the world population are estimated to have some form of disability, and governments spend huge amounts of money to provide welfare facilities to protect their rights and make them inclusive. The literature reveals that people with disabilities (PWDs) are willing to work if they are provided with necessary job support. People with only mobility impairments are commonly named as people with physical disabilities (PPDs). It is a subset of PWDs. PPDs can effectively contribute towards economic growth if their residual physical capabilities are correctly identified. However, employers as well as PPDs themselves find it difficult to identify their residual physical capabilities. Work norms explained in Pre-Determined Motion Time Systems (PMTS) such as Method Time Measurement (MTM) is present for the normal people. These work norms assume that the people have normal capabilities and that they do not have any physical disability. However, there are no such work norms developed to cater for the PPDs. Therefore, the aim of the research was to develop a framework to increase the ability of PPDs to work in industry. The objectives were to explore typical manual work-activities (WAs) similar to those prescribed in PMTS that could potentially be carried out by PPDs, with their residual physical capabilities, explore essential range of movement (RM) of each of the body regions/joints required to perform the identified WAs, formulate a framework mapping RMs of each body regions/joints required to perform typical manual WAs and finally to evaluate and validate it for its purpose, user-friendliness and functionality.

In this pursuit, research was carried out in five distinct phases. In the first phase, typical manual WAs were identified that can be performed by upper and lower extremities using industrial engineering experts (n=3). Then, essential RM of each body region/joint required to perform the identified WAs were determined using relevant medical experts (n=9). Orthopaedic surgeons (n=4) then mapped the RMs that are needed to carry out the WAs to form a framework. These three phases used a modified delphi approach for data collection. In the fourth phase, the framework was evaluated for its purpose and user-friendliness by the intended users of the framework (n=22) in different industries. In the fifth and final study, the functionality of the framework was evaluated with PPDs (n=92) and mapped the work capability of a randomly selected sample of PPDs (n=6) using the framework. The results were compared against the WAs that they were engaged in at the time of the study. The developed guide was named as the WARM mapping tool. Ethical clearance was granted from the Medical Research Institute (MRI), Sri Lanka to carry out the study.

This research proposes a novel philosophical work-related capability and limitations analysis tool to help employ PPDs by identifying suitable WAs based on the degree of disability of the body regions/joints in terms of the corresponding RMs. It is a step towards extending the work norms for PPDs. WARM mapping tool has been developed to guide the employers to recruit PPDs to carryout physical work tasks. All that participated in the usability study proved that it is a convenient and simple tool to use. All 22 practitioners also said that it can also be used as a self-assessment tool by the PPDs. The usability was rated over 60% by all the participants. This tool may be used as a platform to decide on the equipment, facilities, procedures and training that the PPDs will need for effective performance in industry.

Keywords: People with Physical Disabilities, motion capability, employment, PMTS

Dedication

My Grandparents, in memorium,

my parents, Milton Wijewickrama and Bhadra Wijewickrama, in memorium,

and my teachers

in appreciation of sacrifices they had made for me

and

for all who have been sharing their life with me.

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Kokila Madhuri Wijewickrama Abeykoon

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List of Abbreviations

AADL	Advanced Activities of Daily Living
ADA	Americans with Disability Act
ADL	Activities of Daily Living
AHP	Analytical Hierarchy Process
BADL	Basic Activities of Daily Living
CMJ	Metacarpophalangel joint
DGHC	Director General of Health Services
DIPJ	Distal Interphalangeal Joint
DMS	Dimensional Motion Times
FRCS	Fellows of the Royal College Surgeons
GSD	General Sewing Data
IPJ	Interphalengeal Joint
MBBS	Bachelor of Medicine Degree
MECA	Microcomputer Evaluation of Careers & Academics
MMH	Manual Materials Handling
MRI	Medical Recearch Institute
MS	Masters' Degrees
MTA	Method Time Analysis
MTM	Motion and Time Measurement
MTS	Method Time Standards
P and O's	Prosthetists and Orthotists
PCS	Physical Capability Study
PIPJ	Proximal Interphalangeal Joint
PMTS	Pre-Determined Motion Time Systems
PPDs	People with Physical Disabilities
PWDs	People with Disabilities
RM	Range of Movement
ROM	Ranges of Motion
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Ass
SAH	Standard Allocated Hours
SLSPO	Sri Lanka School of Prosthetists and Orthotist
SLMA	Sri Lanka Medical Association
SLMC	Sri Lanka Medical Council
SLOA	Sri Lanka Orthopaedic Associatio
SMV	Standard Minute Value
WA	Work-Activities
WMSD	Work-related Musculoskeletal Disorders

List of Appendices

1 Introduction

Disability is identified as a debilitating condition, which modifies body, appearance as well as Activities of Daily Lives (ADL) (Refer Section 2.5 below), but do not totally destroy their ability to work [1]–[5] and around one billion people or 15% of the world population, have some form of disability [6]–[9]. In terms of their ability to work, experts have contrasting opinions. For instance, it is believed that People with Disabilities (PWDs) have great potential at work [10]. However, there are beliefs of colleagues and superiors about limited work performing ability of PWDs [11], [12]. This shows that both the practitioners and the researchers are in general unclear about the working ability of PWDs.

Discussions have been in existence regarding employment of PWDs since the mid-20th century [13]. It is argued that the inclusion of PWDs in achieving company goals, and that allocating a reasonable percentage of PWDs in organisations with or without considering the size of the organisation is favourable for PWDs [14]. Literature also suggests that PWDs are willing to work if they are recruited to organisations [15]. Citing from previous research, it is stated that two-thirds of PWDs desire to work if appropriate job opportunities are available [16]. Thus, it is clear that PWDs need to be provided with necessary support and guidance to work effectively. Other researchers also support this notion [12], [17]. However, cost of inclusion of PWDs in organisations has not been given due regard in literature, therefore it needs attention in order to explore the possibilities of providing assistance to help them be involved in income generation activities.

Quantification of costs of disability has been difficult due to many reasons. For example, varying definitions of disability [2], varying sources of data [9], limited data availability on lost productivity [9] and having no commonly agreed method for cost estimation [9] have been identified as challenges towards determining the costs of disability and the employment of PWDs. Literature points out two types of costs pertinent to disability categorised as direct and indirect costs. Direct costs are to increase the standard of living by providing full or partial benefits due to early retirement schemes, healthcare facilities, assistive devices [18], expensive transportation facilities and personal assistance [9], [19]. Direct costs also include costs due to reduced work capacity of PWDs. Indirect costs are due to loss of productivity owing to disability [9]. Indirect costs include expenses due to underemployment of family members' leave from work [9], employment in poorly paid jobs [9], under-employment [20], low-skilled and low-status jobs [9], which are unrewarding and un-demanding and staying unemployed to care for PWDs [9]. Literature emphasises that direct costs as well as indirect costs of PWDs are shared by individuals themselves, their families, friends, employers, organisations and society in general [9] resulting in an apparent additional load on the economy. However, there may be a possibility where the PWDs are able to positively contribute to the economy if they are appropriately employed.

Despite potential benefits, many unfavourable beliefs have been identified as barriers to employ PWDs. People in wheelchairs have been branded as unproductive and thought to be lacking in efficiency [21], [22]. Employment and training of PWDs are also identified as a tough task [6], which needs costly accommodations [10]. Furthermore, PWDs are thought to be incapable of marketing themselves at job interviews [10]. As a result, based on the beliefs such as the ones listed, employers arrive at quick and unfavourable judgements about PWDs at interviews, which badly affects their selection [10], [11]. Such beliefs could be the reason for poor employability of PWDs.

Another approach is proposed where the employers try to understand the work ability of PWDs whilst the educators help youth PWDs to market their skills at job interviews [10]. In order to facilitate recruitment and employment of PWDs in organisations, employers need to be able to identify capabilities and limitations of the recruits [23]. However, literature reveals that neither employers nor PWDs know their potential contribution to organisations since both parties do not have a thorough idea of their physical capabilities [16]. Reviews also show that in general a vacuum exists in understanding the capabilities and limitations of PWDs for effective employment, thus warranting further research.

Different classifications of disabilities are explained by [8], [18], [24]. However, the analysis of them reveal that the most commonly used classification is with respect to mobility, cognitive, visual and hearing impairments. Out of these, people with mobility impairments are commonly named as people with physical disabilities (PPDs) [10], [25]. PPDs can have impairments (Refer Section 2.3 below) in at least one of the body regions and/or joints. It is also clear that all body regions and/or joints may not be needed in order to perform all manual Work-Activities (WAs). Therefore, with their residual capabilities, they may be able to perform selected productive WAs. Supporting this notion, the importance of understanding the interaction between PWDs that include PPDs, and the elements of work systems is stressed [6], [7]. This prompts the study of typical manual WAs available in industries thus creating an opportunity to bridge the gap between PWDs and employment.

PWDs tend to earn lesser incomes than persons with no disabilities [20], [26] and cost and energy spent for vocational training has a negative impact leading towards employability despite education and training being provided for PWDs [27]. Limited employability has deprived them of an adequate income for an independent life. Therefore, it is clear that in order to provide them with comfortable living conditions and to reduce the effect on the economy, they need to be employed and effectively involved in income generating activities. However, the possible interventions need to be identified.

A number of studies have been conducted and suggestions have been made to ensure the well-being of PWDs. Defining disability using lay terms [28] so that the general public understands these disabilities is one such attempt. Identifying disability models [28]–[33] (Refer Section 2.4) to facilitate employment is another. Interestingly, employment models for PWDs have also been discussed [11], [20] (Refer Section 2.6). In addition, acts have been formulated to protect PWDs from discrimination [15], [16], [34] and legalisation [4], [34] has been in existence to protect their rights in the workplace.

Once the barriers to identification of PWDs for employment are identified, facilities need to be provided for them in the workplaces. In this regard, the built environment has been identified as important to provide the necessary infrastructure facilities to cater to the requirements of PWDs [15], [35], [36]. In addition, interventions such as assistive technology [16]–[18], [26], [37], wheelchairs [38], universal design [17],

[18], [22], participatory techniques [39] and real-time information capturing [40] have been proposed and introduced in order to improve their independence.

Rehabilitation of PWDs is also being extensively discussed in literature as a way of preparing PWDs to work in industry [23], [41]. Work-related rehabilitation needs are being identified by [20], [32], [42] because it is accepted that PWDs do not have the skills, education, training or experience necessary to effectively perform WAs [15]. Supporting this view, vocational training needs have been identified as essential by [12], [43] while the need to prove the physical capability of PWDs in industry is explained by [44]. The approaches that have been developed so far to assist PWDs to work in industry are too generic [45] and none of the models support in identifying physical capabilities and limitations of PWDs in performing typical manual WAs. Thus, it is important to facilitate both the employers and the PWDs to identify the physical capabilities and limitations as well as the needs in order to be effectively employed.

Most of the studies on employment of PWDs that have been carried out thus far, discuss several issues/problems in relation to difficulties in access to organisations, not having relevant skills, improper education, dissatisfaction of the job as well as vocational training, mismatching capabilities and limitations with the available job opportunities, waste of potential of qualified PWDs and discrimination at employment as explained earlier. However, there is no proper framework identified or developed to ascertain residual physical capabilities and limitations that match with organisational requirements to perform manual WAs, thereby helping to integrate the PWDs with an industry. However, it is discussed that safety of the people with cognitive, hearing and vision impairments in industry is a concern and they are largely not suitable to perform isolation or in large workshops performing typical manual WAs, especially in the manufacturing sector [46]. Therefore, PWDs without sensory impairments, i.e. PPDs, may become the suitable category to perform manual WAs in industry.

PPDs may become ‘differently-abled’ if a framework is available to map their residual work capabilities to the typical manual WAs in industry. Even though job accommodation of PWDs, which includes PPDs, has been identified in literature as a tough task, it is stressed that understanding the interaction between PPDs and the elements of work systems is important [6]. Among the disabled population, there are also qualified PWDs [17], [34]. Underutilisation of the potential of these people is argued as a waste of human resources causing substantial impact to a society [16]. Thus, facilitating the employment of PPDs in industry could have significant economic benefits. Interestingly, a multi-dimensional disability model that integrates the physical capabilities and limitations of PPDs in different aspects of work and is currently being discussed [11], [47] in literature. With this view, suggestions are in place to develop multi-dimensional assessment methods for measuring and understanding residual physical capabilities of PPDs with respect to their strengths, weaknesses, and their compatibility within an industry [16], [47].

In order to gainfully accommodate PPDs in the workplace, employers must be able to know the type of work they can perform, time that the PPDs would take to complete a work cycle, how to determine the remuneration, and the impact that the integration of a disabled individual would have on organisational productivity. In order to fulfil this, research has been done in many disciplines.

The existing Pre-determined Motion Time Systems (PMTS) (Refer Section 2.7) do not generate work standards for PWDs [48]. Thus, modifying PMTS, identifying WAs that PPDs can perform with their residual capabilities, could be a way forward to enable employment. Findings of this research may generate pathways to develop an integrated framework to help employ PPDs in industry, thus supporting all concerned parties that include the PPDs themselves, their dependent families and the employers, which would ultimately have a positive impact on the economy reducing direct and indirect costs.

1.1 Aim and objectives

The aim of this research was to develop a framework to increase the ability of PPDs to work in industry. In this pursuit, the following objectives were considered.

1. To explore typical manual work-activities that could potentially be carried out by PPDs.
2. To identify the range of movements of body regions and joints to perform manual work-activities.

3. To formulate a framework to map the typical manual work-activities to the range of movements of body regions and joints that could potentially be carried out by PPDs.
4. To evaluate the framework.

1.2 Methodology

This study was centred around an inductive-type strategy based on a qualitative analysis methodology as shown in Figure 1.1. Hence, it was of an exploratory, descriptive and explicative research type and its stages were set in a logical order to ensure a clear expression of ideas. Altogether, there were five interrelated studies that formed this thesis. The first three studies focused on the formulation of the framework to map the typical manual work-activities to the range of movements of body regions and joints. After the WARM mapping framework was formulated, it was evaluated using two studies.

In this pursuit, a literature review was carried out using books, journals and online resources in order to identify the research gap and seek possible avenues for research. Initially key words were used to select relevant literature and later citations too were referred. Only literature in English were referred in both printed and electronic publications.

In the first study, typical manual WAs in industries were selected. Separate sets of WAs that can be performed using the upper and lower extremity of human body were identified through a literature review. WAs in the horizontal and vertical planes were considered. All WAs were then refined by Industrial Engineers. In the second study, body regions (such as arm, forearm and leg) and joints (such as shoulder, elbow, hip and knee), which are useful for carrying out typical manual WAs were identified through a literature review. The RMs were also documented for each body region. Afterwards, two standard documents were formulated for upper and lower extremities, containing the set of body regions and joints, and their corresponding RM, which are useful for performing manual WAs using Orthopaedic Surgeons, Prosthetists and Orthotists as the participants.

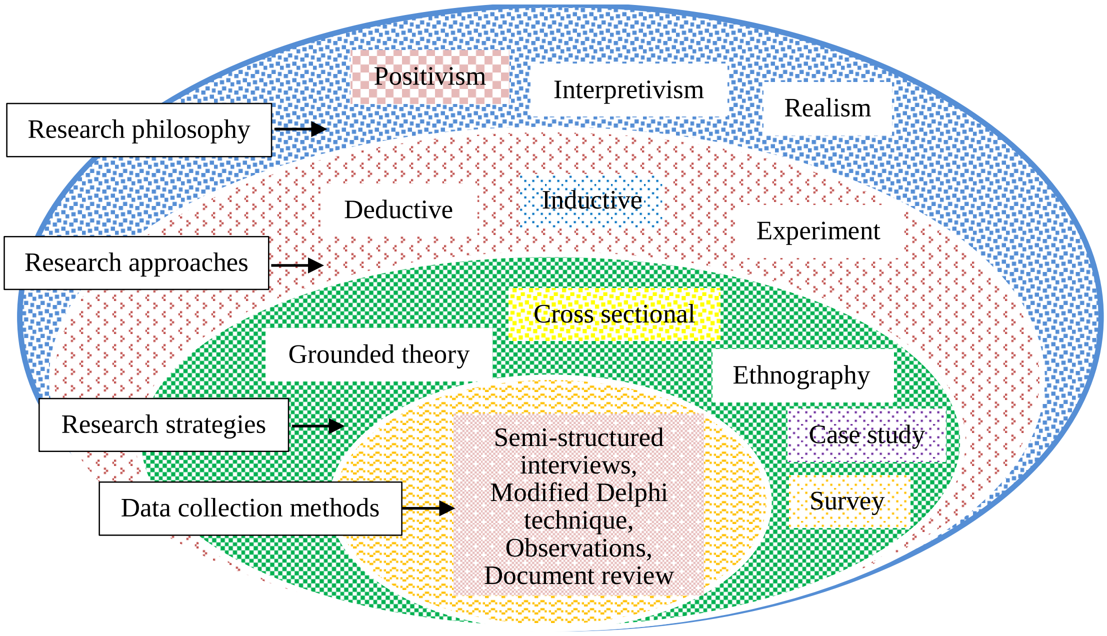

Figure 1.1: Summary of the research methodology as in 'Research Onion'
Source: [49]

The third study was to map typical WAs identified from the first study to the human motion capability required to perform them identified from the second study. This became the basis for a framework to identify WAs that can be performed by PPDs. The study involved Orthopaedic Surgeons and Prosthetists and Orthotists.

The evaluation study involved two phases. In the first phase, a questionnaire survey was administered to assess the usability of the framework by allowing practitioners to use it. HR Personnel, Industrial Engineers, Work-study experts and professionals in-charge of training and rehabilitation who directly engage in recruitment and selection procedures participated in this study. The framework was used to identify and categorise PPDs to perform different WAs. In the second, the focus was on the functionality of the framework. Ethical clearance was granted from the Medical Research Institute (MRI) of Sri Lanka to conduct this study. The participants for the study were PPDs having no visual, cognitive, nervous or auditory impairment.

1.3 Organisation of the thesis

The thesis was compiled in nine chapters. Chapter 01 presents the introduction to the research with the motivation, philosophical framework and a brief methodology of the research. Chapter 02 presents the literature review and explains how known theories have been explored to develop a framework to employ PPDs in industry in an inductive approach. Manual WAs explain in Pre-determined Motion Time Systems (PMTS), which are useful for employment of normal population were identified in the literature. Chapter 03 explains the first expert review study that identified typical manual WAs in industry. Chapter 04 consists of evaluating and refining the anatomical movements of the human body. Chapter 05 demonstrates the process of mapping typical manual WAs with the anatomical movements of body regions and joints which are required to perform them that identified in the previous studies. Chapter 06 provides an evaluation study on usability of the tool. Chapter 07 presents the evaluation study on functionality that was used to categorise PPDs according to their ability to perform typical manual WAs in industry. A general discussion of the research is drawn in Chapter 08 and the final, Chapter 9 presents the conclusions of the research as a whole. The outline of the chapters is presented in Figure 1.2.

1.4 Contribution to knowledge

The foremost contribution of the research was the development of the framework that enables the selection of PPDs to carryout manual WAs in industry. It would also enable to identify manual WAs that PPDs are comfortable in performing. Based on the disability, PPDs can be categorised identifying specific requirements based on their physical capabilities and limitations and create a favourable environment for them. Research findings can also lead to equipment, facilities, procedures and training, pathways, work-stations; based on the physical capabilities and limitations of individual PPDs thereby enabling them to be independent and involved in income generating activities.

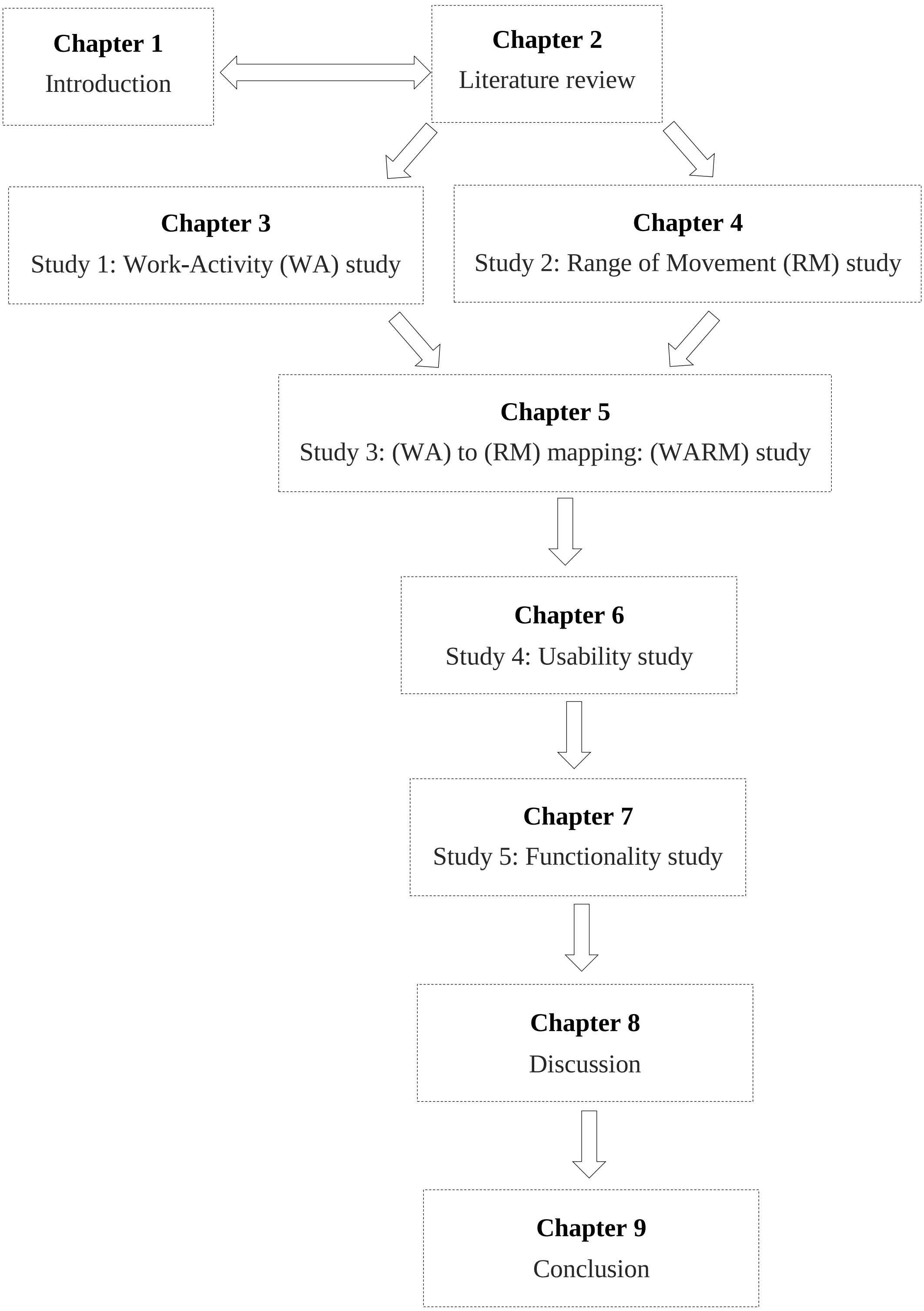

Figure 1.2. Organisation of the thesis

2 Literature review

This chapter is a literature survey presenting a broad picture of the current knowledge pertinent to employment of People with Disabilities (PWDs) in industry with a focus on physical capabilities. Simultaneously, limitations of People with Physical Disabilities (PPDs), which is a subset of PWDs is analysed by synthesising the information available in the literature. The review stresses upon the definitions of disability, current status of employment opportunities for PPDs, and mechanisms available to help employ PPDs in industry.

2.1 Aim and objectives

The aim of this review was to study related research carried out by different researchers and identify gaps in research. In this pursuit, the following objectives were considered.

1. To explore research findings related to employment of PPDs.
2. To identify research gaps.
3. To make decisions on studies to be carried out.

2.2 Review strategy

The literature survey was initiated with a keyword-based title search. An electronic search was carried out using the Science Direct, Google scholar, Emerald, Pub Med and PLOS ONE databases to obtain relevant publications. Printed material were also referred simultaneously to gather knowledge. The keywords used in the literature search classified according to the definitions such as; work content, work capability and physiology are shown in Table 2.1. Thus, both printed and electronic publications that included books, journals, reports, theses, newspaper articles, magazines and databases were accessed. Only the literature available in English were reviewed.

The title-based search resulted in 953 articles altogether. After going through the abstracts of the articles; 253 journal papers, 18 books and three theses were selected for the review. Citations within publications were also searched afterwards and specific searches were conducted using related terminology available in the accessed literature. These extended searches used keywords such as 'sheltered employment', 'supported employment', 'subsidised employment', 'embodied employment', ROM, 'goniometer', 'dynamometer', musculoskeletal load and assessment.

Table 2.1: Keywords used in the literature search

Classification	Keywords
Definitions	'Disability', 'disability definition', 'physical disability', 'physically disabled people', …
Work-Activities (WAs)	'PMTS', 'MTM', 'lifting and pulling', 'locomotor disability', …
Physical capability and limitations	'Anthropometry', 'range of motion', 'muscle strength', 'muscle power grading', 'body deformity', 'grip strength', 'pinch strength', 'chuck pinch', 'types of amputations', 'dynamic and 'static strength',
Methods to match WAs and physical capability	'Employing people with disability', 'legalisation', …

2.3 Context

Different classifications of disabilities are also found in literature [8], [18], [24], [50]. However, the analysis of these reveal that the most commonly used classification is with respect to mobility, cognitive, visual and hearing impairments. However, it is argued that PWDs perform poorly in physical, cognitive, mental, sensory, emotional and developmental activities or some combination of these [9], [18], [29], [34]. Thus, employment is difficult [46].

Physical disability is defined as a functional limitation with restricted mobility and means of access [51]. Mobility impairment restricts the movement or control of body regions of physical disabilities that affect physical capability [8], [24]. Diverse lay terms are also used to define permanent functional differences of PPDs such as impairment, deformity, disability and handicap [8], [28], [30], [52]–[55]. It also defined as the 'want of physical power, weakness, incapacity or mobility' [56] and handicap is defined as a disadvantage for a given individual, resulting from impairment or a disability that limits or prevents the fulfilment of a role that is normal (depending on age, sex, and social and cultural factors) for that individual [28], [57]. Further, it is found that the main type of disability prevailing among people is mobility impairment, which restricts the movement or control of body regions, badly affecting the physical ability to move, manipulate objects and interact with the physical world [8], [52]. Out of these, people with mobility impairments are commonly named as PPDs [10]. As has been stated earlier in Section 2, it is a subset of PWDs. PPDs are those with impairments in at least one of the body regions and/or joints. However, one of the salient features of all the definitions of disability and categorisations is that they undermine the residual physical capability of PWDs to meet occupational demands [53].

2.4 Disability models

Researches have focused only on single dimensional models to determine the disability [47] and explain four models in different perceptions, namely, medical model [28]–[31], [33], [47], social model [29], [31], stigma model [31] and embodied model [31]. The International Classifications of Impairments, Disabilities and Handicaps (ICIDH) classifies nine categories of impairments as intellectual, visceral, aural, other psychological, skeletal, sensory, language, disfiguring and generalised.

Medical model defines disability as a physical or mental impairment which requires medical treatment caused by congenitally or by environmental incidents such as illness, accidents, war and pollution that limit one or more major life activities [28]–[31], [33], [47]. Two essential medical strategies are proposed to prevent and cure the causes of disability [28]–[31], [33], [47]. This model identifies nine categories of disabilities as behaviour, dexterity, communication, situational, personal care, particular skills, loco-motor, other activities and body disposition and how the model can help PWDs to rehabilitate through medical and psychological treatment. In the medical model it is expected that PWDs be treated to sustain and develop their condition [30].

Under this medical model, three lay terms are in use as explained in the medical model namely, disability, impairment and handicap to recognise the limitations of a person. Disability is defined as any restriction or lack, resulting from an impairment, of ability to perform an activity in the manner or within the range considered normal for a human being [28]. Impairment is defined as any loss or abnormality of psychological, physiological or anatomical structure or function [28]. Handicap is defined as a declining disadvantage for a given individual, resulting from an impairment or a disability, that limits or prevents the fulfilment of a role that is normal (depending on age, sex, and social and cultural factors) for that individual [28]. The relationship of disability and society has been analysed by the medical model of disability [29], however, this vague classification has not been accepted in medical terminology. With reference to the medical terminology literature [58], [59], the classification is possible as shown in Figure 2.1. ICIDH uses the overall impact experienced by subjects that influence the value they attach to their health condition by describing functional status associated with health conditions without linking the status of the participants to the component body structures [57].

Social model is defined as social harassment for PWDs causing social and material barriers in the environment [29], [31] and in this perspective, disability is defined as a problem created by society when the PWDs are trying to integrate with that society. The solution that is expected to solve this is by removing the barriers in the social and material environment [31].

Stigma model defines disability as social stigma and restrictions suffered by individuals with physical and mental impairments because they fail to meet the norms of society and focuses on the traits and characteristics of PWDs. The model emphasises the risk of blaming the victim [31] for being disabled.

Rejecting the three models mentioned above, the embodied model [31] is identified as useful for accommodating disability in diversity management research since this recognises bodily aspects of disability in workplace. Embodied model is defined as social and bodily problems suffered by people with physical and mental impairment [31]. This model emphasises bodily differences of disabilities and impairments and draws attention to the bodily differences of PWDs to their experiences, problems and needs. It further investigates how different people with different or similar disabilities and impairments are affected by these and how they experience attempts by organisations to accommodate these PWDs and impairments.

For instance, disability models look at disability in different perspectives. Even though disability is defined in terms of the medical model, the perceptions, attitudes and biases related to PWDs in the workplace is more related to the stigma model [31]. This work determines that issues of embodiment tend to be reduced to issues of medical impairment and perception of physical appearance, and the social model is powerful in understanding the PWDs and disabling aspects of social and material practices. Both disability and impairment is socially constructed, but at the same time, not all the bodily problems and experiences that affect PWDs are socially constructed. Embodied model highlights PWDs as active subjects and represent their social and material surroundings. Therefore, it makes possible for researchers to investigate how disabled employees and job seekers perform WAs and structure their social and material surroundings in the workplace. As a conclusion, an embodied approach may help to deal with a wider range of disability aspects than those admitted in the medical, stigma and social models of disability [31]. Describing the occupational performance model, it is explained that an individual's occupational performance is to be measured in three areas as self-care, productivity and leisure [60].

There are two main categories of physical disability based on the time of onset of the disability: congenital and acquired [4], [21], [46], [61]. Congenital disabilities are the ones that people are born with [4], [21]. Acquired disabilities have a cause that takes effect after birth [4], [21].

Since there seem to be many different definitions and classifications of disability, medical terminology [58], [59] available in literature was synthesised and permanent physical disabilities were categorised as shown in Figure 2.1. According to it, permanent disability of people can occur due to congenital conditions or due to accident or disease. People may become congenitally disabled due to deformities in the body regions or limbs as well as joints [58]. These can be due to missing joints, dislocated joints or stiff joints at birth that lead a permanent disability [58]. Acquired disabilities are due to amputation of a body region and/or deformities in the joints or body regions or limbs due to accidents or disease essentially occurred after birth [62].

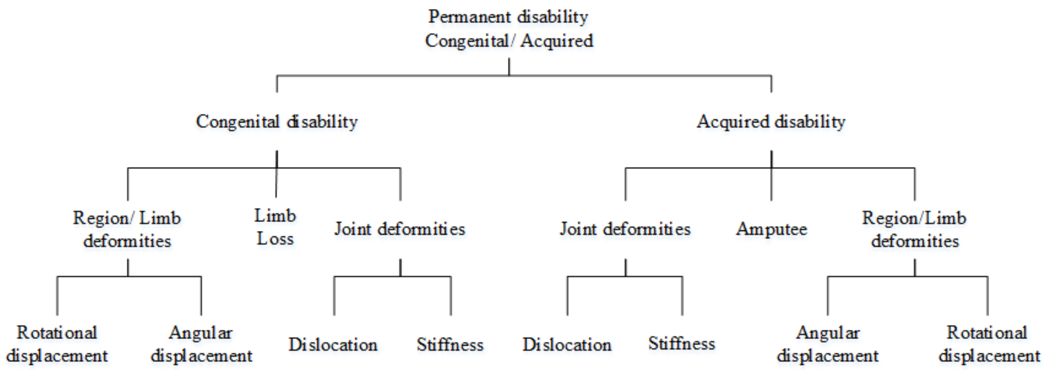

Figure 2.1: Classification of permanent physical disability

This type of categorisation can be useful to determine the residual physical capabilities of PPDs that will ultimately lead to their effective employment. It is interesting to note that there have been attempts to identify disability models that may help in formulating mechanisms for employment.

In many countries, there is a significant proportion of PWDs in their working age [17], [34], [63] that includes those who are qualified to carryout WAs in industry [16]. Literature suggests that PWDs are willing to work, if they are provided with jobs [15] and can be capable of performing almost all the jobs in industry thus making them productive if they are provided with the right environment to work [9]. Similarly, it is believed that PWDs have great work-potential even though they are unable to find employment [10]. Therefore, ill-utilisation of the potential of them wastes human resources, creating a heavy burden on themselves, their families and society at large [16]. However, it is stated that employers do not have access to information about PWDs and the impact of their recruitment [8]. As a result, these workers, although have completed their education at secondary and higher levels, are unable to find suitable employment. This is probably due to the reluctance of the employers to believe that PWDs are capable of contributing to the development of their organisations.

It has been suggested in the literature to measure the degree of disability based on the limitations to perform Activities of Daily Living commonly known as ADL [1]–[5]. The defined ADL for the assessment are cooking, cleaning, eating, bathing, dressing, transferring, walking and toileting [3]. It is documented that despite physical disabilities, some PWDs are capable of performing ADL [64]. However, this measure of disability is too generic and the capabilities and limitations of PWDs at work can still be doubtful for both employers and PWDs. Even if the capabilities and limitations of the recruits are identified by the employers [23], in order to provide specific jobs, the interaction between PWDs and the elements of work systems [6] need to be identified.

In order to improve this situation, researchers have explored why employers should be interested in employing the handicapped [46]. For example, it has been found that ethical responsibility to help PWDs to find employment, being a reliable and productive asset to the employers with minor accommodation and employers receiving federal contracts are a few of the benefits of employing PWDs [46].

PWDs entered the labour market in the beginning of the 20^{th} century [13], but they performed semi-skilled jobs [20]. Although PWDs can potentially engage in income generating activities, there are reasons for low employability that needs to be addressed [36]. Pointing out to a comment made in [50] suggesting that employers need to be sympathetic towards the PWDs in spite of the difficulties faced by the company, [36] expresses how difficult it is to expect that in real life. One reason for low employability is that colleagues and supervisors at workplaces make assumptions about work performance ability of PWDs by judging them based only on their physical and cognitive limitations [12]. For example, [20] states that due to physical and psychological consequences of impairment, individuals with disabilities are not accomplishing reasonable standards of living by their own efforts. This argument is supported by [36]. It is further stated that people in wheelchairs are perceived to be too dependent thus being unproductive and lacking in efficiency [21].

Further scrutiny of literature on the reasons for unemployment of PWDs paved the way to identify additional barriers for employment of PWDs in industry. Authors suggest that inadequate knowledge of employers regarding products, processes or systems suitable for people with impairments [62]; unfavourable labour market policies and labour structure [16], [17], [62], [65], [66], institutional discrimination at work and low rates of payment [4], [16], [20], [31], [34] as barriers for effective employment. The reason for difficulty in accessing a place for a person in a wheeled-chair is mainly due to the environmental barriers and not something to do with the PWDs [22], [66]. Supporting this notion, the principal obstacle for PWDs in the physical environment within the workplace is identified as accessibility issues [17], [36], [66]. These oppose the view that underestimates the physical capabilities of PWDs. These suggest that it is important to facilitate both the PWDs and the organisations that can provide employment to them to positively obtain their contribution to the organisations, hence the economy.

Adopting from previous research, [12] states that it is possible to facilitate workers with disabilities to access goods and services with simplest and least costly work-site modifications that can draw them away from the semi-skilled jobs to other forms of jobs. As the authors suggest, the modifications may be changing working hours, work procedures, work location, or task assignments such as using technology, rehabilitation engineering for sophisticated equipment, building adaptations by redesigning or adapting workplaces and jobs according to the requirements of PWDs through the application of ergonomic planning and design measures. In order to accommodate the diverse perspectives and viewpoints with regard to employment of PWDs, different employment models have been proposed [20], [30], [31].

Even though researchers identify many causes for unemployment to employ PPDs in general, very few fruitful solutions have been put forward (according to literature) in order to solve these issues. After referring to the related information on US government websites, [53] emphasises that protecting the rights of PWDs need to be an important goal of all governments. According to limited available research on employment of PWDs, [20] indicates that formation of anti-discrimination legislation is a key solution to overcoming the problem of unemployment. As such, different legislations/acts have been formulated to protect the rights of PWDs. To fulfil the PWDs desires to work, [16] state that Americans with Disability Act (ADA) came into effect in 1992 and intends to address the welfare of PWDs [15], [30], [31], [34], [67]. Further, according to the ADA, identifying the applicant's capability and assessment to perform a job is an extremely important factor to be considered and they expect employers to understand the capabilities and limitations of PWDs and make reasonable job accommodations and working environments. However, the ADA does not expect to release a disabled applicant as an employee from the obligation to perform essential functions of a job. The Disability Discrimination Act of 1995 (DDA, 1995), which is being practiced in the UK, intends to end discrimination against PWDs [15], [31], [34]. This was amended in 2005 adding the duty to promote disability equality within public authorities. These are encouraging trends in terms of ensuring welfare of PWDs, but evidence of technological interventions is lacking in these initiatives.

2.5 Employment opportunities for PWDs

As explained in Section 2.42.3, there are PPDs in their working age [17], [34], [63] including those who are qualified [16]. Researchers argue that in general they have great work-potential which is essential for their successful employment [10], [16]. Even though the inherent physical work capability of the PWDs is undisputed, a high rate of unemployment and long-term unemployment among PWDs is common [4], [63]. This signifies a substantial gap between transformations of work capabilities into employment. Supporting this view, significant issues for unemployment of PWDs such as not having relevant skills, education, training and experience due to long term sicknesses, inaccessible workplaces and non-structural buildings are emphasised in the literature [15], [63]. Education and training programmes provided to school leavers with disabilities should lead them towards employment [27], but research indicates that it has been difficult to find employment opportunities for PWDs related to the fields that they have obtained vocational skills in [27]. The main reason for this is the difficulty in identifying residual physical capabilities of PWDs for reasonable occupational accommodation [7], [16] wasting the funds and other resources allocated towards vocational training [27]. If a mechanism is in place to identify PWDs in general to select career paths suitable for them, both time and money could be saved whilst providing them with the ability to be employed in suitable jobs and work environments. This will enable them to be enrolled in appropriate vocational training [27] and help them to contribute towards economic development as expected by many researchers [7], [16], [52].

Thus, there is a need to identify typical manual work-activities (WAs) that PWDs in general are capable of performing in industries and residual physical capabilities of PWDs that are required to perform them. As a solution to this, a multi-dimensional framework, which addresses the needs of the PWDs and also the employers is suggested [7]. This could be the way forward to increase the employability of PWDs [6].

It is mandatory to understand the interaction between the elements of the work systems that give rise to job demands and residual physical capabilities of PPDs in order to employ them in industry [6], [7]. However, manual WAs that are able to be performed by PPDs in industries cannot be readily identified by the employers through an interview procedure [10]. The main reasons for this are the inability of employers to determine the residual physical capabilities of the PPDs and PPDs themselves are possibly unaware of their residual capabilities [21], [46]. As a result, they are most likely unable to disclose their capabilities and limitations [10]. In order to facilitate the enacted legislations and empower the PPDs, technological developments are needed for effective recruitment procedures that identify the capabilities and limitations of PPDs in particular and PWDs in general.

Researchers suggest developing multi-dimensional assessment methods to understand and measure residual capabilities of PWDs with respect to their strengths, weaknesses and compatibility [6], [7], [16], [47]. The universal design concept [17] that intends to integrate all PWDs to the workplace by enabling systematic changes without redesigning for individual needs is an attempt towards conceptualising the multi-dimensional approach towards employment of PWDs. In order to boost research related to PWDs within engineering sciences, assistive technology and environmental accommodation are suggested by [18], [40], [65]. They further suggest to enhance the skills with the use of assistive devices, but suitable devices need to be designed that match the residual motion capability of the intended users. This is an indication of the importance of knowing the residual motion capability of PWDs to ensure satisfactory usability.

In order to facilitate employment, several disability models have been proposed in the literature and following is a discussion of the disability models that were most frequently occurring in the publications that were accessed.

2.6 Employment models for PWDs

In one categorisation of employment models, [13] explains seven employment categories for PWDs. They are; quota system, sheltered workshops, self-study method and employment of the disabled without the obligation of employers, working at home, co-operative working method and employment in selected jobs where only PWDs are employed.

In the quota system, authorities influence employers to recruit a percentage of PWDs to organisations in private as well as public sectors [7], [13]. The authorities expect the employers to compare the demands of the jobs and the capabilities of PWDs, recommending the understanding of the interaction between the PPDs and the elements of the work system. Unfortunately, under this system, the methodology by which the comparison needs to be carried out is not explained, probably owing to the unavailability of such a method. Another approach is the self-study method and employment of the disabled without the obligation of employers. ‘Working at home’ is engaging in Information and Communication Technology (ICT) related jobs staying at home and offices [13].

In the co-operative working method, employment is provided in selected jobs where only PWDs are employed. Developed countries further provide special employment programs for PWDs under the following categorisation, namely, sheltered, subsidised, designated and supported [11], [14], [20], [50], [68], [69].

2.6.1 Sheltered employment model

Sheltered employment is offered in protected and isolated environments at state-owned workshops, special businesses or certain segments of ordinary companies, mainly targeting people with severe disabilities [20], [50], [68], specially people with visual and hearing impairments [50]. However, it is stated that sheltered employment is more or less permanent [68].

2.6.2 Subsidised employment model

In subsidised employment, part of the employers' wage cost is compensated by the government and the subsidy is typically phased out over time [11], [68].

2.6.3 Designated employment model

In designated employment, PWDs perform specific work tasks or jobs in designated jobs such as 'car park attendant' and 'lift operators' that they can perform, without affecting work effectiveness or efficiency [20].

2.6.4 Supported employment model

Supported employment is described as a paid employment opportunity for people with developmental disabilities [70]. It provides on-the-job support through personal job coaches for a limited duration [11], [68]–[70]. In order for the PWDs to sustain in a competitive employment environment, work is supported by providing supervision, training and transportation needs [19]. There is no charity fund raised in these enterprises and they are expected to trade with other public and private enterprises making profit or at least break-even.

In many of the countries, sheltered employment has been criticised for inefficiency, and [68] argue that less segregated employment in a more business-like and competitive environment is likely to be more cost effective. This suggestion is more inclined towards the supported employment model. The subsidised model can be helpful to the organisations that intend to employ PWDs because the initial difficult phase of the employer-employee familiarisation process does not become an economic burden to the organisations that employ the PWDs. However, the organisations need to work out a way of integrating the PWDs to the work environment identifying their capabilities and limitations. In the designated employment model, the needs of PWDs are expected to be more comprehensively understood. It will enable the PWDs to be empowered to seamlessly integrate into work environments. Up on close investigation of these employment models, it can be conjectured that the employment models only provide a partial solution to employment problems faced by the PWDs [20]. In addition, none of the aforementioned models support to identify capabilities and limitations of PWDs in performing manual WAs in industry. With necessary support and proper management, the capabilities of PWDs may effectively be harnessed for specific jobs in industry.

In order to facilitate work, costly and sophisticated types of standard, conventional vocational evaluation software systems have also been introduced as explained by [16]. These systems include more than one elementary test to determine certain characteristics of a subject (e.g. achievement, aptitude, interest and temperament). Some of the available vocational evaluation software systems are, Microcomputer Evaluation of Careers and Academics (MECA) [16], which is used for career exploration, Transition Assessment Software System, which consists of an interest test and hands-on work samples [16], Job Specific Applied Academic Assessments [16] and Career Information System [16]. The Valpar Measures [16] is another system used to measure the rate of work. Using these, specific behaviour and worker characteristics such as problem solving ability, concentration, controlling frustration can be rated [16]. For vocational counselling and assessment procedure, which measures attitudes, aptitudes and interests, a system for assessment and group evaluation (SAGE) is used [16].

Test results of these software provide only generic information which do not properly reflect the interaction between deficits of a subject and a specific task [16]. Therefore, using such data, a decision maker may not be able to evaluate an individual's performance to make an informed final decision. Thus, it is strongly advocated to develop a functional assessment methodology in performing specific tasks and task-related work conditions is essential to establish an aggregated measurement that may help an evaluator to assess the physical and psychological capabilities and limitations of applicants with or without disabilities [16].

A continuous influx of PWDs adding into the workforce is predicted by [53]. To accommodate them in the workplace gainfully expecting that employers should know how much time would take to complete a work cycle, how much would be the work performance in a day, how to determine the remuneration for them and what impact would the integration of PWDs have on the organisational productivity. To find answers, it is suggested to modify existing PMTS since they do not generate work standards for PWDs [48], [71]. They suggest to generate a completely new set of task times creating standard times for PWDs or to generate modifiers to existing standard times generalising the entire process as two functional alternatives to provide better working conditions. This puts forward an interesting proposition for research into effectively employing PPDs in industry.

PPDs is a subset of PWDs, where such people seeking job opportunities are low [7]. To plan preventive and curative services for PWDs, the importance of identifying their needs are explained [28]. Definitions of 'need' refer to varying degrees, severity, income, opportunity and availability of help, and may embrace 'eligibility' and which in turn is related to the perceived priorities.

To understand the interaction between the PPDs and the elements of work systems, it is essential to compare the demands of a job with the residual physical capabilities of PPDs [6]. Further, it is suggested to identify workplace adaptations [7], [63]. Literature on trying to identify either work demands or elements of work to identify the WAs that PPDs can perform in industry with their residual physical capabilities has not been found [46]. Therefore, in order to identify functional physical capabilities, the typical manual WAs that PPDs could perform, need to be identified.

In order to perform WAs, the functional physical capability of PPDs is required to be determined in terms of Range of Motion – ROM [58], [59], [72] where ROM refers to the limits of joint motion in the 3D space. To carry out manual work using body regions, in other terms a combination of joints rather than a single joint is usually used. Thus, it is necessary to analyse the movement of the body regions and the joints to help identify residual capabilities of PPDs. However, it is stated that PPDs may not be knowing the residual capabilities that they themselves possess [21]. Even though it is expected that PWDs in general have great work-potential [10], restricted or controlled movements of body regions such as arms, hands and fingers of PPDs reduce their physical ability to move, manipulate objects and interact with the physical world [8], [24].

Researchers identify ROM as a physiological parameter that determines the motion capability to perform manual WAs [72]–[75]. Joint ROM has extensive uses: postural analysis [76], clinical diagnosis [77], job and workplace design [74], dynamic capability analysis [78], find solutions for occupational discomfort [74], laboratory-based studies [30], [79], experiment-based studies [30], develop automation techniques, measuring maximum muscle strength in various angles of selected body regions of normal human beings [74] and assess the reliability of assessment systems such as Rapid Upper Limb Assessment (RULA) [80] and Rapid Entire Body Assessment (REBA) [81]. Therefore, it is important to analyse the movement of body regions especially with respect to the PPDs in order for them to be effectively employed. In order to identify the physical capability useful for performing manual WAs, ROM of each joint and movement of body regions need to be known and it could be useful if the ROM can be mapped to the WAs in industry. This would enable the PPDs to work in industries.

Research on identifying typical manual WAs prevalent in industry, determine body regions, joints and the ROM required to perform typical manual WAs, and categorise PPDs with respect to their ability to perform manual WAs will be particularly interesting because such methods such as PMTS [46], [82] are available for the normal population and are being widely used in industry for job design, recruitment and performance evaluation.

2.7 Work performance

Work performance of man or machine is accomplished by movement [82] and motion study analyses human movements at work systematically, facilitating method improvement [82]. The pioneers in the field of motion study are Frank B. & Lilian M. Gilbreth [83]–[85]. In 1912, they developed the technique of micro-motion study using motion cameras to obtain motion-pictures of tasks or subdivisions of operations [84]–[86].

A few repetitive basic motions that are necessary to perform manual work tasks are identified [87] and such motions are explained as psychomotor performance necessary for work [88], and categorise them in terms of elemental motions (e.g. reach, grasp, move and position) that have been theoretically established in PMTS. PMTS is identified as the time data for the performance of first-order work-units for the analysis of human performance [84], [86]. These data may be used to quantify the time required to carry out different work tasks.

A work-unit is defined as the amount of work or the result of an amount of work. Table 2.2 provides definitions of the various levels of work-units, as the list starts from the eighth-order and goes down to the first-order [84], [86]. Smaller work-units are assigned smaller numbers in this scheme. All of the orders of work units would not be involved in every work-unit analysis and [84], [86] states that decimals of orders can also be assigned when there is a need for orders of work-units between the ones given.

Table 2.2: Definitions of basic orders of work-units

Level	Name	Definition
8^{th}-order work–unit	Results	What is achieved because of the outputs of the activity?
7^{th}-order work–unit	Gross output	A large total of end products or completed services of working group.
6^{th}-order work–unit	Program	A group of like outputs or completed services representing part of a 7th order work–unit but which are more homogeneous subgroup.
5^{th}-order work–unit	End product	A unit of final output; the units in which a program is quantified.
4^{th}- order work–unit	Intermediate product or component	A part of unit of final output; the intermediate product may become part of the final output or merely be required to make it feasible to achieve the final output.
3^{rd}- order work–unit	Task	Any part of the activity associated with, and all of the things associated with, the performance of a unit of assignment by either an individual or a crew, depending on the method of assigning.
2^{nd}-order work–unit	Element	The activity associated with the performance of part of a task which it is convenient to separate to facilitate the designing of the method of performing the task or the time study of the task.
1^{st}-order work–unit	Motion	The performance of a human motion. This is the smallest work-unit usually encountered in the study of work. It is used to facilitate job design or time study and never appears in control system above this level of use.

Source: [84], [86]

Gilbreth in 1912 identified 18 fundamental motions consisting of several basic motions such as ‘reach’ and ‘move’ [83], [85]. However, ‘get or pick up’ and ‘place or put down’ are as two of most frequently used group of motions where mostly ‘get’ is followed by ‘place’ in many instances [83]. However, they are not fundamental motions but as a solution for this, Gilbreth in 1912 reported certain subdivisions or events which he thought as common to all kinds of manual work [85]. He has named them as ‘therbligs’ which is an anagram using the letters in his name, as they cannot be further subdivided [83], [85].

Motion is a first-order work-unit so that starting from basic motions, higher order work-units can be constructed [89]. Therefore, identifying a similar type of building-block comprised of first-order work-units (motions) have been the paramount influence for this research which may be useful to build up wide variety of elements, tasks, processes, intermediate product, end product, program, gross output and finally results of any type of jobs for employing PWDs [89]. Mainly, there are two classes of movements necessary for performing tasks, as ‘effective’ (or unavoidable movements) and ‘ineffective’ [30]. Effective therbligs advance the progress of work while ineffective therbligs do not advance work. Thus, ineffective therbligs need to be minimised. As there are several therbligs which accomplish work such as reach, move, grasp, position, disengage, release, use, assemble, disassemble and pre-position [30]. The therbligs which do not accomplish work are hold, avoidable delay, unavoidable delay and rest to overcome fatigue [30].

However, many terms are used to identify a single work element, it is advocated that uncommon terms and symbols such as mnemonic therblig symbols need to be avoided whenever possible [83], [84], [86]. Therefore, it is useful if common work elements could be identified, measured and named appropriately in order to be used by a wider sector of people [85]. This has paved the way to the development of PMTS [85].

It is evident that PMTS and performance related standard data have been extensively used for skilled workers [85] or the people without disabilities [30]. For example, in the area of work study and job design, PMTS has been an integral component. However, these have not yet been modified to accommodate PPDs. PPDs may also be able to perform certain manual WAs with their limited ROM and residual functional capabilities. Thus, it would be beneficial if PMTS can be modified to accommodate PPDs.

PPDs may perform WAs with their residual capabilities of performing ROM and the strength that they can exert as discussed earlier. However, standardisation of work elements using higher work-order units may be difficult due to the variability in their disabilities (or deformities) and hence residual capabilities. Therefore, indirect work analysis systems such as PMTS are ideally suited to study the work performance of PPDs and detailed discussion of PMTS is warranted.

Predetermined Motion Time Systems (PMTS)

PMTS is defined as a work measurement technique whereby times established for basic human motions are classified according to the nature of the motion and the conditions under which it is made, and they are used to build up the time for a job at a defined level of performance [83], [85], [90]. There are different demonstratives of PMTS, namely, Method Time Analysis (MTA), Work Factor, Engstrom, 400 System, Basic Motion Time Study (BMTS), Method Time Measurement (MTM), Method Time Standards (MTS) and Dimensional Motion Times (DMT) that are being widely used in industry [83], [85], [90]. However, the information about them are not publicly available [83], [85], [91].

The widely discussed advantages of using PMTS over direct work measurement techniques are the ability to design work methods prior to the initiation of work, determine standard processing times prior to start of work and having greater consistency in job design [83], [92]. Each PMTS has its own set of action words which have been defined in detail. PMTS can also be classified by the level of complexity of elements [83]. The basic level consists of single motions that cannot be further sub-divided [83]. However, the elements of most PMTS have several variables, such as distance, object weight, or degree of precision required at the end of the motion, the decision making process can be quite complex, thus adding further to the time required to make an analysis.

2.7.1 Method Time Measurement (MTM)

Method Time Measurement (MTM) is defined as a procedure which analyses any manual operation or method into the basic motions required to perform it, and assigns to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is made. When the motion pictures of sensitive drill press operations were taken and analysed, in terms of Gilbreth's therbligs, those therbligs were eventually discarded since it was found that those were not associated with manual motion. Therefore, many of those were renamed.

Work analysis is carried out using the basic level of MTM [93], [94]. The reason why the MTM system became the one most widespread is probably due to the fact that it was made publicly available with no economical or judicial claims on behalf of the inventor [94]. MTM 1 which is a generic, basic-level system that was established in 1940 by Methods Engineering Council of America [88]. A set of data was developed combining motion study and time study treating them both simultaneously. So that MTM 1 necessitates an experience of motion analysis together with a clear understanding of time-study principles. Use of MTM 1 system is more basic form of MTM family [93] and it is more comprehensive thus its application is highly time consuming [94]. However later version of MTM 2 system was further developed, reducing the 350 old values in MTM 1, to 39. In MTM 1 system, element classifications are 'reach', 'move', 'grasp', etc. and in the basic MTM 2 elements, those are 'get' and 'put' data where 'get' includes the motion of reaching with the hand or fingers to an object, grasping the object, and subsequently releasing it. Since time consuming is high in MTM 1, MTM 2 systems are widely practised in industries. Even though MTM 3 was also created, it was not accepted widely [94].

Physiologists accepted that the hand and arm movements of the body can be divided into a number of standard elements and the purposeful movement made by a person with hand or arm falls into one of the following categories such as 'reach', 'move', 'turn', 'grasp', 'position', 'release' and 'disengage' [84], [88]. Supporting this sentiment, it is evident that PWDs (that includes PPDs) require more time to perform simple assembly and disassembly tasks than people with no disabilities by allowing them to carry out a few manual WAs of MTM [71]. However, for meaningful employment of PPDs, it is essential to assess the residual physical capabilities in moving and manipulating objects, and interacting with other physical activities [6], [7], [46]. Anthropometry and biomechanics are essential parameters that govern physical capability of a person [95].

Anthropometry is defined as the science or discipline of measurement and the art of application [55], [96], [97] that establishes the physical geometry, mass properties and strength capabilities of the human body [96]. Anthropometry deals with the measurement of the dimensions and other physical characteristics of the body such as volumes, centres of gravity, inertial properties and masses of body segments [72]. Biomechanics synthesis knowledge from the physical and engineering sciences with knowledge from the biological and behavioural sciences to improve working conditions, however its limited and restrictive nature makes less generality and applicability in the workplace. Biomechanics focuses primarily on the dimensions, composition and mass properties of body segments together, mobility in the joints, the mechanical relation of the body to force fields, vibration and impacts, the voluntary actions of the body in bringing about controlled movements in applying forces, torque, energy and power to external objects such as controls, tool and other equipment [98]. In order to investigate human anatomical limbs or body segments and joints in upper and lower extremity which have been useful in working were reviewed. The key limbs and body areas that were identified were the trunk, neck, shoulder, upper arm, elbow, forearm (lower arm), wrist, hand and fingers in the upper extremity and upper leg, knee, ankle, foot and toes in the lower extremity [58], [59], [72], [74], [81]. For each of the above limbs and joints, ROM were also identified as described and appeared in literature [58], [59], [72], [74], [81].

2.7.2 Human muscular strengths

Physical capacity or the capability of a worker is also evaluated through muscular strength [99], [100]. Muscle strength is a basis for manual material handling, job design and worker screening and worker's physical capacity is evaluated through muscle strength [99]. Essentially, the physical demand of a job should not exceed workers' capabilities as explained in the fundamental concepts in ergonomics, manual material handling and job design [101]. Some of the other relevant factors affecting human strength are identified by [100] and they are age, gender, posture, reach distance, arm and wrist orientations, speed, duration and frequency of exertions and the influence of prehension strength characteristics such as pinch width and grasp type which can also be of influence. Therefore, to design a proper job, comprehensive knowledge about physical job demands and limits of worker's capabilities are important [99].

Although there are suggestions to indicate that muscle strength is also important along with the joint motion to perform WAs, hardly any specific studies were present in the literature on PPDs and their residual physical capability requirements for effective performance of manual WAs in industry. Research leading towards the identification of residual capabilities of PPDs to perform WAs could potentially reveal the latent potential of PPDs for work, increase their employability and thereby empower them to lead an independent life.

2.7.3 Manual material handling tasks and muscular strengths

The knowledge of biomechanical as well as occupational biomechanical application in the workplace may also be useful for employment of PPDs. Kinematics is a term used by Greeks “to move” and is described as the study of bodies in motion without regard to the causes of the motion [97]. It is concerned with the linear and angular positions of bodies and their time derivatives [97], [102].

Lifting, lowering, pulling, pushing and carrying are identified as material handling tasks which require human muscle strength [99], [103]–[105] states that muscular strength is necessary to exert forces and torque to operate equipment, control and sustain external load without inflicting personal injury.

However, these are more abstract tasks, which may not be generalised. Due to the degradation of muscular strength, functional capabilities reduce and there are possible risks of injury or re-injury in performing physical activities [104]. Minimising strength requirements of a task, cumulative disorders can be reduced [106]. In order to be able to generalise tasks need to be decomposed by methods such as task analysis [107] to elemental level, for example to therbligs. This will lead to generalisation of activities/tasks.

Manual handling also involves more intricate tasks. For example, the ‘pinch strength’ [5] facilitates the effectiveness of the dynamic pinch for the light weight objects of daily life and depends on the ability of the fingers and thumb to produce fingertip force with sufficient magnitude and directional control. Thus, fingertip force vectors must be of sufficient magnitude to prevent slipping and be well directed to oppose the actions of the other fingers [5], [106]. Then, mechanical advantage over the pinch strength in the positions of wrist joint, elbow joint and joints in the hand and fingers and the size of the object being pinched is also discussed [106]. They further elaborate on the use of peak pinch strength when applying pinch forces for very short durations and sustained pinch strength which is useful in more abstract situations. The strength requirements of a task should be minimized, and in the case of pinch grips this involves designing tools, workplaces, etc. to accommodate the optimal levels of variables influencing pinch strength. Therefore, detailed study on these show that they are needed for performing manual WAs.

Lifting, carrying, pushing and turning the forearm (pronation and supination) are identified as the most common upper limb activities [108]. Measurement and analysis of maximal human muscle strength is important in ergonomics, sports and rehabilitation [108]. It further elaborates that to compare the strengths of a healthy and ill person, maximal force is the parameter which is easier to use and also to set standards. Muscle power and 'hand intrinsic motion' [58], [109] are commonly used to assess human muscle strength.

2.7.4 Muscle power grading

Human performance is governed by various factors other than work-units [89] for instance muscular ability is needed to perform WAs [103]. Performance depends greatly on the ability to understand task directions, remember instructions, concentrate one's attention on task demands, and perceive important task details. As training progresses the elemental abilities such as control precision, multi-limb coordination, rate control, arm-hand steadiness, finger dexterity, manual dexterity, reaction time, response orientation, speed of arm movement, wrist-finger speed and aiming; develop [89].

Muscle power grading is a quantitative method of assessment of the muscle power to determine the level of capability/limitations in terms of muscle strength [109]. Muscle strength [109] is assessed by gauging the examiner's ability to overcome the patient's full voluntary muscle resistance.

The normal power is dependent on the patient's age, sex and build. The power grading scheme is as follows:

0 - complete paralysis

1 - flicker of contraction possible

2 - movement is possible when gravity is excluded

3 - movement is possible against gravity

4 - movement is possible against gravity + some resistance

5 - normal power

If any weakness is detected, then the examiner must note the pattern [109]. Thus, an analysis of this nature can be used to determine the weakness/disability of a person.

2.8 Summary

This chapter reviewed the current knowledge on disabilities, gaps in research with regards to work capabilities of PWDs and data collection methodology for the research. The PWDs in their working age with particular emphasis on PPDs were discussed.

There is a large number of PWDs and most of them are willing to work if they are provided suitable employment. Since employers as well as PWDs do not know the capabilities for work, they face difficulties in finding employment. PPDs who are a subset of PWDs, too find difficulties in employment since employers cannot understand the physical capability. The review revealed pathways for further research. There are employment models like the subsidised and sheltered, but there are no methods available to identify the residual capabilities of PPDs for them to be effectively employed. Authors propose multi-dimensional approaches for filling this gap that will facilitate employment of PWDs.

For employing PWDs some steps have been taken as explained in literature. However, the work carried out for PPDs is insufficient for their successful employment. In order to develop a suitable protocol for employing PPDs, WAs that are available in industry has to be identified. However, the existing PMTS work standards have not been defined for PWDs [48]. Thus, it was essential to study the available PMTS and decide the suitable, manual WAs to help employ PPDs.

After identifying the WAs that can be performed by PPDs, it was necessary to identify their residual physical capabilities. Since PPDs have different kinds of deformities as explained in Figure 4.1, a suitable system which would be satisfactory to identify the residual physical capabilities for the PPDs population is required. ROM was identified as a beneficial technique.

Even though, there have been many attempts to help employ PPDs, a proper system has not yet been in practice to map work elements with residual physical capabilities of PPDs. The literature emphasized that mapping work elements with the elemental movements of body regions and/or joints, creates room for further work to develop a multi-dimensional framework. Therefore, firstly work is needed to identify work elements that are available in the industry that the PPDs are capable of performing. Secondly, elemental movements of body regions and/or joints are needed to be identified. PMTS is a potential starting point to identify work elements and ROM may be useful for studying the capability to develop a framework that would enable effective employment of PPDs.

3 Expert survey: Work-Activity (WA) study

Chapter 1 and 2 broadly discussed the reasons for unemployment and underemployment of People with Disabilities (PWDs), reported disability models and existing employment models for PWDs. Even though there are models to categorise PWDs in general [29]–[31], none support to recognise residual physical capabilities [46] of People with Physical Disabilities (PPDs), thus limiting their employability depriving them of an independent life. This chapter discusses the study that was carried out to select, evaluate and refine the typical manual work-activities (WAs) in industry.

Literature on typical manual WAs that PPDs can perform within an industry is limited. However, several interesting studies have been carried out by several researchers to improve employability of PPDs in industry. Through experimentation it is revealed that PWDs that include PPDs require more time to perform simple assembly and disassembly tasks than people with no disabilities [48]. The reason they have identified is the restricted or controlled movements of the body regions such as arms, hands and fingers of PPDs that inhibit the ability to freely move, manipulate objects and interact with the physical world [8], [24]. Further, it is stated that the demands of work should not exceed the functional capabilities of workers with disabilities [7]. Thus, it is essential to assess the residual physical capabilities of PPDs with respect to the movement of the body regions and joints, required to move and manipulate objects to perform manual work in general [6], [7], [46].

In order to understand the interaction between the PPDs and the elements of the work systems, it is suggested to correlate job demands and physical residual capabilities of PPDs [6], [7]. However, it is evident that the employers are not fully equipped to do this. There is also a possibility that even the PPDs themselves, are unsure about the residual capabilities that they themselves possess [21]. Unfortunately, there are hardly any specific studies present in literature on PPDs to understand their physical residual capability requirements for effective performance of WAs in industry. In short, no framework is present to understand the physical capabilities of PPDs with respect to job demands. Therefore, it is essential to identify the typical manual WAs prevalent in industry, determine the body regions, joints and the Range of Motion (ROM) required to perform the manual WAs and categorise PPDs with respect to their ability to perform manual WAs. Such attempts could reveal the latent potential of PPDs for work, increase their employability and thereby empower them to lead an independent life.

Literature on work study elaborates the principles of work and work norms for the normal population. In this respect, a few repetitive basic motions have been identified that are necessary to perform manual WAs [87]. They are analysed as psychomotor performance at work, and identify them in terms of elemental motions (e.g. reach, grasp, move and position) or elements that constitute the Pre-determined Motion Time Systems (PMTS) [88]. In order to benchmark the functional capabilities of PPDs against the normal population, the typical manual WAs that the PPDs can perform need to be identified. However, evidence on applications of these basic motions with respect to PPDs is limited in literature. Thus, research is needed to investigate the extent to which PPDs can perform elemental motions or manual WAs with their limited motion capability.

Direct measurement systems, i.e. time studies, are used to determine the processing times in industry. Alternatively, a standard data array in PMTS makes it possible to determine the processing times with greater consistency than the direct measurement systems [83], [85], [92]. For example, manual WAs are described in some of the PMTS representatives in literature. MTM [48], [84]–[86], [92], [94], [110], [111], Work Factor [84], [85] and MTA [84], [85] are three such methods that are available. Thus, PMTS represent an interesting proposition to determine the typical WAs carried out in industry.

PPDs may be able to perform at least a portion of the manual WAs explained in PMTS as the normal people with their limited functional capabilities, i.e. residual capabilities. If such manual WAs can be identified, it could enable the PPDs to be employed to perform specific tasks. To compare the demands of a job with the capabilities of PPDs and understand the interaction between the PPDs and the elements of work systems are suggested by [7]. Therefore, for meaningful employment of PPDs, researchers suggest to assess the worker’s functional limitations and residual capabilities [6], [7],

[46]. As mentioned earlier, they strongly believe that the demands of work should not exceed the functional capabilities of workers with disability. However, no literature could be found to identify the work demands in terms of elements of work or the WAs which could materialise the idea. Therefore, an in-depth study of the WAs needs to be carried out in order to map them against the functional capabilities of the PPDs. In this context, identifying and categorising the typical manual WAs carried out in industry becomes a pre-requisite to benchmark the functional capabilities of PPDs.

3.1 Aim and objectives

The aim of the study was to categorise typical manual WAs in industry to help employ PPDs. The objectives were,

1. to identify typical manual work-activities in industry.
2. to categorise the work-activities.
3. to refine and review the categorisation.

3.2 Methodology

A sample of participants who are experts in industrial engineering was recruited using a stratified sampling technique [49], [112]. Later, the other participants of the study were selected using a snowballing approach for sampling [49], [113]. This sampling strategy was used to select participants due to the limited expertise of professionals involved in the area of study. Informed consent was obtained using the format shown in (Appendices 3.1 is the English version and 3.2 is its Sinhala translation) from all participants to take part in the study. To collect demographic data from experts, a structured format was used and is shown in Appendix 3.3.

3.2.1 Study design

Demographic information of the participants, i.e. designation and the speciality, types and locations of the workplaces, qualifications, types and countries of training, professional memberships, experience in the position in years and the previous posts held were recorded. If the participants of the study were willing to receive a copy of the final document, the name, contact telephone number and e-mail address were requested.

In order to prepare for the study, the typical manual WAs carried out in manufacturing industries for people without disabilities were derived from various literature sources [82]–[84], [87], [90], [91]. The typical manual WAs that are performed in different work planes were selected from the commonly known method-time measurement representatives (e.g. MTM 1 and MTM 2) and were listed in a format similar to the one shown in Table 3.1. This document was considered as the 'initial draft document'.

Table 3.1: Descriptions of manual WAs.

Manual WAs	Description
WA $_1$	…….
WA $_2$	…….
….	…….

The reviewing process of the study was conducted using a modified Delphi method [49]. This review technique was purposely selected because bringing the experts to one place to conduct the study was not practical. Out of the selected participants, one of the experts acted as the moderator of the Delphi process. The study protocol explained in Figure 3.1 was then followed to refine and review the 'initial draft document' in several rounds by the experts, until the WAs got saturated. In this process, the initial draft document was scrutinised by the moderator in several rounds of discussion and then the 'initial document' was obtained. The 'initial document' was refined by the group of experts using unstructured interviews with the participants. The document which was subjected to scrutiny was named as the working document. This document was reviewed by the moderator every time a modification (i.e. addition, deletion or amendment of information) was proposed. This cycle of refining and reviewing was carried out in succession with all the participants and the moderator, until the final document containing a set of WAs were reached.

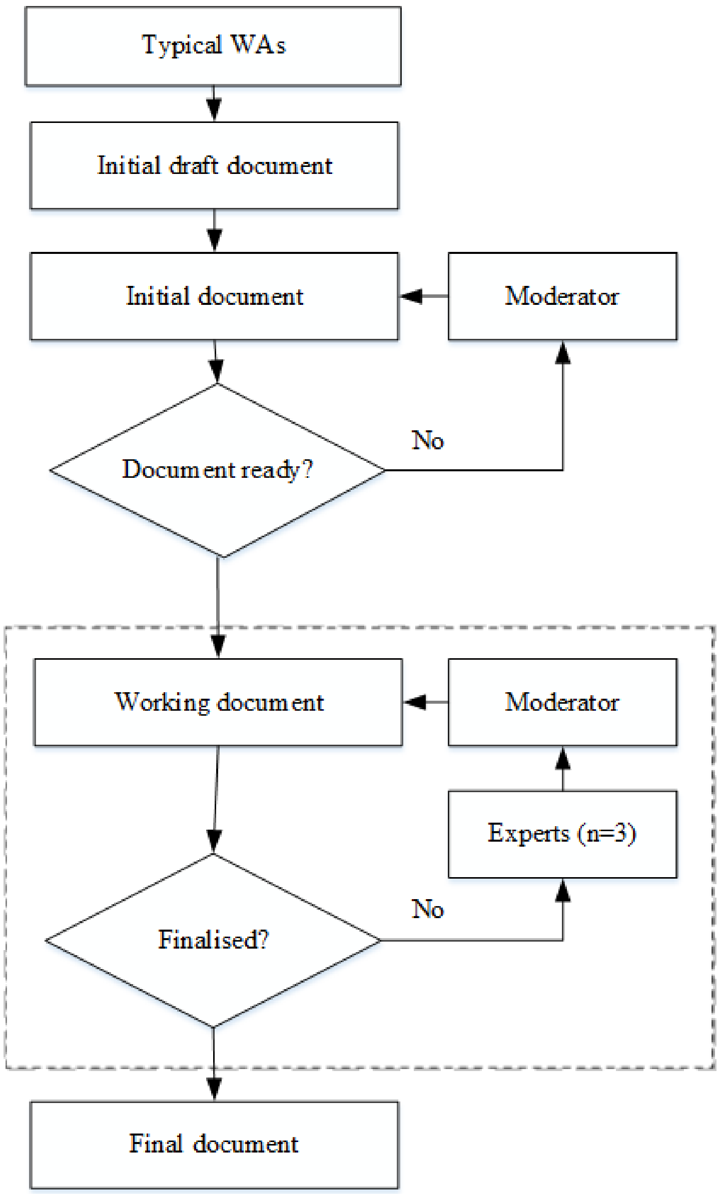

Figure 3.1: Study protocol for expert review survey

3.3 Method of analysis

Demographic data of the participants collected during the study were analysed based on designation and speciality, type of workplace, location of workplace, qualifications, type and country of training, professional memberships, experience in the position in years and previous posts held.

Initial draft document

Currently practiced and easily accessible PMTS representatives in industries were studied and manual WAs were extracted from the work unit analysis reported in literature. In MTM 1 and MTM 2 representatives, WAs to perform 'movement' in possible different work planes using upper extremity body regions and joints were selected. Since hand activities were not readily recognised in MTM 1 and MTM 2 representatives, further literature was surveyed and depending on the complexity of the hand activities, 'get' ('grasp'/ 'grip') activities were extracted. These were termed as manual WAs. WAs that can be performed using lower extremities were also selected in a similar fashion.

Initial document

The 'initial draft document' that consisted of the WAs selected from the PMTS representatives was presented to the moderator of the study and was asked to review before being presented to the rest of the experts. Typical manual WAs that are performed in different work planes (i.e. vertical and horizontal) in the upper and lower extremities were listed separately in this document. For these WAs, the 'maximum' and 'minimum' levels of performance were also noted. The resulting document was named as the 'initial document'.

Working document

The PMTS representatives in the 'initial document' were analysed and added, deleted and the information was amended by all expert participants one after another based on different criteria such as useful WAs (mostly) and complexity for both in upper and lower extremities. This was considered the 'working document'. Every time the working document was refined by an expert, it was reviewed by the moderator and this process went on for several rounds as indicated in Figure 3.1. When there were no new suggestions (i.e when the point of saturation was reached), the moderator terminated the process and the document was finalised. This was named as the 'final document'.

3.4 Results

Three experts participated in the study. One out of them acted as the moderator. Out of the three experts, two had doctoral level qualifications while the other had a master level research degree. Two of the participants had foreign qualifications and speciality in the fields of industrial engineering, while the other participant had work experience in an industrial engineering division in a manufacturing organisation. All the participants had more than twelve years of experience in the areas of mechanical and industrial engineering.

Altogether, 50 iterations of review and refine cycles took place in the study and all the participants spent about 90-120 minutes for each session conducted for document reviews. The chosen typical manual WAs from both MTM 1 and MTM 2 by the experts are included in Table 3.2.

Table 3.2: WAs identified in upper extremity

MTM 1	Description	MTM 2	Description	Other	Description
Reach	Hand position in maximum & minimum work area	Crank	Move an object in a circular path with the hand.	Crank (for stirring)	Move an object in a circular path with the fingers
Move	Transport an object to maximum & minimum work	Re-grasp	Change the grasp of an object		
Turn	Turn the hand either empty or loaded			No grip	Hand forms percussive or sustained
Apply pressure	Re-grasp or squeeze	Apply pressure	Same as MTM 1	Power grip	Keep the object in contact & clamp it
Grasp	Further classified	Get	Further classified	Power & precision grip	Provide power grip & precise manipulation
Position	Align, orient, & engage an object with another object	Foot motion	Further classified	Precision grip	Obtain precise control in gripping
Release	Relinquish control of an object				
Disengage	Break the contact between one object & another				

The 'reach' and 'move' WAs in horizontal and vertical planes are shown in Table 3.3.

Table 3.3: 'Reach' and 'Move' WAs identified in upper extremity

Reach				Move			
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Reach maximum	Reach maximum	Reach minimum	Reach minimum	Move maximum	Move maximum	Move minimum	Move minimum

The 'grasp' activity in MTM 1 and similar 'get' activity in MTM 2 were renamed as 'grip' (grasp/get) and were further subdivided into four classes based on the complexity of work and precision requirement of hand motion as 'no grip', 'power grip', 'power & precision grip' and 'precision grip' [114] and the broad classification and description are shown in the Table 3.4.

Table 3.4: Description of 'grip' ('grasp'/ 'get') WAs

'Grip' classification	WAs	Description
No grip	Percussive	Single finger placed on surface: finger either rested or pushed in as in striking action.
	Sustained	Single finger placed on surface as in stroking action.
Power grip	Hammering/tapping	Hand power object rested across palm & enclosed by fingers.
	Pliers	Lateral object held between thumb (any) fingers.
	Cylindrical grip	Wrapping the fingers around an object, with the thumb in opposition
	Spherical grip	Gripping/grasping a spherical object
	Disc	Thumb & fingers curled around outside of object
Power & precision grip	Screw-driving	Pinch object resting against palm & grasped between thumb & fingers
	Shearing	Resting with three fingers, one finger & thumb
Precision grip	Fingertip	Tips (pads or sides) of the thumb & fingers.
	Pinch grip	Pads of the thumb with the side of fingers
	Key grip	Object is held between the index finger & the pad of the thumb, while the remaining fingers are usually flexed round to provide extra support
	Complex (writing)	Object is rested on thumb & pressed by three fingers (index, middle and ring)
	Claw grip	Palm against surface & the tips or pads of the thumb & all four fingers hooked around object

‘No grip’ was classified again into ‘percussive’ and ‘sustained’. ‘Power grip’ was categorised into five, i.e. ‘hammering/tapping’, ‘pliers’, ‘cylindrical grip’, ‘spherical grip’ and ‘disc’. ‘Power and precision grip’ was classified into ‘screw-driving’ and ‘shearing’. ‘Precision grip’ as categorised into ‘fingertip’, ‘pinch grip’, ‘key grip’, ‘complex (pen)’ and ‘claw grip’.

Typical manual WAs of lower extremity explained in MTM 1 is ‘step’ and in MTM 2 is ‘foot motion’. ‘Step walking’ and ‘step (climbing)’ were added and it was decided to use ‘Pedalling’ for clarity of use. WAs that can be performed by lower extremity are described in Table 3.5.

Two methods of ‘step climbing’ were described based on the method of performance of PPDs. In one way ‘step climbing’ can be performed using single hip, single knee and single ankle in the same side of the body and on the other way using both hip, knee and ankle. The WAs performed by the lower extremity were step walking, step climbing and pedalling. By considering such requirements in industry, WAs for the lower extremity were identified as shown in Table 3.5.

Table 3.5: Classification of WAs in lower extremity

Work-Activity	Description
Step walking	Movement of the leg or the body forward or backward.
Step climbing	Stepping by single foot or both feet by changing body with or without leg movement.
Pedalling	Foot is moved with the ankle serving as a hinge, or the instep serving as a fulcrum of the motion without moving the body. Motion is pivoted at hip, knee or instep.

3.5 Discussion

This study was used to identify a set of manual Work-Activities (WAs) prevalent in industry in order to help selecting people with physical disabilities (PPDs) to carry out such activities with their residual capabilities. This section mainly discusses the justification of the use of literature to find WAs, its generalisability and the methodological limitations that would affect the generalisability of the findings.

Work analysis is carried out using a basic level of MTM [86], [93], [94], developed by Maynard in the United States [90] which was mainly used in this study. The reason why the MTM system became the one most widespread is probably due to the fact that it was made publicly available with no economical or judicial claims on behalf of the inventor [94]. These factors were considered by the experts when choosing and accepting the PMTS representatives.

MTM is identified as the most common PMTS in the world and exhibits an internationally valid performance standard for manual tasks, thus establishing a worldwide uniform standard of planning and performance for a global business [110].

The 'Initial draft document' was prepared selecting manual WAs useful for performing 'movement', and other psychomotor activities. The typical manual WAs performed in horizontal and vertical work areas [46], [115] were identified. 'Apply pressure' were selected from MTM 1 and MTM 2 schemes.

'Reach' and 'move' WAs can occur in horizontal and vertical planes of right and left hands to some reference, where the reference may be the feet or the midpoint of a line between the heels of the feet and for immobile seated workers, the frame of reference might be the workbench [46]. In 'motion economy' explanations, humans can 'reach' and 'move' to their minimum and maximum distances due to the pivoting-joints [116], thus based on this phenomena, 'maximum reach', 'minimum reach', 'maximum move' and 'minimum move' were defined.

Hands are identified as important instruments of daily lives, and its work varies from very fine motor skills, such as writing to very gross motor tasks such as digging [75]. Thus, literature was studied to select suitable hand activities since the classifications were not readily available in literature. Several classifications of grasping activities/motions are explained as, 'no grasping motion required', 'grasping involving closing of the hand or fingers with one motion' and 'complex grasping motion'. However, the action requires the muscles of the hand or arm to take up the weight of an object [46]. The classification of 'grip' ('grasp'/'get') WAs explained in the Table 3.4, include power grip, hook grip, press, pulp pinch and lateral or key pinch [5].

MTM 1 system is a more basic and comprehensive form of MTM family [93] thus, its application is highly time consuming [94]. However, the later version of MTM 2 system was developed, reducing the 350 old values in MTM 1, to 39. In the MTM 1 system, element classifications are ‘reach’, ‘move’, ‘grasp’, etc. and in the basic MTM 2 elements, those are ‘get’ and ‘put’ data where ‘get’ includes the motion of reaching with the hand or fingers to an object, grasping the object, and subsequently releasing it. In the same manner, ‘put’ is defined as the motion of moving an object to a destination with the hand or fingers. The activity ‘put’ too has several classifications as continuous smooth motion, discontinuous motion, but without obvious correcting motion (i.e. unintentional stop, hesitation or change in direction), discontinuous motion, with obvious correcting motions and lastly, put weight depending on the weight of the object moved. These get and put data have integrated motions which are difficult to generalise. For a specific industry, this integrated motion system may be versatile. Even though, MTM 2 is more popular with this ‘get–put’ elements; due to its specificity, complexity and complicated nature, all the elements had not been selected for the research, and the expected difficulties forecast during generalisation of the findings for all industries and people. Since time taken is high when MTM 1 is used, MTM 2 systems are widely practised in industries, however MTM 2 has been identified as very specific [94] limiting its validity. Even though MTM 3 was also created, it has not been accepted widely [94]. This justifies the use of MTM 2 mainly in the current study.

Currently, the MTM system and its modern versions are in extensive use in many different industries for calculating production times for line balancing, line pace setting and in calculation of business tenders [94]. As an example General Sewing Data (GSD) System is widely used in the apparel sector which has been directly derived from using the MTM family [117]. This also provides justification for the use of MTM to identify the typical WAs prevalent in industry.

The building-block of identifying and categorising WAs was based on the first order work unit analysis [86] (Refer Section 2.7). The first order work-units form human motion and these were re-named as manual WAs in this research. Starting from first order work units (i.e. WAs), higher-order work units can be constructed [84]. Hierarchical Task Analysis [107], [118] could be one of the ways of achieving this. Therefore, identifying building blocks of human motion comprising first order work units can have a paramount influence for this research. These can be used to build a wide variety of work elements, tasks and processes. If the selection of the WAs is exhaustive, it can be an ideal platform to make these WAs and the derivatives of higher order tasks universally acceptable.

To perform manual WAs, it is always suggested to confine to the 'lowest classification of movements' [82]. For example, to move fingers, the pivoting point that one should use are the knuckles. To perform an activity using finger motions, only knuckles should be used as pivoting points to move the relevant body regions. Similarly, to perform finger and wrist motions, it is necessary to use the wrist as the main pivoting point [87]. This way of describing motion is in line with the argument of combining first order work units to construct higher order work tasks.

Any task should always be performed with minimum muscle effort if possible [119]. Further, if two consecutive motions are opposite in direction and perform one after the other, one muscle gets expanded while the opposite muscle gets contracted [119], soon after that muscle action is over, next action starts with the expanded muscle getting contracted and the earlier contracted muscle starting expansion [119]. If, another pivoting point is moved unnecessarily, this continuous muscle action will not take place at the intended pivoting point and therefore unnecessary movement of the pivoting point will take place resulting in a higher degree of energy consumption [119]. Therefore, to perform any WA, the lowest classifications of human motions are necessary [82]. This is also a justification for the use of the first order work units to define WAs in this research.

Methodological limitations

One key feature observed when carrying out the literature review was the unavailability of recent literature. This can be considered as a limitation of the research. Most of the literature referred in this chapter were from 1980's or earlier, showing that hardly any novel contributions have been made in this area. However, this also provides a justification for proposing this research in order to benefit the PPDs in particular and the economy in general.

PMTS is a technique used to design not only the motions but also the timing for a job. The scope of this study was limited only to motion analysis but not the timing. For specific industries timing may be possible for the WAs identified in this research perhaps in next stages. It may be a valuable contribution to elemental timing since the typical elements or the WAs have been identified. Functional capabilities of PPDs which is a question for employers [6], [7] also may be calculated. It is important to note that the timing of jobs performed by PPDs may be useful in many operational strategies such as measurement of performance, rating and allowances scales of PPDs. [48] explain that people with finger disabilities require more time to perform manual WAs than with no disabilities, using MTM multipliers that developed for basic PMTS elements such as 'grasp' and 'position'. Similarly, individuals with finger disabilities require a substantially longer time to perform simple assembly and disassembly tasks [48] thus with reference to their previous work all the instances of individual disabilities may be evaluated properly. They reveal the increase in time could be as much as one hundred-percent more than what individuals without disability take. Here they have not stated whether they have considered a standard individual without disability or not.

Further research may be needed to determine the strength exertions needed to carry out WAs [120] especially with respect to the PPDs. It may require expensive and dedicated or customised instruments such as electromyography [46], [121], [122]. This was not considered during this study, even though it was identified as important. This is another limitation of the study.

The pinch forces are greater when the subject is standing than when sitting and also when the arm is supported as opposed to free [123] and similar results are reported [124]. However, contradictory results have been found by [125] that pinch strength is slightly greater when the arm and forearm are free and found no differences regardless of the posture (i.e. whether the subject is standing or sitting). In addition, several authors in several studies [106] have reported that the average female pinch strengths are between 65% and 79% of the male subjects. Such studies can be used in order to incorporate muscle power into the WAs identified in this research.

When considering the sampling strategy used in this study, the main difficulty was to identify the initial participant. This is mentioned as one of the features in the snowball sampling method [49], [113]. However, the main advantage over the other sample selection strategies is that it requires only a small sample and the major disadvantage is that the second group of respondents suggested by the first group may be very similar and not representative of the population with that characteristic as well [113]. However, the snowball sampling technique supported this type of study, as a thorough knowledge of all PMTS representatives was needed and also, since the availability of people with thorough knowledge of all PMTS representatives were rare.

3.6 Summary

This chapter explains the study conducted with the experts in Industrial Engineering to identify typical manual WAs that can be performed by PPDs. Now the need is to identify body regions, joints and their corresponding RMs needed to perform the identified WAs, in order to employ PPDs. This is discussed in the next chapter.

4 Expert survey: Range of Movement (RM) study

The previous study explained the procedure used to identify, refine and review typical manual work-activities (WAs) in industry to help employ PPDs to work in industry. Once the WAs are determined, work capability of PPDs needs to be evaluated. Thus, it is essential to recognise the residual physical capabilities of PPDs with respect to the ability of movement of the body regions and joints. This chapter presents the study carried out to evaluate the physical capabilities of the body regions and range of motion (ROM) of the joints to perform manual WAs.

It is well established that the PWDs in general have great work-potential [10]. Supporting this notion, it is stated that PWDs are capable of performing almost all the jobs if the right environment is provided [89]. However, PPDs require more time to perform simple assembly and disassembly tasks than people with no disabilities because of their restricted or controlled movements of body regions such as arms, hands and fingers [48]. This negatively affects the physical ability to move, manipulate objects and interact with the physical world [8], [24]. For meaningful employment of PPDs, it is essential to assess residual physical capabilities interacting with other physical WAs [6], [7], [46]. Thus, it is essential to understand the physical capabilities with respect to physical movement of body regions and joints to enable PPDs to carryout typical manual WAs. However, there are hardly any specific studies present in literature on PPDs, which would help to understand the physical capability requirements to effectively perform manual WAs in industry.

Employers expect employees to add value to their organisations, and employers will recruit PPDs only if their ability to perform specific work tasks is certain [6], [7], [23]. Researchers suggest future Engineers to accommodate persons with the most common disability conditions in specified work [46]. Even after many (30) years, researchers again suggest that employers need to look at means to improve decisions on employing PPDs [36], showing that the problem remains unsolved. However, some employers hire PWDs, unfortunately without having a proper method of selection [7]. A wide ranging research and government efforts have also been undertaken in this regard [36], but still there are opportunities to generate better ideas and strategies to ensure the employability of PPDs. Also, it is suggested to analyse jobs to identify physical and mental requirements that could limit successful and safe performance of an applicant with disabilities [46]. More recent suggestions to compare job demands and capabilities of PPDs [6] indicate that this gap has been a long-standing one after about 33 years . Thus, it is apparent that there is room to identify suitable jobs that match the residual capabilities of PPDs for their fruitful employment.

Gross body actions include reach, lift, position, push and carry and describe how the body and its posture are used [46], and they suggest to include additional notes supporting to obtain information about gross body actions for each work element at interviews and observations. Later, it is proposed to develop a multi-dimensional assessment system for understanding and measuring residual capabilities of PWDs with respect to their strengths, weaknesses and compatibility [16], [47]. Therefore, it is evident that there is a vacuum in methodologies to identify work performance capability of PPDs to carry out specific WAs to determine human motion capability. This detrimentally affects the reliable selection of PPDs to work and thus limits the opportunities for PPDs to work in industry.

Researchers define ROM as a physiological parameter that determines the motion capability to perform manual WAs [72], [73], [75]. Joints and their capability are evaluated according to the ROM they permit [59]. Further, ROM occurs in three different planes: in the sagittal plane-flexion/extension, in coronal plane-abduction/adduction and in the rotational plane-internal and external rotation and supination and pronation [58], [59]. Thus, ROM refers to joint motion in the 3D space. The joint ROM are obtained mainly from experiment-based studies and used in postural load analysis [76], [126]; clinical orthopaedic diagnosis [77]; job and workplace design [77], [114]; personal protective equipment design [127]; dynamic capability analysis [78]; occupational health and discomfort analysis [74], [128]. Therefore, ROM is identified as a potential parameter that can be used to determine the residual capabilities of PPDs. However, ROM is defined for joints obtained through laboratory tests as discussed in the Section 2.6.

Work is usually carried out using body regions and a combination of joints rather than using a single joint. In order to identify residual capabilities of PPDs to carryout work, the capability of moving body regions as well as the joint ROM are necessary. Therefore, ROM alone cannot be used to assess the movement of the body. Instead, Range of Movement (RM) of body regions/joints in combination needs to be studied in order to help assess the residual capabilities of PPDs.

4.1 Aim and objectives

The aim of this study was to establish the Range of Movement (RM) of body regions and joints necessary to perform manual WAs in industry. The objectives were,

1. to study joint Range of Motion (ROM) that have been established experimentally.
2. to identify the Range of Movement (RM) of body regions and joints necessary to perform manual work-activities in industry.
3. to verify the identified RMs.

4.2 Methodology

In order to identify the human body regions, joints and corresponding RM required to perform manual WAs in industry, a study was conducted with medical experts. The expert participants were recruited using a stratified sampling technique followed by a snow-balling technique [49], [112], [113] to add participants to the study. This sampling strategy was used to select participants due to the limited expertise of professionals involved in the area of study. After contacting one individual from each category, all other subjects within the same layer were contacted. Informed consent was obtained using the format shown in (Appendices 3.1 is the English version and 3.2 is its Sinhala translation) from all participants to take part in the study. To collect demographic data from experts, a structured format was used and is shown in Appendix 3.3.

4.2.1 Study design

The designation and the speciality, type of workplace and the location, qualifications, type and country of training, professional memberships, experience in the position in years and previous posts held were elicited from the participants. If they were willing to receive a copy of the final document, the name of the expert, contact telephone number and e-mail address were also requested.

An initial draft document that contained the Range of Motion (ROM) information was prepared through a review of literature. Online databases and literature were referred and thematic analysis [129], [130] was carried out to identify human body regions, joints and their corresponding ROM. The body regions/joints in the upper and lower extremities that are useful for performing manual WAs in industry were analysed separately. Commonly occurring terminology was used to identify the body regions/joints in order to eliminate ambiguities in the use of terminology. Additions, deletions and combinations of body regions/joints and the ROM were discussed with the moderator and the 'initial document' was prepared.

This process was conducted as a modified Delphi technique [49]. This review technique was purposely selected because bringing the experts to one place to conduct the study was not practical. Again, additions, deletions, combination of ROMs, and changes to terminology were performed during the refinement process. Refinement was performed using several rounds as discussed in the WA study, until a final set of RMs for body regions/joints were reached. The working document was scrutinised by the participants to make sure that it converges to a final document that has everyone's consensus. The study was then extended as per the study protocol explained in Figure 4.1 to refine and review the working document in succession.

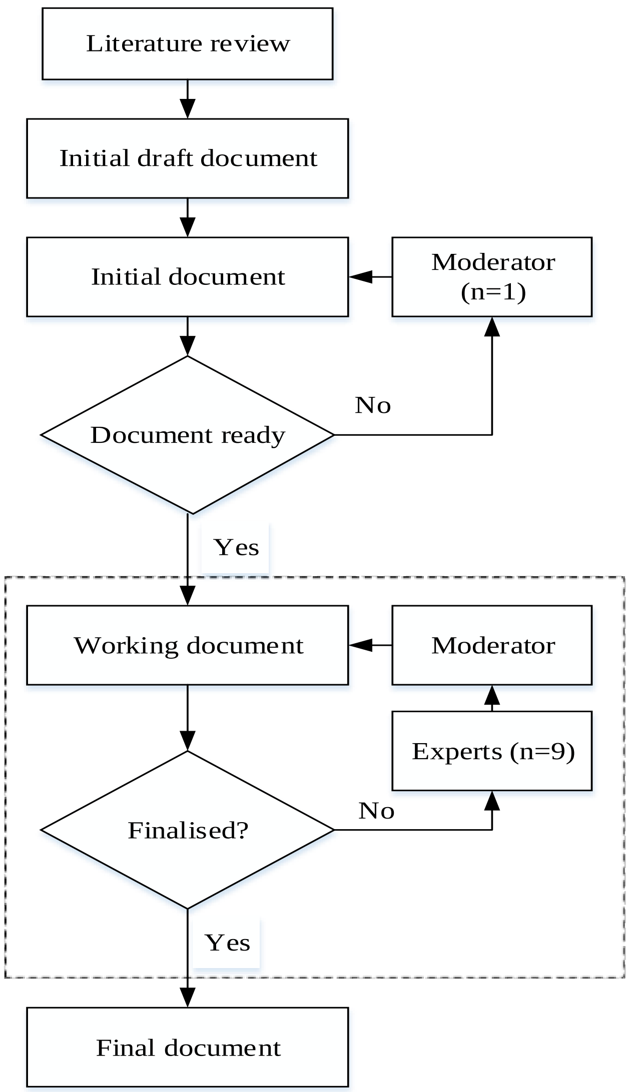

Figure 4.1: Study protocol for expert review survey

4.3 Method of analysis

Demographic data collected from the participants were analysed to categorise them according to their designation and speciality, type of workplace and location, educational qualifications, type and country of training, and professional memberships. The mean and standard deviation of the years of experience in their positions were also calculated.

The body regions and joints, and corresponding ROM in upper and lower extremities which are helpful in performing manual WAs were identified through thematic analysis [129] of the literature. The body regions, joints and corresponding ROM were chosen from available standard literature (e.g. [114]). The document prepared using the information from that literature was named as the initial draft document. Then, additions, deletions and combinations of body regions and joints and the ROM were discussed with the moderator. The initial interviews with the moderator resulted in the initial document, which was a formatted document to be presented to the rest of the participants for the next stage of the research as indicated in Figure 4.1.

The initial document consisting of the ROM of body regions and joints was then reviewed by all other participants of the study one after another, and after every session with an expert, the comments were reviewed by the Moderator.

The initial document after the first review was named as the working document. Additions, deletions and combinations of body regions and joints, and changes to terminology were carried out during the refinement process. Such meetings were conducted in a cyclic fashion until the information in the document got saturated. The saturation point indicated that there were no further proposed changes to the working document and at that point, this was considered the ‘final document’.

4.4 Results

Two sets of medical experts i.e. Consultant Orthopaedic Surgeons (n = 6) and Prosthetists and Orthotists (n = 3) participated in the study. All Surgeons had the Bachelor of Medicine Degree (MBBS) from Sri Lanka and were Sri Lanka Medical Council (SLMC) registered. All had been working as Medical Officers prior to obtaining their Postgraduate Degree qualifications. Five of the participants had obtained Masters’ Degrees (MS) from Sri Lanka, while the other participant had obtained it from the UK. All had overseas exposure. Five were Fellows of the Royal College Surgeons (FRCS). Out of the six Consultants, five participants had more than 15 years of experience while the other had six years of experience with a mean of 11.7 years (standard deviation = 5.0). At the time of the study, many of them were heading the orthopaedic units of government hospitals and all were members of other professional bodies such as the Sri Lanka Medical Association (SLMA) and Sri Lanka Orthopaedic Association (SLOA).

The Prosthetists and Orthotists (P and O’s) had a three years Diploma from the Sri Lanka School of Prosthetists and Orthotists (SLSPO). One of them also had a

Bachelors' Degree from Thailand. The participants were directly involved in providing physiotherapy treatment for patients and manufacturing artificial limbs for the PPDs.

'Initial draft document' - identification of body regions and joints

In order to prepare the "initial draft document", 28 journal articles and 04 books were referred. Human body regions and joints were identified separately as trunk, head, neck, shoulder, shoulder (pectoral) girdle, arm and forearm, upper arm, elbow, lower-arm, wrist, hand, palm and fingers, thumb, index finger, middle finger, ring finger and little finger of the upper extremity and hip, thigh, leg, knee, lower limb, ankle, foot and toes of the lower extremity. Different terminology has been used by researchers as shown in Table 4.1.

ROM reviewed in literature

For each joint, ROM were identified, for example, in Rapid Entire Body Assessment - REBA [76], [77], [81] define different postures of flexion and extension in trunk, neck, upper arms, lower arms and wrists using the positions of 0^0, 20^0, 45^0, 60^0 and 100^0. Rapid Upper Limb Assessment - RULA [76], [80], [131] is used to assess the right and left sides and separate body regions: twist and side-bend postures for neck and trunk, evenly balanced posture of legs and feet. Forearm 'rotation' is explained by [74] and 'pronation and supination' of the forearm is explained by [132]. Through this analysis, the ROM of human body regions and joints were compiled. This information is detailed in Table 4.1 for both upper and lower body.

Table 4.1: ROM of human body regions and joints

Body regions & joints	Movement	References
Trunk	Upright, flexion and extension, twist	[133]–[135]
Head	Flexion and extension, lateral bending, rotation	[136], [137]
Neck	Flexion, extension, abduction, adduction, twist	[74]
	Flexion, extension, rotation, lateral bending	[126], [138]
Shoulder	Flexion, extension, adduction, abduction, medial rotation, lateral rotation	[58], [73], [123], [127], [133]
Upper Arm	Flexion, extension, abduction, adduction, circumduction, twist	[74], [98]
	Flexion, extension, adduction, abduction, medial rotation, lateral rotation	[64]

Body regions & joints	Movement	References
Elbow	Flexion, extension, pronation, supination	[64], [74], [126], [138]
Lower-arm	Movement not found in literature	[80]
Forearm	Pronation, supination	[132], [139]
Wrist	Flexion, extension, radial deviation, ulna deviation	[126], [132], [138]
	Flexion, extension, adduction, abduction	[64], [140]
Hand	Flexion, extension, gliding, pronation, supination	[139]
Fingers	Flexion, extension, abduction, adduction, gliding.	[64]
Hip	Flexion, extension, adduction, abduction, Internal rotation, external rotation	[138]
Upper Leg	Movement not found in literature	
Leg	Bilateral weight bearing, walking or sitting or unilateral weight bearing or an unstable position	[59]
Knee	Flexion	[126]
	Flexion , extension	[141], [142]
Ankle	Dorsi-flexion, plantar flexion, adduction, abduction	[59], [138]
Foot	Movement not found in literature	
Toes	Movement not found in literature	

The 'initial draft document' included the body regions and joints, and corresponding ROMs useful for performing manual WAs in industry. This document was refined in 26 rounds of discussions with the moderator (one of the orthopaedic surgeons). The reviews of the moderator resulted in several changes: 'Upper arm' was renamed as 'arm'. The upper arm and shoulder joint were considered as one unit since they always work together. It was named as the 'Shoulder (arm)'. The 'Lower arm' was renamed as 'forearm'. Motions of wrist and hand were considered as similar, and therefore hand (and palm) was replaced by the wrist. The thumb and all other-fingers were added to the document. Since the thumb has different ranges of motion compared to the other fingers, it was taken separately. 'Opponence' was added to ROM of thumb as shown in Table 4.2. The other four fingers were also added.

Table 4.2: Description of opponence

Movement	Description	Reference
Opponence of thumb	Motion of touching the pads of DIPJ* (the extreme pad) of all other fingers (index, middle, ring and little) one at a time by the thumb.	[64]

***Distal interphalangeal joint**

Changes were also made to the part of the document pertinent to the lower extremity. ‘Hip’ was entered into the document and the ‘lower leg’ was renamed as ‘leg’. The other human anatomical limbs and joints were, ‘knee’, ‘ankle’, ‘foot’ and ‘toes’.

Working document

After studying the ‘initial document’, the maximum and minimum angles of ROM were added by one of the participants during the early stages of the study. Two other changes were also made to the document by adding shoulder girdle, and circumduction of all four fingers and the thumb. All Consultant Orthopaedic Surgeons accepted the addition of ‘circumduction’ to the document. However, they opposed the idea of adding the shoulder girdle as a ROM necessary for performing manual WAs.

Final document

The final document was established by using a total of four rounds of discussions to review the document, i.e. each expert was met four times. After reviewing the initial and working documents, the document was named as “Anatomical Movements of Human Body” by one of the participants instead of ROM in the classical sense and the other participants and the moderator agreed with the suggestion. The capability to perform WAs were termed as Ranges of Movement (RMs). They were established by the participants by refining the ROM data that was presented to them during the study. Table 4.3 contains the RMs in the final document.

Table 4.3: Body regions/joints and their movements

Human body regions/joints	Anatomical movements
Neck	Flexion, extension, right tilt (side flexion-right), left tilt (side flexion-left) lateral rotation (turn)-left, lateral rotation (turn)-right
Trunk	Flexion, extension
Shoulder (arm)	Flexion, extension, abduction, adduction, internal rotation, external rotation medial rotation, lateral rotation circumduction
Elbow	Flexion, extension
Forearm	Pronation, supination
Wrist	Flexion, extension, radial deviation, ulna deviation circumduction

Human body regions/joints	Anatomical movements
Thumb CMJ	Flexion, extension, abduction, adduction, opponence, circumduction
Thumb *MCPJ	Flexion, extension
Thumb **IPJ	Flexion, extension
Index finger *MCPJ	Flexion, extension
Index finger ***PIPJ	Flexion, extension, abduction, adduction
Index finger ****DIPJ	Flexion, extension
Middle finger *MCPJ	Flexion, extension
Middle finger ***PIPJ	Flexion, extension, abduction, adduction
Middle finger ****DIPJ	Flexion, extension
Ring finger *MCPJ	Flexion, extension
Ring finger ***PIPJ	Flexion, extension, abduction, adduction
Ring finger ****DIPJ	Flexion, extension
Little finger *MCPJ	Flexion, extension
Little finger ***PIPJ	Flexion, extension, abduction, adduction
Little finger ****DIPJ	Flexion, extension
Hip	Flexion, extension, side flexion (right), side flexion (left) lateral rotation (left) & lateral rotation (right)
Knee	Flexion, extension, abduction, adduction, internal rotation, external rotation, circumduction
Ankle	Flexion, extension
Foot	Plantar flexion, dorsiflexion
Toes *****MTPJ	Inversion, eversion
Toes ***IPJ	Flexion, extension

*Meta carpopalengeal joint, **Inter phalangeal joint, ***proximal interphalangeal joint, ****distal interphalangeal joint, ***** Meta tarcel palengeal joint;

Eleven body regions/joints, which are useful and necessary to perform manual WAs were identified in the upper extremity. These were neck, shoulder (arm), elbow, forearm, wrist, thumb and index finger, middle finger, ring finger, little finger and trunk. In the lower extremity, four body regions/joints were identified. They were hip, knee, leg, and foot. The final document named as the ‘Anatomical Movements of Human Body’ is shown in Figure 4.2.

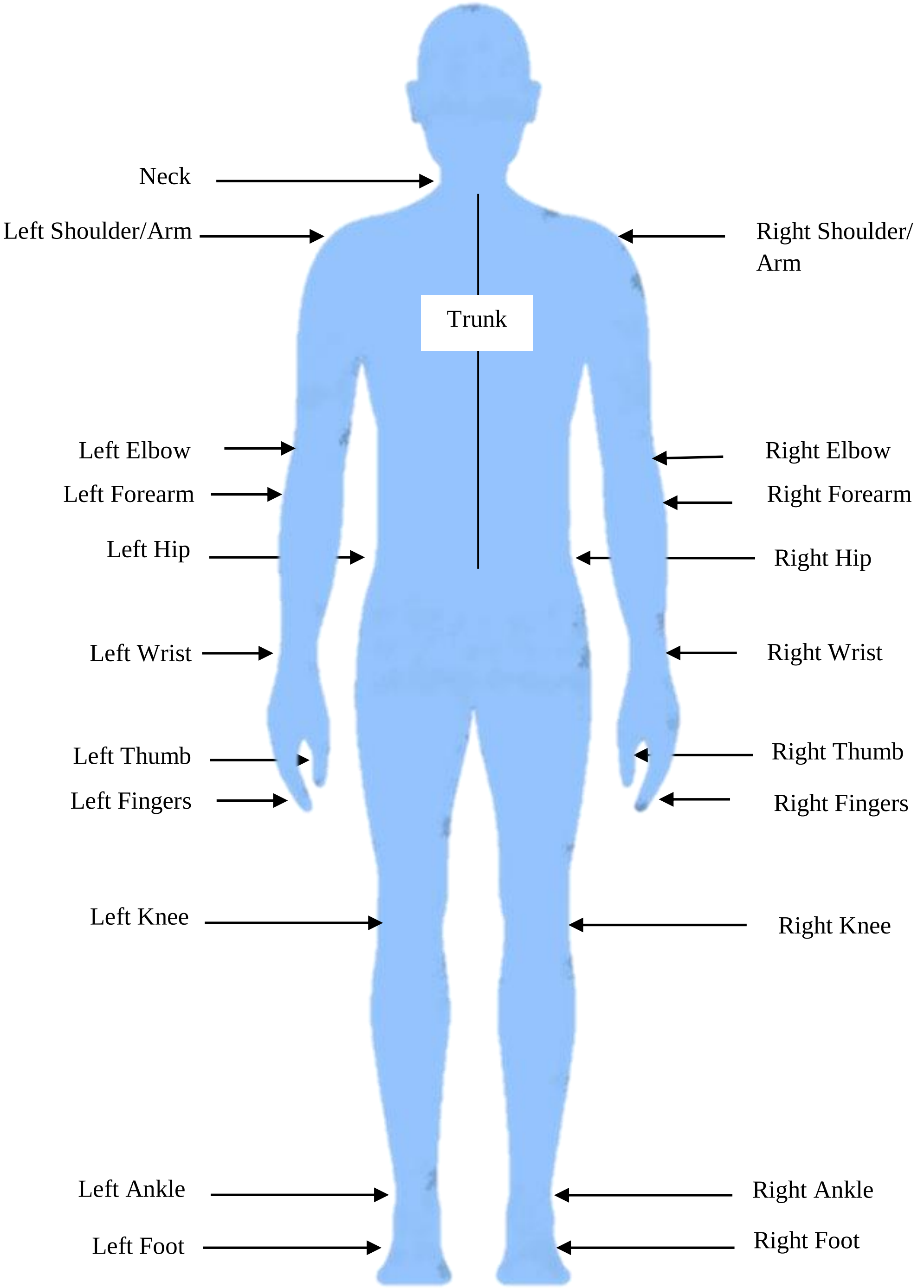

Figure 4.2: Anatomical movements of human body

4.5 Discussion

For effective employment of PPDs in industry, understanding their physical capability to perform WAs is essential. Thus, a research need was identified to prepare a standard document, consisting 'human body regions, joints and ROM necessary to compile manual WAs in industry' to help employ PPDs.

As explained in Table 4.1, 'medial and lateral rotation' are identified as the ROM of shoulders [126], [138]. However, the same is identified as the ROM of upper arm [64]. Finally, it was decided to carry out an expert review study to identify, refine and standardise human anatomical body regions and joints which are useful for performing manual WAs. As explained in literature, traditionally, body regions and joints were considered separately. Later, in this study some body regions and joints which perform together were identified as one unit. For example, in the final document, shoulder (arm) was considered as a unit rather keeping as a standalone. Thus, in future references of the study, 'body regions/joints' were used together.

ROM has been applied in many laboratory-based studies but different authors used different terms for body regions and joint ROM as shown in Table 4.1. There were two broad concerns when initiating this study: the mismatching and absent terms of important ROM in biomechanical literature. Therefore, there was an inability to prepare a justifiable standard document consisting body regions, joints and ROM require for working, through a literature review alone.

When it was having unstructured interviews with experts in the field of physiotherapy, several important ROM were found, which were different or absent in literature. As an example, opponence of thumb is the motion of touching the pads of DIPJ (the extreme pad) of all other fingers (index, middle, ring and little) one at a time by the thumb, which is unable to measure by a goniometer [64] and it is important in many grasping motions, was not available in biomechanics literature, however in the orthopaedic terminology. So this important parameter was added during the study by the experts. The body region/joints and corresponding ROM were chosen from frequently available language in order to eliminate ambiguities in the use of terminology.

RULA is designed for assessing the severity of postural loading of the upper extremity. Even though the contribution of REBA [81] and RULA [131] are indebted in the operational world, they assess WAs and postures of human movement only in trunk, neck, upper and lower arms, wrists and legs but not the fingers. If hand functioning is included in REBA and RULA which is a limitation of use, it will have a tremendous contribution. Furthermore, RULA assesses WAs and postures in neck, upper arm, lower arm, wrist, trunk and leg. For all these body regions and joints in upper extremity, a score is calculated. However, for lower extremity it is considered whether the legs and feet are well supported.

Various Researchers use ROM for many uses: developing automation techniques, dynamic [139] and static models, jigs and monitors to measure and evaluate specific joint performance [143], find solutions for occupational discomfort [121], and derive equations to obtain maximum muscle strength in various body regions of normal human beings and to assess the reliability of assessment systems [80], [144]. On the other hand, inability to measure physical performance of manual WAs could be used to understand the severity of disability of an individual based on the effective motion capabilities and limitations at work. Thus, ROM is identified as useful to measure human motion capability. However, limitations and capabilities of PPDs based on ROM, has a vacuum creating research to investigate the capability of performing elemental motions or manual WAs. Out of all, joint ROM is the significant parameter in designing job and workplace (Refer Section 4) and in clinical diagnosis [77], dynamic capabilities of industrial workers [78]. Discussions in general, evaluate laboratory-based and experiment-based studies, however limited literature is available explaining ROM, necessary for typical manual WAs. The relationship between posture [92], balance, ROM [92], muscle power [109] and movement necessary for performing manual WAs is also not very well documented. In fact, there are differences between the related terms used in medical and work-study related literature.

Methodological limitations

The initial meeting of expert review study was held in a corridor which was not feasible to make a recording. At the clinics, there were patients, other medical doctors, nurses and relatives of patients around, while the discussions were being carrying out.

Therefore, notes were taken down by the researcher and sometimes the experts also made notes in their own hand-writing. This is a limitation to the methodology. If the environment was healthy to record narrations of the experts on their own wordings, it would make a strong justification to the study.

Muscle power grading is used to assess human muscle strength which has a subjective nature. This assessment may be carried out by a physiotherapist. The importance of muscle power and 'hand intrinsic motion' [58], [145] in carrying out manual WAs were explained by one of the expert participants. For "drop wrist", "palmer flexion of wrist" and "flexed wrist" are synonyms, which was their main concern in performing WAs whether it is for ADL's-cooking, bathing, cleaning, etc [64] and Advanced Activities of Daily Living (AADL) since with such, carrying out manual work is impossible. However, P and Os' make prosthetic arms to make the wrist straight which may support them during their AADL [1]. However, its applications and performances in industrial settings need to be researched. If the muscle power grading could be assessed, capability and limitations of PPDs could be finalised. However, now there is a requirement to assess muscle power by a practitioner even for WAs who are capable for doing so.

Static and dynamic muscle strength are also identified as important quantitative parameter [100], [109]. However, measuring the strength of PPDs using a dynamometer was questionable with PPDs as their ability to operate the instrument was a question. So it's a limitation to methodology. Sophisticated and costly instruments such as electromyography are available to evaluate body signals similar to muscle pain [46], [146], [147] and hand strength measurement [46]. However, such an instrument has not been available to use for this study. Then, the development of a grip measurement tester for measuring strength is suggested [148]. However, slow-motion films or videotape observations are suggested to determine hand posture [46].

American with Disabilities Act (ADA) 1990 does not permit worker screening, so that predictions are suggested [100], even though they are not accurate. In this research, the screening was done to avoid the involvement of PWDs with multiple disabilities. The other parameter considered was the age, as age is important for some joint ROM: wrist has the highest age induced ROM reduction in upper extremity and hip and knee have the age effects in the lower extremity [77].

4.6 Summary

RM has paramount importance in performing physical WAs. In order to carry out manual WAs, neck, shoulder (arm), elbow, forearm, wrist, thumb, index finger, middle finger, ring finger, little finger and trunk in the upper extremity and hip, knee, leg, and foot in the lower extremity and corresponding RM may be useful for employing PPDs. These study findings lead to the study and development of a two-dimensional framework.

5 Work-Activity (WA) to Range of Movement (RM) mapping study

The previous two chapters explained the first and the second studies which were carried out to identify typical manual Work-Activities (WAs) in industry and Ranges of Movement (RM) of body regions/joints needed to carry them out. This chapter discusses the third study that was carried out to develop a two-dimensional framework by mapping typical manual WAs with physical functional capabilities in terms of RMs of body regions/joints to identify residual capabilities of the PPDs.

Employers are reluctant to offer chances for the PPDs since their motion capability at work is questionable [7]. Previous research reveals that PPDs too feel doubtful about their capabilities and limitations, even if they are provided with jobs or tasks to perform in a particular organisation [21]. Thus, research is needed to investigate the motion capability of PPDs to perform elemental motions or manual WAs. Therefore, it is essential to identify typical manual WAs practiced in industry in terms of body regions/joints and the RMs required to perform them in order to facilitate employment of PPDs. Categorisation of PPDs with respect to their ability to perform various types of manual WAs is also important. Such attempts could reveal the latent potential of PPDs for work, thereby increasing their potential for employment. This will ultimately help to empower them to lead an independent life.

In order to understand the interaction between the PPDs and the elements of the work systems, a comparison between the demands of jobs with the capabilities of PPDs is suggested [6], [7]. As researchers suggest, it is important to understand the relationship between PPDs and the elements of the work systems to enhance the employability of PPDs [6], [7], [16]. For example, researchers expect that a multi-dimensional framework will find solutions to understand the job demands and functional capabilities of PPDs [6], [7], [16], [47]. They believe that the demands of work should not exceed the functional capabilities of workers with a disability, explaining the necessity of benchmarking the motion capabilities of PPDs. Unfortunately, no framework or tool that supports to benchmark the motion capabilities of PPDs has yet been published. Thus, developing a framework that maps both capabilities and limitations of PPDs to the job demands may finally have benefits to both PPDs and employers. Therefore, study of task elements and physical capabilities and limitations of PPDs together would be an interesting proposition to help PPDs to be effectively employed.

A few repetitive basic motions that are necessary to perform manual work tasks are identified [87] and such repetitive motions have been analysed as psychomotor performance necessary for work, and categorised them in terms of elemental motions (e.g. reach, grasp, move and position) that have been conceptually constituted in PMTS [46]. However, consideration of the theory of basic elemental motions with respect to PPDs is limited in literature.

It is reported that PPDs have limited or no RMs in their deformed or disabled body regions/joints [58]. With limited RM, PPDs may be able to perform at least a few selected typical manual WAs in industry for which they can be employed. However, both employers and PPDs need to know which specific movements in the body regions/joints are necessary to perform such WAs. As have been mentioned earlier, a multi-dimensional framework is needed to understand the importance of interaction between PPDs and the elements of the work system for employing PPDs and find solutions based on the demands of work and functional capabilities of PPDs [6], [7].

5.1 Aim and objectives

The aim of the study was to develop a framework to map typical manual Work-activities (WAs) to the movements that could potentially be carried out by PPDs in terms of Range of Movement (RM) of body regions/joints.

The objectives were,

1. to map the range of movement of each body regions/joints to perform typical manual work-activities to form a framework.
2. to review and refine the framework.

5.2 Methodology

In order to map the previously identified RMs of human body regions/joints and WAs identified in industry, a cohort of expert participants needed to be selected. Thus, to select the participants, a stratified sampling technique [49], [112] was used. After contacting the first individual, a snow-balling sampling approach [49], [113] was adopted to add further participants to the study. This sampling strategy was used to select participants due to the limited expertise of professionals involved in the area of study.

Consent was obtained to take part in the study using the format shown in (Appendices 3.1 is the English version and 3.2 is its Sinhala translation) from all participants. To collect demographic data from experts, a structured format was used and is shown in Appendix 3.3. A modified Delphi approach [49] was used, to refine and review the mapping of the study protocol. The demographic data collected from the participants included the designation and speciality, current workplace, type of work, location of workplace, qualifications, type and country of training, professional memberships, experience in the position in years and previous posts held. If the participants of the studies were willing to receive a copy of the final document, the name of the expert, contact telephone number and e-mail address were requested.

5.2.1 Study design

The final documents that resulted from the previous two studies that consisted of RMs of body regions/joints and typical manual WAs were initially presented to the moderator of the Delphi process. With the consultation of the moderator, a tabular array was prepared with the typical manual WAs in columns and body regions/joints and corresponding RMs in rows to form a matrix/grid using a semi-structured interview protocol. This was considered as the initial draft document.

The blank spaces in the matrix were expected to be shaded by the moderator and the other expert participants, within several rounds of semi-structured discussion sessions as shown in Figure 5.1. The typical manual WAs were clearly explained to the moderator, after which, all the WAs were critically analysed individually and mapped with the required RMs of the body regions/joints.

The basis for shading was the necessity of body regions/joints and corresponding ranges of movement to perform the typical manual WAs. This matrix was considered the ‘working document’. It was then reviewed and refined by the other participants in a sequential manner. After each of the refinement was completed by the participants, the moderator also reviewed the decisions to make sure that the map was converging into a final document.

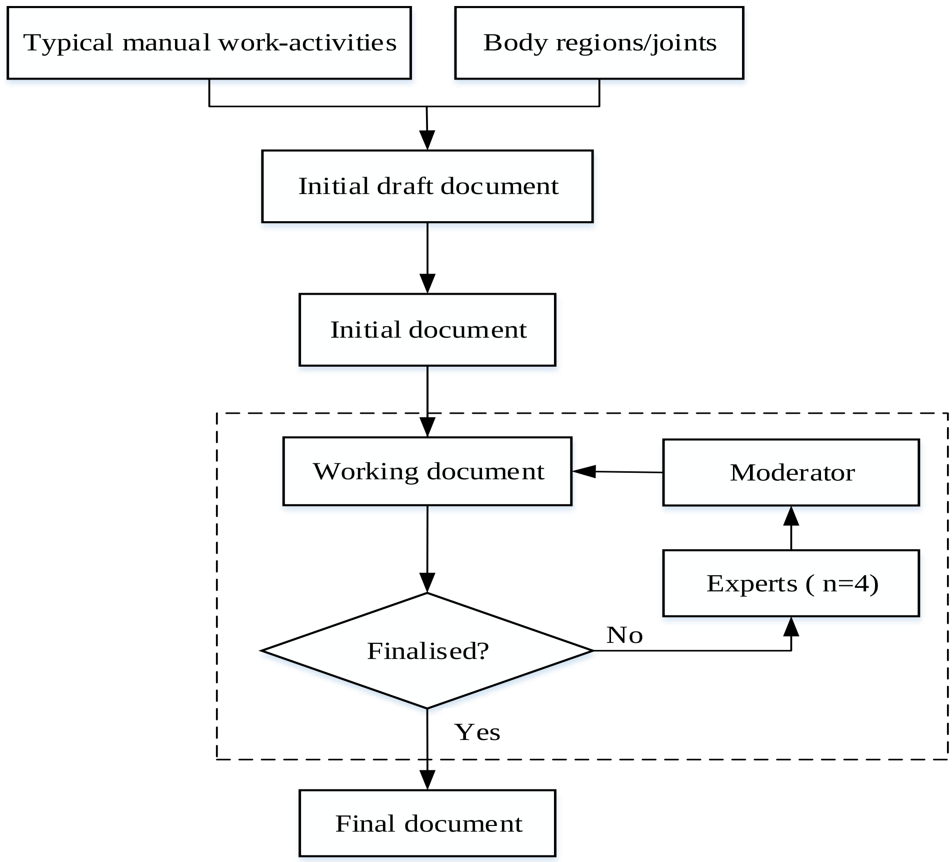

Figure 5.1: Study protocol for expert review survey

5.3 Method of Analysis

All the contacts of probable respondents were provided by the participants. The same moderator and other expert participants that took part in the ‘RM – experts’ survey’ also took part in this study. The same demographic data collected from the Consultant Orthopaedic Surgeons for the previous expert review study of ‘RM’ in Chapter 3, were used for the analysis.

Qualifications, years and fields of experience and memberships in professional bodies were first collated. The participants were categorised according to their qualifications.

The years of experience was averaged and the number of participants having memberships in professional bodies were recorded.

The final documents of the previous two studies containing the typical manual WAs and RMs for different body regions/joints were organised in a two-dimensional array as shown in Figure 5.1. The body regions/joints necessary to carryout WAs were then mapped as shown. An MS Excel® spread-sheet with the RMs in rows and WAs in columns was prepared. Whenever a body region/joint (BR) was identified that is needed to carry out a WA, the corresponding (intersecting) cell (i.e. the intersecting cell) was shaded. For example, as shown in Table 5.1, if several RMs of BR_i are needed to carryout WA_i, the cells that belonged to both BR_i and WA_i were shaded. It was named as the 'initial draft document' and was presented to the moderator where the relationship between each of the WA and RM was described in detail using a walkthrough approach.

Body regions/joints	RM	WA1	…	WAj	WAk	WAm
BR_1	RM_1					
	…					
BR_i	RM_i			[shaded]		
	…					
	…					
BR_{ii}	RM_{ii}					
BR_n	RM_n					

Figure 5.2. Mapping typical manual WAs with body regions/joints RM

A study protocol similar to that in Fig 5.1 was followed to refine and review the mapping between WAs and RMs. Thus, body regions and/or joints necessary to perform each WA were refined and reviewed in succession on a 'working document' using many rounds of walkthroughs and interviews. Additions, deletions, combination of body regions/joints, and changes to terminology were performed during the refinement process. This process continued until all the participants agreed on the final mapping. The document was finalised when cells to be shaded for all essential RMs of human anatomical body regions/joints required to perform typical manual WAs were identified in the iterative process and there were no further additions to the shaded cells in the grid.

5.4 Results

Demographic data collected from the moderator and the other three surgeons in the second expert review study in Chapter 4 were used for this since the same group of experts participated in the study.

There were Consultant Orthopaedic Surgeons (n = 4) as participants for the study. All Surgeons had the Bachelor of Medicine Degree (MBBS) from Sri Lanka and were SLMC registered. All Consultant Orthopaedic Surgeons had been working as Medical Officers prior to obtaining their Postgraduate Degree qualifications. Three of the participants had obtained Masters' Degrees (MS) from Sri Lanka, while the other participant had obtained it from the UK. All had foreign exposure. All four were Fellows of the Royal College Surgeons (FRCS). Out of the four consultants, three participants had more than 15 years of experience while the other had six years of experience. At the time of the study, many of them were heading the Orthopaedic Units of government hospitals and all were members of other professional bodies such as Sri Lanka Medical Association (SLMA) and Sri Lanka Orthopaedic Association (SLOA). One of the participants acted as the moderator for the research.

The awareness of PMTS of the participants were questioned after explaining the aim of the study. Since none of them had known about PMTS, a description of WAs were produced and explained comprehensively. Then they were allowed to identify body regions/joints for each activity and were marked in the Table 5.1. Time spent for each discussion and document review was about 15-20 minutes.

Table 5.1: RM of body regions/joints for typical manual WAs

Typical manual WAs	Description	RMs of body regions/joints
Reach	……………	……………
Move	……………	……………
….	……………	……………

After finalising body regions/joints for all the WAs, corresponding RMs were identified by the same group of participants. Then all the suggestions were mapped in an Excel-sheet. Again the participants were allowed to review the same document and some changes were suggested by them. For example, initially all the participants identified all the RMs of shoulder/arm as necessary for 'reach' and 'move', later one participant suggested that only 'internal and external rotation' are necessary (for that).

Depending on the distance that the human arm can 'reach' or 'move', 'maximum reach', 'minimum reach', 'maximum move' and 'minimum move' were defined [46]. If a PPDs is incapable of moving the shoulder (arm) but the elbow is movable, s/he may perform only 'minimum move' and 'minimum 'reach' but not the 'maximum reach' and 'maximum move'. Each of these WAs was considered both horizontal and vertical planes. To obtain the maximum reach/move, the shoulder (arm) needs to have its maximum extension.

As per Table 5.2, to 'reach maximum distance in the horizontal plane', body regions/joints that are required to perform, were shoulder (arm), elbow, forearm and wrist. In addition, corresponding RMs necessary to perform the WA were flexion, abduction and adduction, internal rotation and external rotation of shoulder (arm); flexion and extension of elbow; pronation and supination of forearm; flexion and extension of wrist.

Table 5.2: Body regions/joints necessary for 'Maximum' and 'Minimum' movement

Body regions/joints	Reach Maximum distance in horizontal plane	Reach Minimum distance in horizontal plane
Shoulder (arm)	Internal rotation	Internal rotation
	External rotation	External rotation
	Abduction	Not necessary
	Flexion	Not necessary
Elbow	Flexion	Flexion
	Extension	Extension
Forearm	Pronation	Pronation
	Supination	Supination
Wrist	Flexion	Flexion
	Extension	Extension

To ‘reach minimum distance in horizontal plane’, body regions/joints require to perform were shoulder (arm), elbow, forearm and wrist. Only RMs required to perform were internal rotation and external rotation of shoulder (arm) and flexion and extension of elbow; pronation and supination of forearm; flexion and extension of wrist. As per Table 5.2, a PPD who has slight internal and external rotation, but no flexion and extension of shoulder (arm), may perform ‘minimum’ movement. If this person is provided the work closer to him, he may be able to perform work.

To ‘reach maximum distance in vertical plane’, in addition to the strength required, same body regions/joints require to perform were the shoulder (arm), elbow, forearm and wrist. In addition, the RM required to perform were flexion, abduction and adduction, internal rotation and external rotation of shoulder (arm); flexion and extension of elbow; pronation and supination of forearm; flexion and extension of wrist.

To ‘reach minimum distance in the vertical plane’, body regions/joints require to perform were shoulder (arm), elbow, forearm and wrist. Additionally, ROM require to perform this activity were internal rotation and external rotation of shoulder (arm); flexion and extension of elbow; pronation and supination of forearm; flexion and extension of wrist.

To obtain ‘maximum move in the horizontal plane’, the same body regions/joints and RM were required as explained in ‘maximum reach in horizontal plane’.

The shaded cells in Figure 5.2, show that the RMs of body regions/joints and useful to perform WAs according to medical experts. For example, according to the narratives of the four participants;

> “To ‘reach maximum distance in horizontal plane’, body regions required to perform are shoulder (arm), elbow, forearm and wrist, and for this, RMs are flexion, abduction and adduction, internal rotation and external rotation of the shoulder (arm), flexion and extension of elbow, pronation and supination of forearm and flexion and extension of wrist.”
>
> Participant 01

> “To perform ‘reach minimum distance in horizontal plane’, internal rotation and external rotation of shoulder (arm), flexion and extension of elbow, pronation and supination of forearm and flexion and extension of wrist are necessary.”
>
> Participant 03

Similarly, RMs required to perform WAs in lower extremity were identified. For example, one participant said that;

> "Step climbing is based on a number of body regions used for climbing: one hip, one knee and one ankle of one side of the body while the other side of the body is stationary."
>
> Participant 03

Further, the experts addressed the importance of stability of the upper body in order to perform work. It was also mentioned that the muscle strength is required for movements. For instance,

> "Neck and trunk stability is required for any activity to be performed."
>
> Participant 04

> "To perform 'reach maximum distance in vertical plane', muscle strength is also required in addition to the body regions/joints that are needed to perform to 'reach maximum distance in horizontal plane."
>
> Participant 01

> "With mild internal and external rotation of shoulder (arm), non-gripping actions (percussive and sustained) can be performed, if the flexion and extension of elbow, wrist and fingers are available."
>
> Participant 02

> "Opponence of thumb is useful to 'apply pressure', 'hammering/ tapping', 'pliers' and 'cylindrical grip'."
>
> Participant 03

> "If only thumb, index and middle fingers of a person functions properly, he can perform 'turn', 'apply pressure', non-grip, power grip, precision grip, re-grasp and crank."
>
> Participant 04

Depending on the ability to move the fingers, 'grasp/get' activities were further classified into 'no grip', 'power grip', 'power & precision grip' and 'precision grip'. Essential RMs required to perform these activities were also identified.

Similarly, discussions were made to finalise the RMs required to perform WAs in the lower extremity. Step (climbing) was further divided, based on the number of body regions used for climbing: by means of one hip, one knee and one ankle of one side of the body while the other side of the body is immovable and climbing with both sides of the body as normal persons do. Finally, the WARM mapping framework developed for upper extremity and lower extremity are shown in Figure 5.3 and Figure 5.4 respectively.

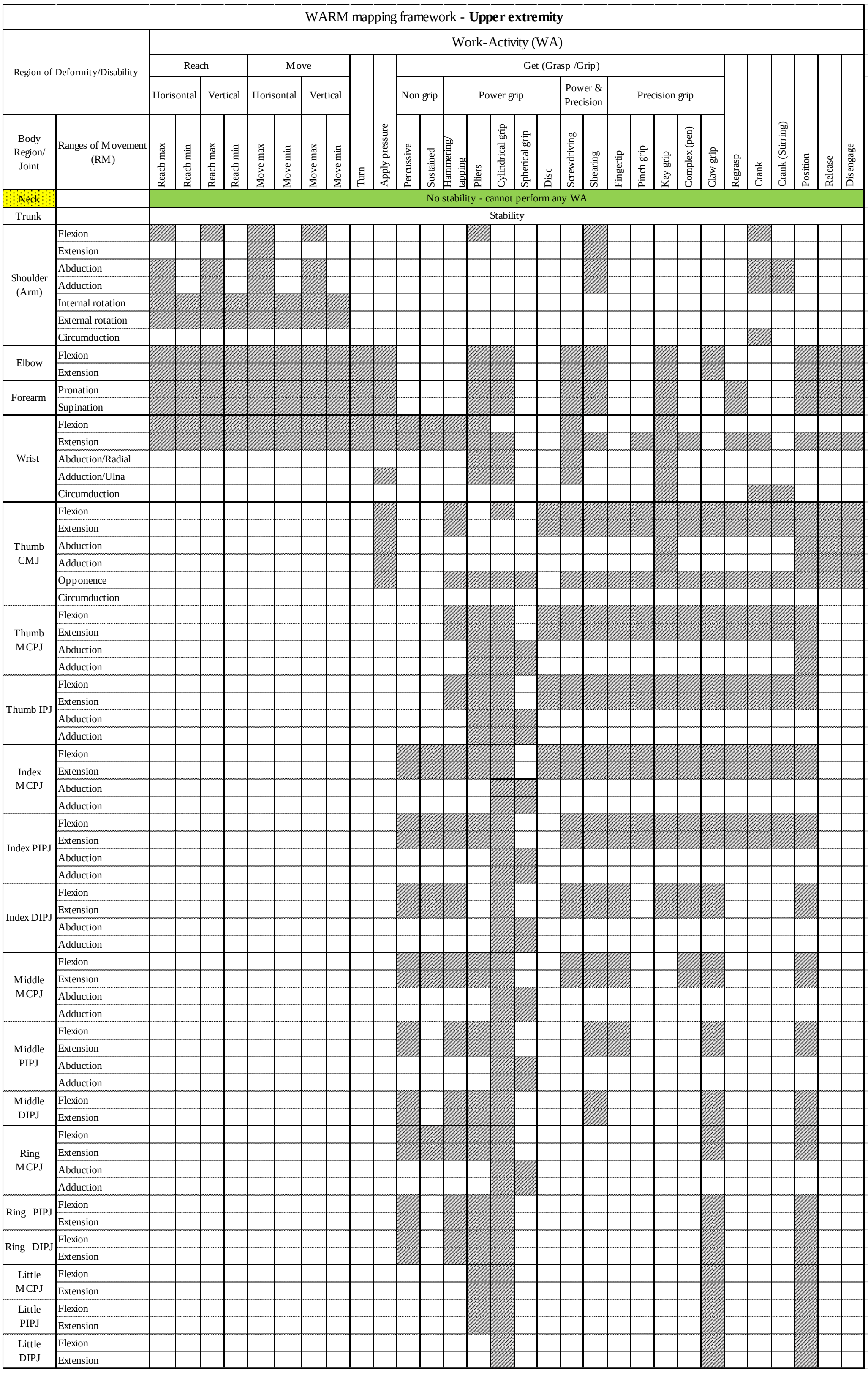

Figure 5.3: WARM mapping framework (upper extremity)

WARM mapping framework -**Lower extremity**					
Region of deformity/disability		Work-Activity (WA)			
		Step climbing			
Body Region/Joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking	Machine pedalling
Hip	Flexion				
	Extension				
	Abduction				
	Adduction				
	Internal rotation				
	External rotation				
	Circumduction				
Knee	Flexion				
	Extension				
Ankle	Plantar flexion				
	Dorsiflexion				
Foot	Inversion				
	Eversion				

Figure 5.4: WARM mapping framework (lower extremity)

5.5 Discussion

With conditions such as advanced arthritis and quadriplegia, ability to grip, capacity to pinch objects and capability to extend the joints through a normal ROM may all require job accommodation [53]. This striking framework builds a communication bridge between the employer and PPDs mainly. Numerous advantages of using this framework for the employers are: to identify capabilities and limitations of PPDs at the interviews by asking questions related to their motion capability and limitations as in the map, in order to recruit them for employment in industry; proper job assignment; facilitating to provide suitable training and re-training needs; facilitating to maintain skill inventory; understand work place requirements of PPDs and facilitate them accordingly; understand the usability of assistive devices of PPDs [18]. PPDs also have many advantages: to find suitable jobs with higher order levels [84], [86]; suitable workplaces based on their capabilities and limitations, to assess their own capabilities and limitations at specified work situations when employed.

These findings may lead to many novel research areas; such as, list out WAs for specific industries, time such WAs, categorise work based on complexity and create a data base that PPDs can evaluate their potential and contribution and one into which an employer can log onto, in order to select PPDs with required functional capabilities.

As per the work unit analysis explained in literature, first order work unit is the human motion, which was renamed as manual WA in this research. This framework helps the employers to identify capabilities and limitations of PPDs in order to grade them for recruitment for employment at their organisations and for PPDs, to assess their own capabilities and limitations at specified work situations in employment.

Work-related performance of individuals with finger disabilities is substandard to those with all fingers intact and fully functional [79], but PMTS analyses these WAs in terms of 'grasp' or 'get', without broader classification. The actions required and performance capabilities when using a screwdriver are quite different to those when using pliers (or other types of hand tools), so the present study was initiated to investigate particular issues related to the wearing of gloves when using pliers. In fact, pliers were chosen as the hand tool to study because the demands (and thus performance measures) are quite distinct from those of a screw-driving task and therefore gave the opportunity to research into a broader range of the possible effects of wearing gloves in industrial tasks.

Different jobs require different ROM of body regions/joints. Job rotation of PWDs in employment at sheltered workplaces is examined by [14]. The typing posture while using the conventional keyboard requires arms abduction, pronation of forearms, and extension of wrists, ulnar deviation and finger extension in order to fit the keyboard. Pronation and supination is highly prevalent in screw-driving tasks [74]. In wood working industry, neck flexion/rotation and arm movements are involved. Torque exertion involves the total normal grip force and the friction between hand gloves and handle surface. Torque exertions are used in operating knobs, hand tools, valves and circular electric connectors. There are three types of torque exertions as supination/pronation (S/P), wrist extension/flexion (E/F) and radial/ulnar (R/U) deviation [149]. With reference to the previous work, it is demonstrated that individuals with finger disabilities require a substantially longer time to perform simple assembly and disassembly tasks [71]. They revealed that the increase in time could be as much as one hundred percent more than what individuals without disability take. Here, they have not stated whether they have considered a standard individual without disability.

Methodological limitations

The advantage of snowball sampling is that it requires a smaller sample, and the major disadvantage is that the second group of respondents suggested by the first group may be very similar [150] and not representative of the population with that characteristic.

Documents to be discussed and reviewed with experts were always taken in the correct order since the experts were found to be very busy at clinics, Discussions were carried out while the patients were away obtaining X-rays, and notes were to be noted down. However, considering the busy schedules of the experts, document maintaining was done.

5.6 Summary

This chapter explains the final expert review study conducted with orthopaedic medical experts to map WAs and RMs to develop the WARM mapping framework to enhance employability of PPDs in industry. The next chapter will discuss the questionnaire survey that was conducted with stakeholders of the study to identify views to improve the usability of the developed framework.

6 Usability study

The previous chapter described the exploratory study which was developed by mapping typical manual Work-Activities (WAs) in industry to the RMs of body regions/joints to form the WARM mapping framework to help employ People with Physical Disabilities (PPDs). This chapter explains the fourth study carried out with the intended users of the framework to identify the usability evaluation for its purpose, clarity, usefulness, limitations and possible areas of improvement or modifications for further development of the framework to ensure its user-friendliness.

The developed framework was expected to be used by the practitioners who are involved in recruitment, selection for vocational training of personnel for jobs at organisational level, training and retraining in industries, designing jobs, manufacturing assistive devices and wheeled-chairs for the use of PPDs and for courses for PPDs developers globally. As such, evaluation of the usability testing of the framework is essential.

6.1 Aim and objectives

The aim of this study was to evaluate the usability of the WARM mapping framework. In this basis, the following objectives were considered.

1. To evaluate the framework for its clarity and user-friendliness.
2. To propose improvements or modifications for further development of the framework.

6.2 Methodology

A stratified sampling technique [49], [112] was used for recruiting participants of the study and a snow-balling technique [49] was adopted to add participants further.

6.2.1 Study design

Data were collected by walkthrough interviews and by subsequent administering of a structured questionnaire survey with reference to the WARM mapping framework to validate the usability of the framework. A sample of participants were selected and recruited, who are employed as Vocational Training Instructors and Personnel from rehabilitation centres, bakery and service industries such as banking, software and diverse fields of manufacturing industries such as (garments, electronics and food). The views of the usability of the WARM mapping framework were collected through interviews and walk through from the above samples.

Initially, consent was obtained using Appendix 6.1 or 6.2 from all individual participants to take part in the study. Demographic data were collected from the participants using Appendix 6.3 about the type and location of the workplace, qualifications, designation, professional memberships, experience in the position in years and previous posts held. If the participants of the study were willing to receive a copy of the final document, the name of the participant, contact telephone number and e-mail address were requested.

Afterward, a copy of the WARM mapping framework (Figures 5.3 and 5.4) were presented and the questionnaire survey using Appendix 6.4 was administered. To analyse data quantitatively, a number of responses of the participants were considered; the usefulness of the WARM mapping framework, intended users and the purposes of the framework in the way participants think, initial impression about the layout and likes and dislikes about the format. In the meantime, comments were qualitatively analysed as; ‘no use; unable even to further develop’, ‘little use; can further develop’, ‘vague; need to further improve’, ‘clear; easy to understand’ and ‘good; effective format’. Responses were also collated to suggest significant changes to the format. Information/Data that they wished to see added to the format for improvement, were also allowed to be stated.

With regard to the framework, the following aspects were quantitatively and qualitatively tested using scales such as Likert Scales [49], [112] for clarity of the purpose, interest towards the content, attractiveness of characteristics in the format, clarity of the mapping shadings, attractiveness of typography (i.e. lettering, heading and title), the balance of WAs versus RMs in the format, quick information collection, easiness to read information, writing style of information, relevance of information to the participant’s professional needs, user-friendliness, suitability of the format for first-time users and the enthusiasm to explore the format in future. Any other comments were also recorded.

6.3 Method of analysis

Demographic data of the participants were analysed based on designation, current workplace, address, qualifications, professional memberships, experience in the position in years and previous experience. The participants were categorised according to the sections based on the areas of working. Quantitative and qualitative data were analysed separately. The experience of the participants was also averaged. If the participants of the study were willing to receive a copy of the final document, the name of the expert, contact telephone number and e-mail address were requested.

Questions in the structured questionnaire were analysed mainly to evaluate the usefulness, intended users and the purposes of WARM mapping framework. To assess the novelty of the contribution, it was asked whether they have seen a similar format previously to help recruit and employ PPDs. The initial impression, likes and dislikes about the format were asked in order to judge the clarity of the framework. They were allowed to suggest one significant change and data they liked to be added to the format to further improve user-friendliness. The usability and the recommendation of the format to a colleague in the future were also asked.

6.4 Results

The usability study involved 22 participants from various disciplines including Human Resources Personnel, Industrial Engineers, Vocational Training Instructors, Work-Study Experts and Professionals' in-charge of Training and Rehabilitation of those who are directly engaged in selection and recruitment of PPDs for employment. The participants were from diverse fields such as manufacturing industries (i.e. garment, electronics and food(, rehabilitation centres, bakery and service industries similar to banking and software.

Four of the participants had Bachelors' Degrees. Five participants were National Diploma Holders. All others had G.C.E. A/L qualifications. All had an average 18.0 years of experience)s.d = 18.0(and service ranging from minimum 2 years to a maximum of 40 years in recruitment and training of PPDs. Some participants also had exposure to the manufacturing of assistive devices.

All of the participants stated that they hadn't seen a format like this before, and positively commented about its usefulness. Shedding light on the usefulness of the WARM mapping framework, 17 out of the 22 participants said that it is useful for stakeholders such as PPDs, employers, vocational trainers and Governments. Two participants also wanted to include families/parents and one participant wanted to include Non-Governmental Organisations (NGOs) to the list of stakeholders. One participant said that the WARM mapping framework is for 'all human beings'. The survey participants commented that they can confidently select PPDs for employment. The design, content and the purpose of the format were classified by the participants in general as 'agreed' or 'strongly agreed' thus showing the degree of clarity of the presentation of the WARM mapping framework.

The participants in general also believed that anyone can map WAs and RMs using the framework easily. 77% of the participants did not have any disparate comments about the format and 22% did not make any suggestion saying everything was there in the framework, thus individuals said that nothing should be changed.

The evaluators were clear about the purpose of the format with 47% of the participants strongly agreeing, while 53% agreed. They identified that the WARM mapping framework is for PPDs in the future as well as for the present since it will help them to be rehabilitated by identifying residual capabilities of PPDs.

Out of the 22 participants, 12 said that the framework links WAs and RMs while six participants went onto say that the objective of the framework is to identify WAs, RMs, as well as link WAs and RMs. Two identified that the framework can only be used to identify WAs while they thought that the framework can be used when interviewing for assessing people. Some of the participants noted that the WARM mapping framework can be useful for improving productivity. By and large, according to the participants, the WARM mapping framework described body regions and joints and also the relationship between movements and relevant body regions/joints.

Initial impression of 14 participants about the clarity and the learnability of the format was good and effective. Five participants identified the format as clear and easy to understand while one suggested to improve it further. 75% of the evaluators "agreed" on the clarity of the shading used throughout the framework while the other 25%

"moderately agreed" upon it. 85% of the evaluators also "agreed" on both comprehensiveness of the content and the user-friendly design of the framework while the other 15% "strongly agreed" on it.

The participants had the following views on versatility of the WARM mapping framework. They stated that the WARM mapping framework is a foundation for many paths, thus believing early identification of residual capabilities and limitations of PPDs. They agreed that self-employment and self-assessment are possible for PPDs for getting usefully engaged in work. Some of them appreciated the work because of its multidisciplinary nature. They also observed that the WARM mapping framework will be more useful in the future.

All the participants except two said that they would recommend the WARM mapping framework at this stage of development to a friend or a colleague. Only one participant would use the framework only when they recruit PPDs and the other wanted to use it after studying the framework further. As expected with the above comments, all the participants had selected 'moderate', 'agree' or 'strongly agree' scales for all the facts about the format.

Key themes were identified in terms of its usability (clarity and user-friendliness) and suggestions were made for further work. Thus, many participants suggested to develop the framework as a software and develop a database to obtain two-fold benefits and to make it available in the worldwideweb so that any PPDs may judge their residual capabilities as well as limitations and employers can select PPDs based on job requirements. Few of the comments are as follows;

> "WARM mapping framework convert to a software and a database to obtain two-fold benefits and keep available in the worldwideweb so that PPDs may judge their individual performance and employer can select PPDs based on their requirements."
>
> Participant No. 2

Capturing the mental condition of PPDs, which was not covered in this research was also suggested as further research by a few of the participants.

> "Add mental condition: welfare and mental health should be considered."
>
> Participant No. 14

> "Add mental condition since they should have willingness to work."
>
> Participant No 12

One participant identified that the purpose of the framework is to select PPDs for vocational training, recruitment/employment and design workplaces ergonomically while another participant thought the purpose was to design workplaces ergonomically; one said the WARM mapping framework is to select PPDs for vocational training and recruitment/employment. In addition to all these suggestions, one participant added ‘society’.

Following were the three likings of participants about the WARM mapping framework.

The points of view of the participants in employment and training, were as follows. The framework was identified as a good framework to select PPDs for training based on the disability and to prepare workplaces accordingly. Suitable jobs can be selected for PPDs. They believe that anyone can map on the framework. Few quotes of the participants are as follows.

> “We can select PPDs for employment for them to have better lives.”
>
> Participant No 6

> “This analysis is good, as this format is helpful to recruit PPD’s.”
>
> Participant No 2 & 19

The views of participants in supporting it as social responsibility model for PPDs were as follows:

> “PPDs in future and present”, “To help them is very good to rehabilitate them.” “Very good since this can identify capabilities of PPDs.”
>
> Participant No 4

> “To help them is very good to rehabilitate them.”
>
> Participant No 9

> “This format will change the world.”
>
> Participant No 8

> “Since this is useful for children with disabilities, important for their teachers.”
>
> Participant No 20

Some of them appreciated doing this type of work since it supplied all the details.

> “Good, it has supplied more details. This analysis good, as this is helpful to recruit PPD’s associates to the industry.”
>
> Participant No 19

Out of all, 77% participants did not have unlike about the format. Following are the three things the participants disliked about the WARM format. One participant stated that since he couldn't study more, he couldn't state anything that he disliked about the format.

The following were suggested to make one significant change to the WARM mapping framework.

Individuals had the following suggestions:

> "No change is needed. Need to study to make a novel change. Create an online program to make self-assessment."
>
> Participant No 10

> "Since this is an initial step, allow it to move smoothly and later do suggestions, putting 100% to the format".
>
> Participant No 6

Individuals had the following comments:

> "No need to change; everything has been included", "Need to study to make a novel change", "According to my knowledge, nothing needed."
>
> Participant No 9

Participants had the following views on global contribution of the framework as shown in Figure 6.1.

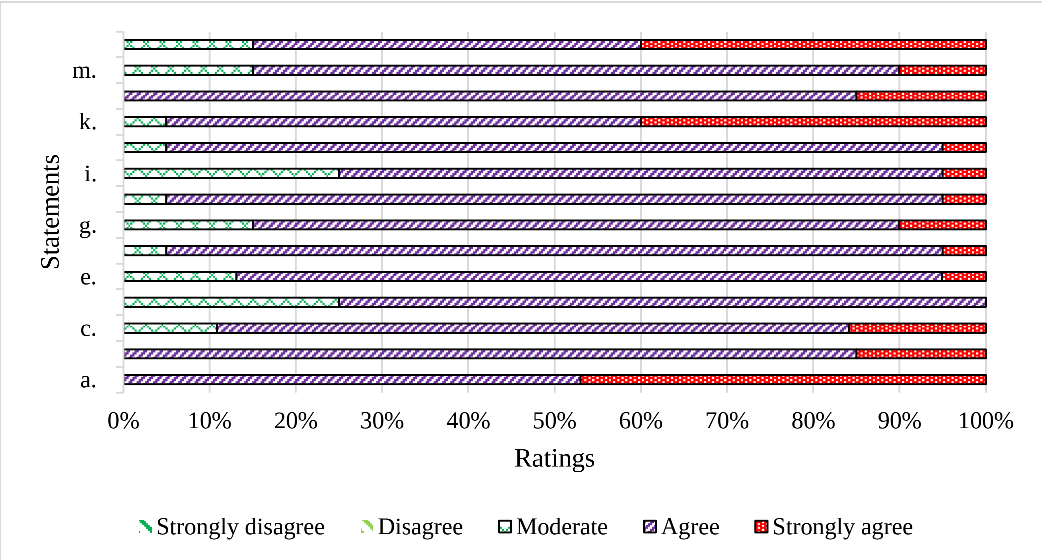

Figure 6.1: Views of the participants

Statements for Likert scale

a. This format has a clear purpose.
b. The content of this format interests me.
c. This format has characteristics that make it attractive.
d. The shading used throughout this format are clear.
e. The typography (lettering, heading and title) is attractive.
f. The format has a good balance of activities versus RM.
g. I can get information quickly.
h. Information is easy to read.
i. Information is written in a style that suits me.
j. Descriptions have the right amount of information.
k. The information is relevant to my professional needs.
l. This format is designed with users in mind.
m. This format is well-suited for first-time users.
n. The content makes me want to explore the format further.

Following improvements were suggested to the framework by the participants.

Pictures, animations and game-activities were suggested to build self-confidence of PPDs. As an example, creating a Gmail account was suggested in order to type something on their own, definitions with pictures, give PPDs financial knowledge; they do not, to develop their morale, more details can be given when applying practically.

Views of the participants were obtained by walkthrough and subsequent administering the questionnaire survey.

6.5 Discussion

This study was conducted as a first step to evaluate the functionality of the usefulness of the WARM mapping framework. The areas to be further developed were also mentioned by the stake holders. The WARM mapping framework was developed by mapping typical manual WAs and RM useful for performing them by integrating two different arrays of theories interrelated to each other, namely Industrial Engineering and Orthopaedic Bio Medicine and Ergonomics (Physiotherapy). This study was identified as important, as it helps to identify ambiguous terminology and to improve the clarity of terms used when introducing the WARM mapping philosophical two-dimensional framework to the world.

It was difficult to discourse this research at the inception since one type of terminology was entirely different to the other field and vice-versa. The meaning and the content in the statements have been proved by the participants in the following way. Some participants wanted to study the tool further, in order to make more comments. In the structured statements it was questioned from the participants using ‘a’, which says that, the content makes me want to explore the WARM mapping format and its content further.

Mainly to enhance clarity, the participants suggested to use visual aids and to enrich user-friendliness, a software was proposed to be developed. However, they too wanted to use the framework to decide the user-friendliness and initially they suggested to see the application given to PPDs. Further, modifications such as ‘translating the framework to sinhala language’ were suggested to increase the usability. Throughout the study, participants didn’t show any signs of negativity, but many appreciated it.

To carry out evaluation testing of models, researchers use usability studies [151]–[154]. Similarities with the usability evaluation tests are that they too use the Likert Scale with a ‘five-point’ system to administer questionnaire surveys from potential users [151]. This type of usability evaluation studies which are carried out at the end of a research are called ‘summative evaluation’ since this type of studies are conducted at the end of work to understand its usability [154].

6.6 Summary

This chapter presents the usability study that was conducted to evaluate the usability of the framework developed, and the next chapter will present the ‘physical capability study’ that was done to evaluate the functionality of the WARM mapping framework. Finally, the categorisation of PPDs was carried out according to the WAs that can be performed with the residual disabilities.

7 Functionality study (Physical capability study)

The previous chapter explained the study conducted to evaluate the usability of the WARM mapping framework. It was then required to evaluate the functionality and validation of the newly developed WARM mapping framework. Thus a study was carried out and is presented in this chapter.

7.1 Aim and objectives

The aim of the current study was to evaluate the functionality in order to validate the WARM mapping framework. The objectives of the study were,

1. to investigate the ability of the framework to categorise PPDs according to their residual physical capabilities.
2. to group a cohort of PPDs according to the WAs that they can perform using the framework.
3. to determine the ability of the framework to select PPDs for given manual WAs in industry.
4. to identify residual physical capabilities of PPDs that are unable to be captured using the framework.

7.2 Methodology

The study protocol consisted of requests for permission, informed consent and data collection through interviews, walk-through and observations. Thus, the study consisted of several stages, which included preparing study formats for application lodging for ethical clearance, obtaining permission from organisations and individuals and obtaining written consent of the participants. Categorisation of PPDs was also performed according to congenital and acquired considering the circumstance of disability.

7.2.1 Study design

The study procedure included screening of the participants, demographic data collection from the screened subjects, relevant information collection and finally anthropometric and RM measurement. Stratified sampling technique [49], [112] was used to recruit participants. The sample was drawn from the PPDs who were employed in organisations, residing in ‘homes for PWDs’ and in rehabilitation hospitals and private lodgings. The following government and private sector organisations were selected for primary data collection:

i. Places in which PPDs were employed,
ii. Rehabilitation centres for PPDs,
iii. Vocational training centres for PPDs,
iv. Industries where artificial limbs and feet were manufactured/provided for PPDs,
v. Industries where assistive devices (wheel chairs and crutches) were manufactured for PPDs.

Individuals with physical disability/disabilities were selected from different locations, such as their homes. The researcher conducted walk through studies at all the places and interviewed all the screened subjects to collect data, after receiving the permission from the relevant authorities. PPDs were observed while they were at work and therefore, the researcher had to visit the organisations several times to collect the necessary data.

The proforma shown in Table 7.1 were used to collect data from the participants. After finalising these formats, an application was lodged for ‘ethical clearance and scientific evaluation’ and it was granted by the Medical Research Institute (MRI) of Sri Lanka to carry out the research about the selected group of participants. The ‘ethical clearance and scientific evaluation’ was obtained for the study as per the ‘Code of ethics’ [49] and the researcher was expected to adhere to the behavioural norms established by the ethical clearance and scientific evaluation committee.

Table 7.1: Summary of physical capability study formats

Study purpose	Document	Appendices
Step 1: Request permission	Covering letter	Appendix 7.1
	Participation request: Physical capability study of people with physical disabilities	Appendix 7.2
Step 2: Awareness	Study guide: Physical capability study	Appendix 7.3 and 7.4
	Participant Information Sheet: Physical capability study	Appendix 7.5 and 7.6
Step 3: Request consent	Consent form: Physical capability study	Appendices 7.7 and 7.8
Step 4: Data collection	Screening forms	Appendix 7.9
	Demographic data	Appendix 7.10
	Deformity/disability condition	Appendices 7.11 and 7.12
	Anthropometric data	Appendix 7.13
	Musculoskeletal functioning	Appendix 7.14

Step 1: Permission from organisations

A “Covering letter” (Appendix 7.1) and the “Participation request: Physical capability study of people with physical disabilities” (Appendix 7.2) were sent requesting permission from organisations to meet the participants and to collect data from them.

An introduction about the research, for instance the aim, research needs, the expected outcomes and the benefits were mentioned in the “Participation request”. The short descriptions about the process of screening, obtaining the consent of participants, collection of demographic data, measuring relevant anthropometric dimensions of the body regions with disability. The documents planned to be shared with the participants and the expected time duration for the study were also stated in the document for their information.

After obtaining permission, in every visit, the prospective study group which is the people with only physical disabilities in the organisation were summoned and an introduction about the researcher, the supervisors of the project and the affiliated university were expressed. The aim and the study procedures were explained to them showing the relevant proforma. Step 2 gives a detailed description about the awareness session for the PPDs.

Step 2: Awareness of PPDs.

The study guide was prepared in English and Sinhala languages (Appendix 7.3 and Appendix 7.4) to communicate the study procedure to the participants of the study. The aim of the research and the data collection procedure were explained in the document. In addition, the need to carry out an interview to help to screen and obtain written consent and demographic data of the participants, the procedure of carrying out anthropometric measurements of body regions/joints with disability and the expected duration for the study were also mentioned. Statements were included to assure the confidentiality of the gathered information and removal of subjects' identities at the time of data analysis. Finally, the participants were invited to take part in future studies, if they wish to.

The participant information sheet that was prepared in English and Sinhala languages (Appendix 7.5 and Appendix 7.6) was also distributed among the participants who were selected for the study after the screening process. The aim, the research problem, importance of active participation and necessary information to help adapt work tasks and procedures to suit PPDs for higher productivity and thereby help increase the employability were informed to the participants. The expected study time, a note indicating the strict confidentiality of gathered information, thanking note for agreeing to participate in the study, and their freedom to withdraw from the study at any stage and invitation to help in future studies were also included. The contact details of the researcher were included at the end.

Step 3: Informed consent

After explaining about the documents (study guide and participant information sheet), the group was allowed to ask questions to clarify doubts about the research and the study procedures. When the group was satisfied with the answers, the written consent of each participant were obtained. The consent form (Appendices 7.7 is the English version and 7.8 is its Sinhala translation) was prepared to obtain the consent of the participants to participate in the study. The name of the subject and an identification number was stated at the top of the page. The document consisted of several standard statements and boxes were provided in front of each statement to be initialled by the participants. Lastly, space was provided to write the names and ink the signatures of both the participant and the researcher.

Step 4: Data collection protocols

For screening the subjects, pro-forma furnished in Appendix 7.9 was used and the parameters considered were age (within a range), type of disability (physical or non-physical) and condition of disability (developmental or non-developmental). The age of the participant was asked to decide the subject' ability to stay in the study population. Age range considered to be eligible to take part in the study was the standard working age i.e. between 18 to 55 years as defined by the labour laws [155]. In the screening form, under the 'age', there were three categories such as "working age", "non-working age" and "remarks", thus, a tick mark was to be placed in the relevant box. The second category was to decide the type of disability (physical or non-physical) by observations and/or by individual discussions with the participants. Each individual was carefully observed and allowed to explain about all their impairments like hearing, vision, speech mental and nervous disabilities/concerns. The last parameter was the condition of disability to determine the type of deformity/disability as progressive or non-progressive. For this, ethical verbal communications as well as supportive statements such as referrals issued by medical practitioners, service interruption certificates and disability rankings provided by employers were carefully analysed. Finally, subjects in their working age, who had only non-developmental physical disabilities were selected for the study.

The direct observation method [85], [92] and measurements were used for data collection from the PPDs. The PPDs were observed only while they were at work, care homes or under treatment and therefore, several visits had to be made to the same organisation to collect all necessary data. All the data were collected personally by the researcher.

Demographic data were collected using the proforma in Appendix 7.10 from the individuals who were selected through screening. Information gathered included the name, gender, age, date of birth, height in centimetres, weight in kilograms, address, district and the circumstance of disability (at birth or after birth due to an accident, war or other reason). Highest educational qualification, previous work experience and the duration at work, previous training/s and its type and the current workplace and the occupation were also noted.

The lists consisting possible deformity/disability conditions that could occur in both upper and lower extremities were included in forms (Appendix 7.11 and 7.12). All the disabilities of each subject were then marked in the appropriate sides of the list (e.g. right or/and left). Additional information was obtained about the condition of the disability as ‘deformed’, partially paralysed or missing. In the same form, the circumstance of disability was marked as congenital or acquired.

Anthropometric data of the deformed body regions of the PPDs were measured in millimetres using a set of Harpenden anthropometers and were recorded. Then, the form shown in Appendix 7.13 was used to collect and record the RM information of body regions/joints with deformities that have limited musculoskeletal functionality. The RMs were measured in degrees using a set of JAMAR goniometers and recorded in the form shown in Appendix 7.14. Deformity or disability conditions in both upper and lower extremities were identified, measured and recorded.

7.3 Method of analysis

Demographic data collected were analysed for age, gender, date of birth, height, weight, address, district and circumstance of disability. Then, the PPDs were categorised based on the WAs that they can perform according to the WARM mapping framework by mapping the deformed, partially paralysed, missing body regions/joints to the WAs.

Another analysis was carried out for the participants with congenital disabilities without having the required body regions/joints and also RMs for performing WAs that they are unable to perform as stated in the WARM mapping framework, but having developed some essential physical capabilities.

The data collected from all the PPDs were analysed separately based on different parameters such as disability prevalence in either upper extremity or lower extremity. Out of the persons who had disabilities only in one extremity, it was analysed whether they are in the left or right sides of the body. Furthermore, participants with multiple disabilities in upper and lower extremities and disabilities in left and right sides of body were also differentiated. Work performing capability analysis was made for the participants with complete paralysis and partial paralysis. Based on the body regions that could be moved, WAs that can be performed were identified.

Finally, the WAs and RMs of selected participants were analysed for the purpose of assessing the ability of the WARM mapping framework to identify residual work capability. For this, subjects were selected representing the entire population. The WARM mapping framework was used to identify the WAs they can perform and compared against the work that they were performing.

7.4 Results

'Ethical clearance and scientific evaluation' for the study was granted by the Medical Research Institute (MRI) and the procedure is explained in Appendix 7.15. Appendix 7.16 and 7.17 show the letters issued by the MRI granting the ethical approval and scientific evaluation for the study. The permission granted by Director General of Health Services (DGHC) for data collection from patients in some of the government hospitals is shown in Appendix 7.18 while the Appendix 7.19 showing the permission granted by the Additional Director of Social Services for data collection from Vocational Training Centre, Seeduwa which is a vocational training centres for PPDs at working age.

Having undergone the screening process, in the Physical capability study, (n=92) participants were observed. Out of them, 63 subjects were with acquired physical disabilities and 29 were found to be with congenital disabilities. Nine participants with congenital physical disabilities had disabilities in both upper and lower extremities. Out of all, only one subject was found with congenital limb loss or non-existence.

The circumstances of the disability of the participants included all three categories, congenital, acquired and amputee. Table 7.2 provides a summary of all the categories of subjects participated in the study. The subjects had congenital disabilities and acquired disabilities in which acquired disabilities happened due to war, illness, accident, burnt and amputations. Deformities were categorised as upper extremity, lower extremity and both upper and lower extremities.

Table 7.2: Summary of deformities/disabilities of subjects

Time of disability	Percentage deformities/disabilities in different extremities				
	Upper	Lower	Upper & lower	Total	%
Congenital	06	14	9	29	31.5
Acquired – Amputees		17	-	17	18.4
Acquired - other (War, illness, accident & other)	23	13	10	46	50
Total participants	29	44	19	92	100
% of participants	31.5	47.8	20.6	100	

In the sample of PPDs, there were 31.5% with disabilities in the upper extremity only. It was 47.8% for the disabilities in the lower extremity only. There were 29 PPDs with congenital and 63 PPDs with acquired disorders. Out of this 63, 17 PPDs were amputees.

Figure 7.1 shows the graphical presentation of Table 7.2.

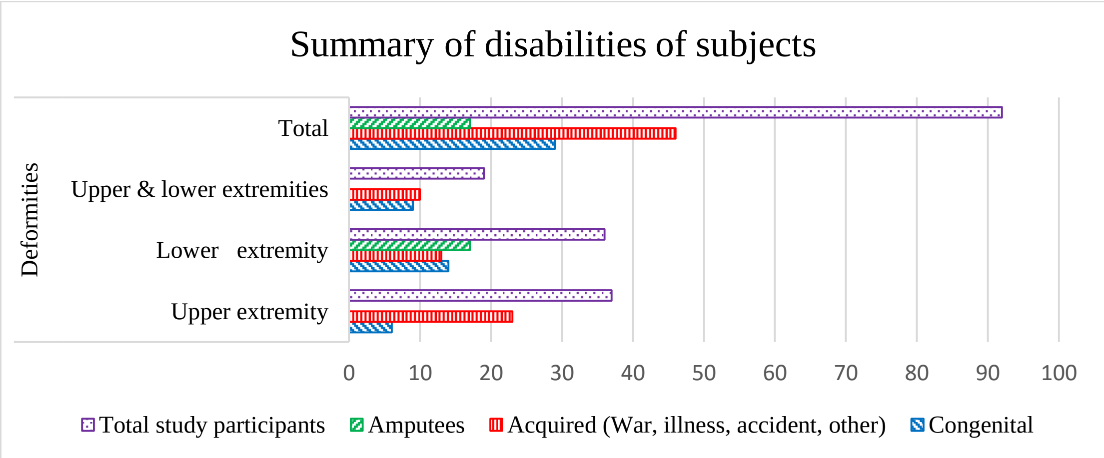

Figure 7.1: Summary of disabilities of participants

Amputees, a sub category of acquired physical was a majority (18.5%) in the population. The number of participants with congenitally missing limb was low in the group (1.1%). Amputees who had acquired disability, were able to explain their disabilities and difficulties exactly in many instances however for PPDs with congenital disorders, it took longer time for the researcher to understand their physical abilities, disabilities and difficulties.

Different deformity/disability conditions of body regions/joints in upper extremity that were found from the study are listed in Table 7.3. Deformities/disabilities of all the subjects were identified and categorised as per the Table 7.3. Some subjects had multiple deformities/disabilities in either upper extremity or lower extremity as well as both extremities. While some subjects had deformity or disability conditions in either right side or the left side of the body as well as in both sides of the body. PPDs were present for all the possible clusters (Refer section 2.2).

Table 7.3: Body regions/joints in upper extremity (left and right) used for categorisation of deformities/disabilities of participants

Affected body region/joint	Deformities /disabilities		
	% of Left	% of Right	% of Left and right
Neck			
Trunk			
Shoulder (arm)	2	3	1
Elbow	4	3	2
Forearm	5	4	2
Wrist	7	4	1
Thumb	7	5	1
Index	8	5	1
Middle	6	6	1
Ring	6	5	1
Little	5	5	1

Deformed body region/joint in those who had problems in ‘shoulder’, ‘whole arm from shoulder to elbow’ and ‘arm above elbow: between shoulder & elbow’ in Appendix 7.11 were categorised into ‘shoulder (arm)’ in Table 7.3.

Similarly, deformed joint in those who had problems in ‘elbow’ were categorised into ‘elbow’ and ‘forearm (between elbow & wrist)’ were categorised into the ‘forearm’ in Appendix 7.11. Deformed joint in those who had problems in ‘wrist’ and ‘whole hand below the wrist’ were categorised into ‘wrist’. Deformed body region/joint in those who had problems in ‘whole thumb’ and ‘tip/part of thumb’ were categorised into ‘thumb’. Deformed body region/joint in those who had problems in ‘fingers- index, middle, ring and little', 'single or many fingers' and 'tip/part of finger' were categorised under relevant fingers such as index, middle, ring and little.

In the lower extremity, deformities or disabilities in 'hip' and 'thigh' were categorised into 'hip'. Similarly, deformed joint in those who had problems in 'knee' and 'ankle' were categorised into 'knee' and 'leg' were categorised into 'knee'. Deformed joint in those who had problems in 'ankle' were categorised into 'ankle'. Deformed body region/joint in those who had problems in 'whole foot' were categorised into 'foot'. However, 'whole toe' and 'tip/ part of toe' did not take for granted as important to perform an activity. Similarly, body regions/joints in lower extremity are depicted in the Table 7.4.

Table 7.4: Body regions/joints in lower extremity (left and right) used for categorisation of deformities/disabilities of participants

Affected body region/joint	Deformities /disabilities		
	% of Left	% of Right	% of Left and right both
Hip	1.3	1.3	7.7
Knee	5.2	7.1	16.1
Ankle	9	11	11
Foot	9.7	10.3	10.3

Among the 92 participants, disabilities were found in 245 body regions/joints in the upper extremity and 235 in the lower extremity. The participants had 1819 instances of limited or no RM useful for work. After studying the PPDs, number of deformed instances in all identified body regions/joints of both upper and lower extremities and their percentages observed are shown in Table 7.5.

In order to understand the interaction between the PPDs and the elements of the work systems, it is suggested to correlate job demands and capabilities of PPDs [6], [7]. However, it is evident that the employers are not fully equipped to do this. There is also a possibility that even the PPDs themselves, are unsure about the residual capabilities that they themselves possess [21]. Unfortunately, there are hardly any specific studies present in literature on PPDs to understand their residual physical capability requirements for effective performance of WAs in industry. In short, no framework is present to understand the physical capabilities of PPDs with respect to job demands. Therefore, it is essential to identify the typical manual WAs prevalent in industry, determine the body regions, joints and the Range of Motion (ROM) required to perform the manual WAs and categorise PPDs with respect to their ability to perform manual WAs. Such attempts could reveal the latent potential of PPDs for work, increase their employability and thereby empower them to lead an independent life.

Table 7.5: Number of deformed instances and their percentages observed during the physical capability study

Extremity	Deformed body region/joint	Number of instances	%
Upper	Neck	01	0.41
	Trunk	-	-
	Shoulder (arm)	17	6.94
	Elbow	23	9.39
	Forearm	23	9.39
	Wrist	30	12.24
	Thumb	35	14.29
	Index finger	33	13.47
	Middle finger	30	12.24
	Ring finger	28	11.43
	Little finger	25	10.2
	Total	245	100.00
Lower	Hip	30	12.77
	Knee	72	30.64
	Ankle	73	31.06
	Foot	60	25.53
	Total	235	100.00

Work capability

The WARM mapping framework was validated for selected number of (n=6) participants and the results are shown in Figures 7.2 to 7.13.

Participant 01 (ORG 08/02), who had a 'neck' deformity couldn't keep the neck stable. According to the WARM mapping framework, to perform work, stability of neck is essential. Since this participant did not have neck-stability any form of WA is not possible for this participant as per the Figure 7.2. However, this participant can perform all the WAs that need the lower extremity as shown in Figure 7.3. The participant did not involve in any form of work.

Participant 02 (ORG 01/07), who had deformity/disability in ‘left elbow flexion and extension’ had limited RMs as shown in the Figure 7.4. According to the WARM mapping framework, with that deformity/disability conditions the participant was capable of carrying out WAs such as ‘percussive’, ‘sustained’, ‘hammering/tapping’, ‘spherical grip’, ‘disc’ and ‘fingertip’. This participant can perform all the WAs using the lower extremity as shown in Figure 7.5. The participant was engaged in a sewing operation using an industrial sewing machine.

Participant 03 (ORG 05/12), had deformities/disabilities in the forearm, wrist and all the joints of index, middle, ring and little fingers in the left side as presented in Figure 7.6. After plotting in the WARM mapping framework, this participant cannot perform any work using the left hand. Since the preferred hand was right, the participant can perform all the WAs using the right hand. This participant also can perform all the WAs using the lower extremity as shown in Figure 7.7. This participant had been selected for sewing machine training program at the Vocational Training Centre.

The participant 04 (ORG 06/03) had similar kinds of deformities/disabilities in both left and right sides of the body in upper and lower extremities. The shoulder (arm) had lesser muscles, forearm to wrist had mild deformities and had a deformed leg from the hip. The participant had limited RMs of shoulder (arm) extension, wrist flexion, extension, radial & ulna deviation and circumduction thus was unable to perform RMs such as shoulder (arm) flexion, internal and external rotation and circumduction, elbow/forearm flexion and extension in the upper extremity. As shown in Figure 7.8, when mapped it was identified that the participant was capable of performing ‘percussive’, ‘sustained’, ‘hammering/ tapping’, ‘spherical grip’, ‘disc’, ‘fingertip’, ‘pinch grip’ and ‘complex (pen)’.

Since the participant had deformities/disabilities in the whole leg from hip, as shown in Figure 7.9, performance of any WA using the lower extremity was not possible. Since the participant could sit, if the job was provided closer to the subject, WAs could be performed. This participant was performing ‘hand-sewing’ using the physical capability of performing ‘pinch grip’.

Participant 05 (ORG 07/04) had the deformities/disabilities in backward 90^0 rotated foot but with movable ankle joint and backward rotated toes. According to the WARM mapping framework drawn for the participant he was capable of performing WA, ‘pedalling’ as shown in Figure 7.10 even with the deformities/disabilities. This participant was operating a sewing machine using the physical capability of performing ‘pedalling’. The sewing machine was modified as per the capabilities and limitations. This participant can perform all the WAs using the upper extremity as shown in Figure 7.11.

Participant 06 (ORG 06/01) had deformities/disabilities in both left and right sides of the lower extremities in all the body regions/joints from hip. According to the WARM mapping framework drawn for this participant as shown in the Figure 7.12, the participant is unable to perform any WA using the lower extremity. However, the subject was capable of performing all the WAs using the upper extremity identified by the WARM mapping framework as shown in Figure 7.13.

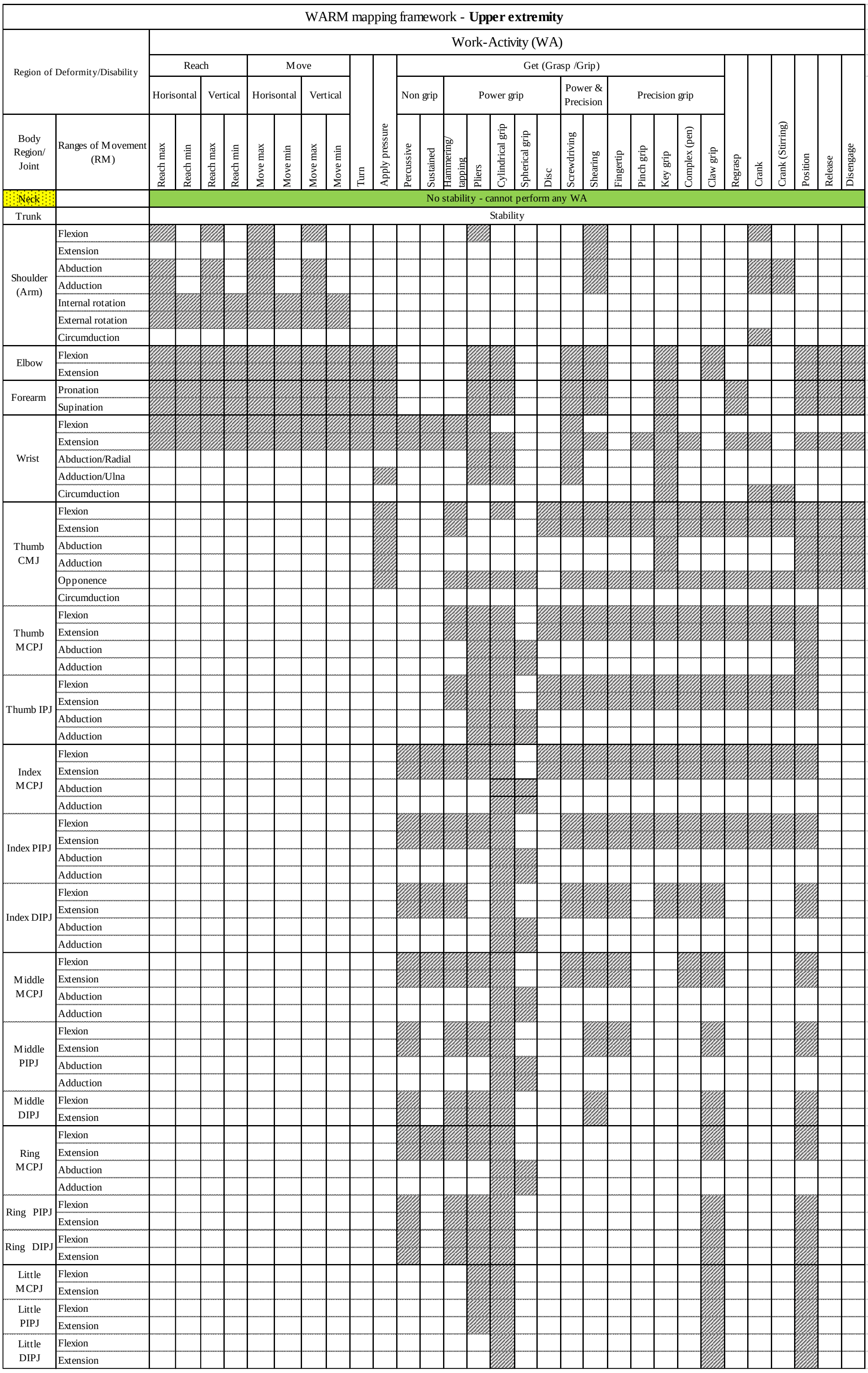

Figure 7.2: Work capability analysis of participant 1 (upper extremity)

WARM mapping framework - **Lower extremity**					
Region of deformity/disability		Work-Activity (WA)			
		Step climbing			
Body Region/Joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking	Machine pedalling
Hip	Flexion	▨	▨	▨	▨
	Extension	▨	▨	▨	▨
	Abduction		▨		
	Adduction		▨		
	Internal rotation	▨	▨	▨	
	External rotation	▨	▨	▨	
	Circumduction				
Knee	Flexion	▨	▨	▨	▨
	Extension	▨	▨	▨	▨
Ankle	Plantar flexion	▨	▨	▨	▨
	Dorsiflexion	▨	▨	▨	▨
Foot	Inversion				
	Eversion				

Figure 7.3: Work capability analysis of participant 1 (lower extremity)

WARM mapping framework - **Upper extremity**																															
Region of Deformity/Disability		Work-Activity (WA)																													
		Reach				Move						Get (Grasp /Grip)																			
		Horisontal		Vertical		Horisontal		Vertical				Non grip		Power grip					Power & Precision		Precision grip										
Body Region/ Joint	Ranges of Movement (RM)	Reach max	Reach min	Reach max	Reach min	Move max	Move min	Move max	Move min	Turn	Apply pressure	Percussive	Sustained	Hammering/ tapping	Pliers	Cylindrical grip	Spherical grip	Disc	Screwdriving	Shearing	Fingertip	Pinch grip	Key grip	Complex (pen)	Claw grip	Regrasp	Crank	Crank (Stirring)	Position	Release	Disengage
Neck		Stability																													
Trunk		Stability																													
Shoulder (Arm)	Flexion																														
	Extension																														
	Abduction																														
	Adduction																														
	Internal rotation																														
	External rotation																														
	Circumduction																														
Elbow	Flexion																														
	Extension																														
Forearm	Pronation																														
	Supination																														
Wrist	Flexion																														
	Extension																														
	Abduction/Radial																														
	Adduction/Ulna																														
	Circumduction																														
Thumb CMJ	Flexion																														
	Extension																														
	Abduction																														
	Adduction																														
	Opponence																														
	Circumduction																														
Thumb MCPJ	Flexion																														
	Extension																														
	Abduction																														
	Adduction																														
Thumb IPJ	Flexion																														
	Extension																														
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Index MCPJ	Flexion																														
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	Adduction																														
Middle MCPJ	Flexion																														
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	Adduction																														
Middle DIPJ	Flexion																														
	Extension																														
Ring MCPJ	Flexion																														
	Extension																														
	Abduction																														
	Adduction																														
Ring PIPJ	Flexion																														
	Extension																														
Ring DIPJ	Flexion																														
	Extension																														
Little MCPJ	Flexion																														
	Extension																														
Little PIPJ	Flexion																														
	Extension																														
Little DIPJ	Flexion																														
	Extension																														

Figure 7.4: Work capability analysis of participant 2 (upper extremity)

WARM mapping framework - **Lower extremity**					
Region of deformity/disability		Work-Activity (WA)			
		Step climbing			
Body Region/Joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking	Machine pedalling
Hip	Flexion				
	Extension				
	Abduction				
	Adduction				
	Internal rotation				
	External rotation				
	Circumduction				
Knee	Flexion				
	Extension				
Ankle	Plantar flexion				
	Dorsiflexion				
Foot	Inversion				
	Eversion				

Figure 7.5: Work capability analysis of participant 2 (lower extremity)

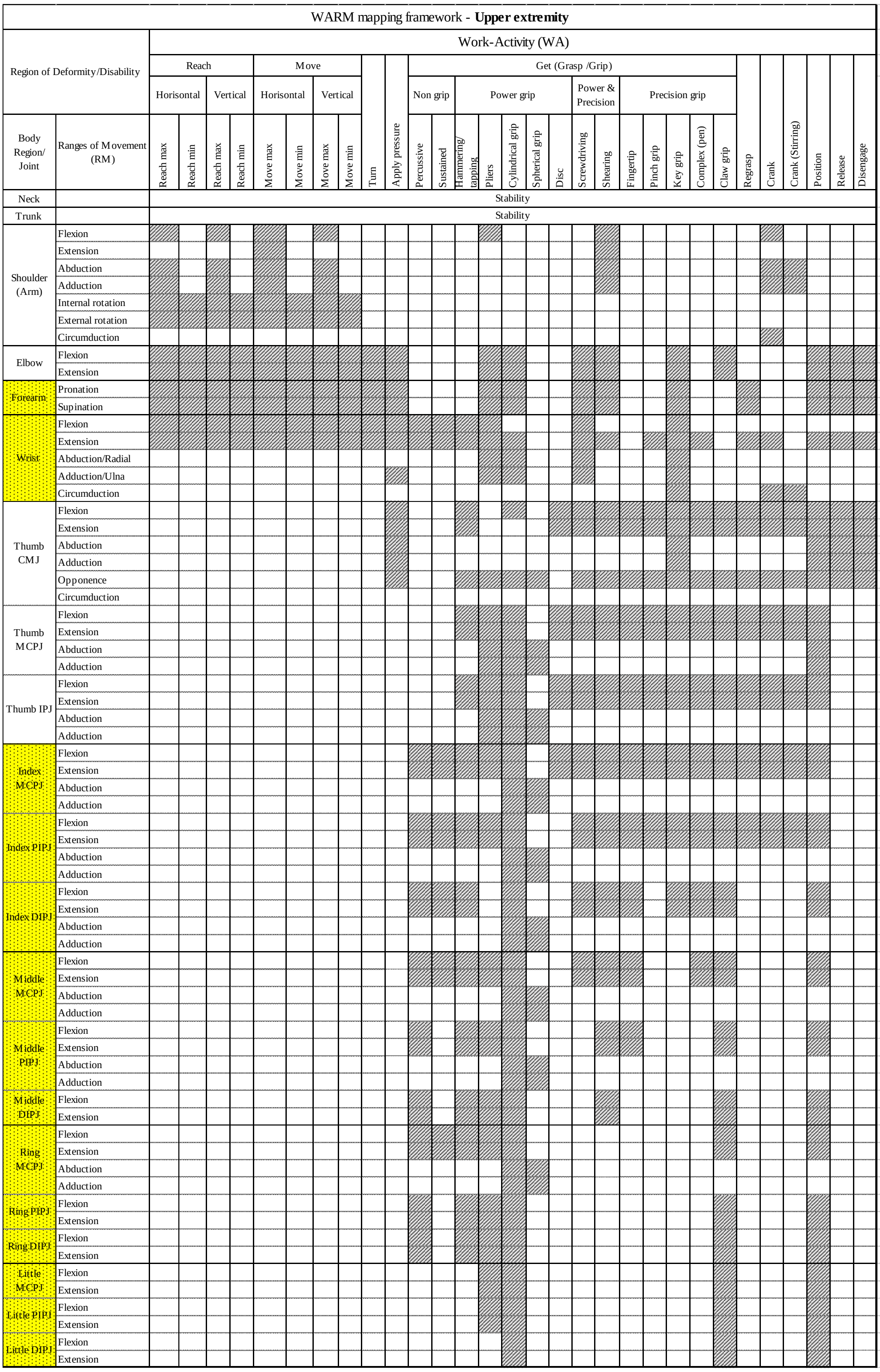

Figure 7.6: Work capability analysis of participant 3 (upper extremity)

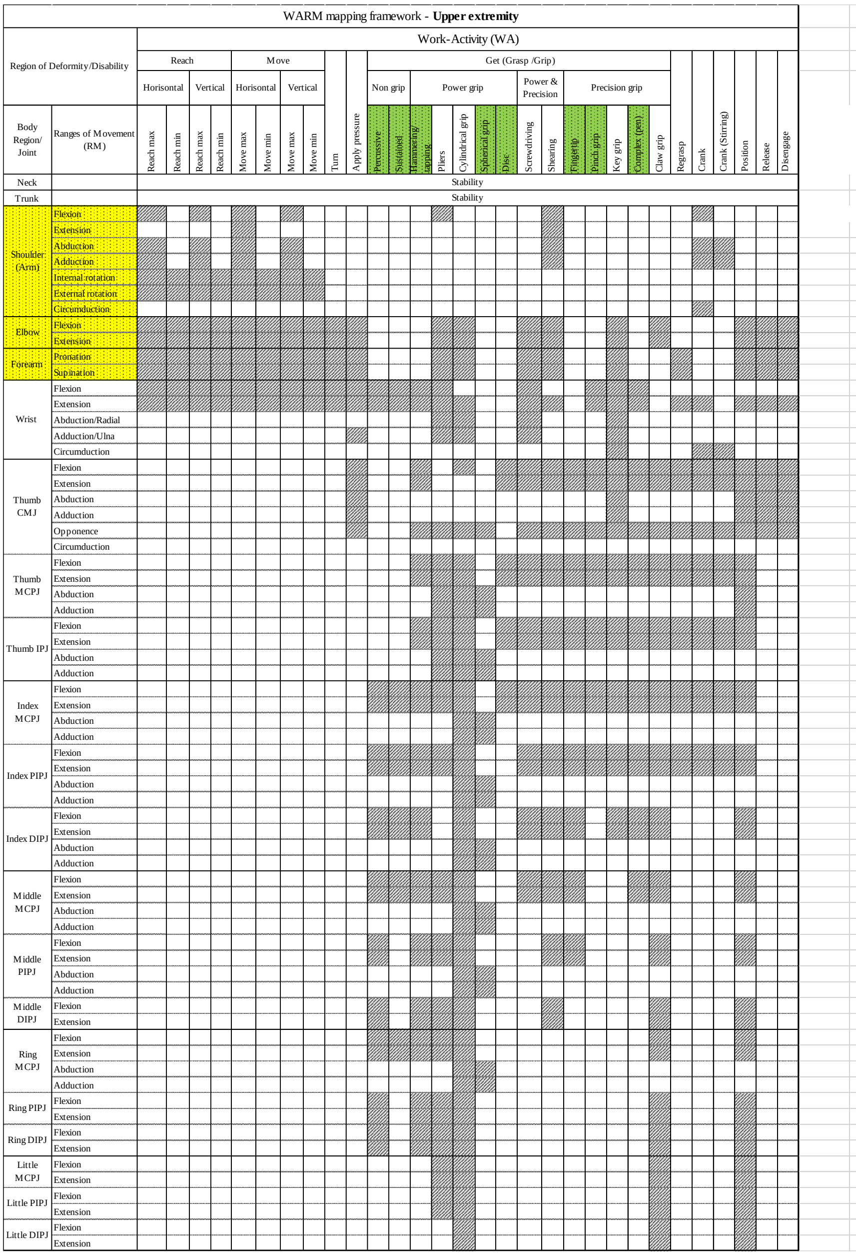

Figure 7.7: Work capability analysis of participant 3 (lower extremity)

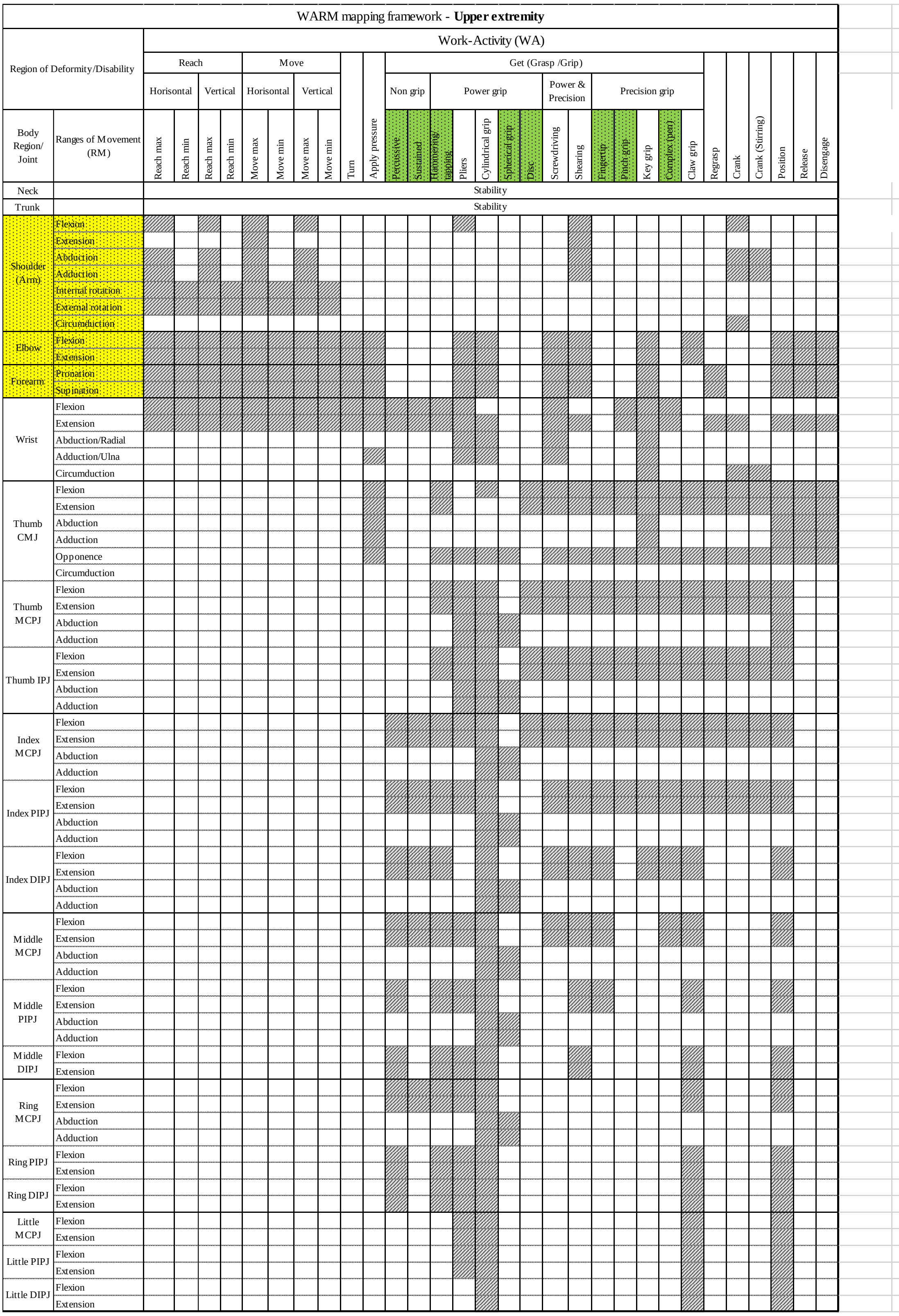

Figure 7.8: Work capability analysis of participant 4 (upper extremity)

WARM mapping framework -**Lower extremity**					
Region of deformity/disability		Work-Activity (WA)			
		Step climbing			
Body Region/ joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking	Machine pedalling
Hip	Flexion				
	Extension				
	Abduction				
	Adduction				
	Internal rotation				
	External rotation				
	Circumduction				
Knee	Flexion				
	Extension				
Ankle	Plantar flexion				
	Dorsiflexion				
Foot	Inversion				
	Eversion				

Figure 7.9: Work capability analysis of participant 4 (lower extremity)

WARM mapping framework - **Lower extremity**					
Region of deformity/disability		Work-Activity (WA)			
		Step climbing			
Body Region/ Joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking	Machine pedalling
Hip	Flexion	▨	▨	▨	▨
	Extension	▨	▨	▨	▨
	Abduction		▨		
	Adduction		▨		
	Internal rotation	▨	▨	▨	
	External rotation	▨	▨	▨	
	Circumduction				
Knee	Flexion	▨	▨	▨	▨
	Extension	▨	▨	▨	▨
Ankle	Plantar flexion	▨	▨	▨	▨
	Dorsiflexion	▨	▨	▨	▨
Foot	Inversion				
	Eversion				

Figure 7.10: Work capability analysis of participant 5 (lower extremity)

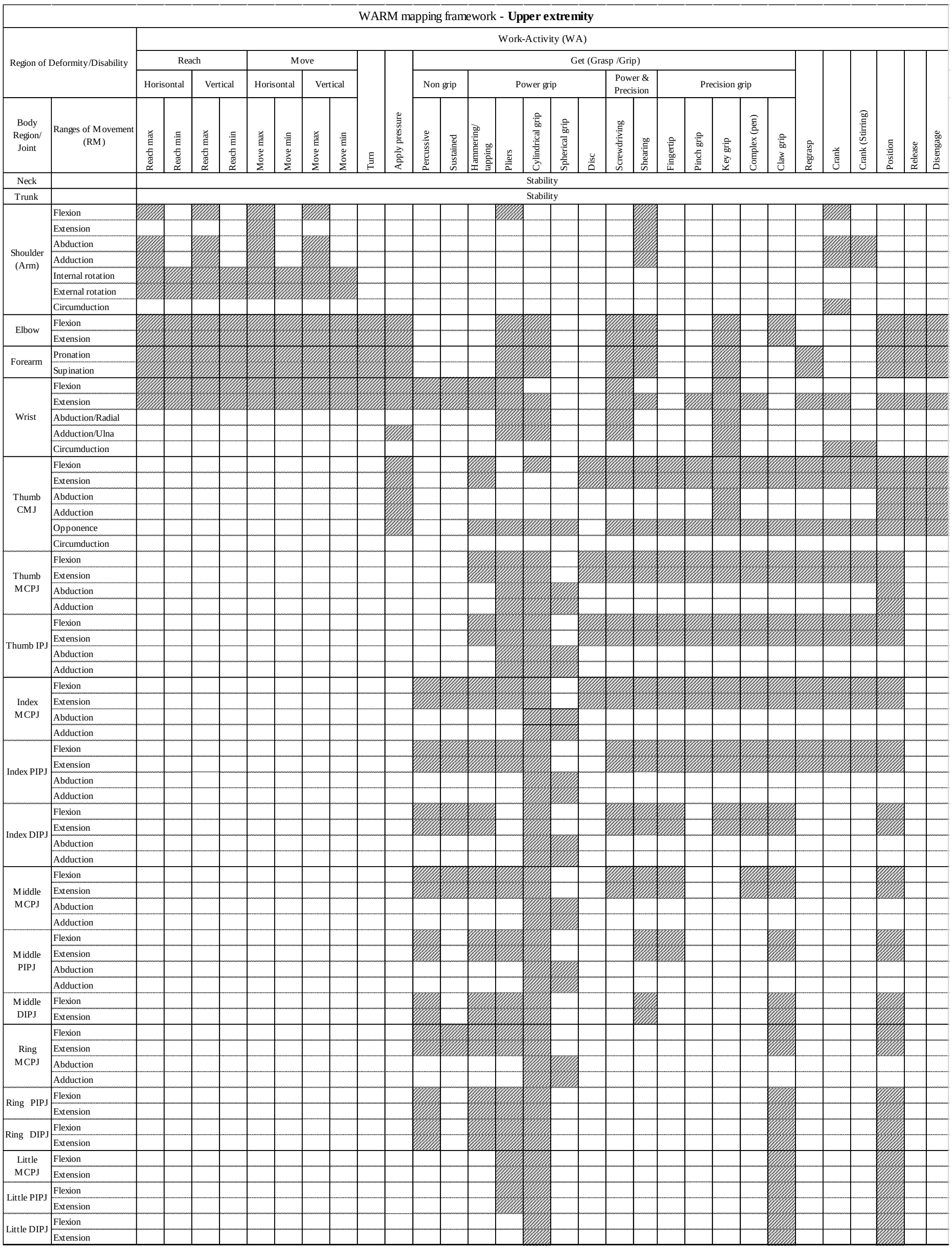

Figure 7.11: Work capability analysis of participant 5 (upper extremity)

WARM mapping framework - **Lower extremity**					
Region of deformity or disability		Work-Activity (WA)			
		Step climbing			
Body Region/ Joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking	Machine pedalling
Hip	Flexion				
	Extension				
	Abduction				
	Adduction				
	Internal rotation				
	External rotation				
	Circumduction				
Knee	Flexion				
	Extension				
Ankle	Plantar flexion				
	Dorsiflexion				
Foot	Inversion				
	Eversion				

Figure 7.12: Work capability analysis of participant 6 (lower extremity)

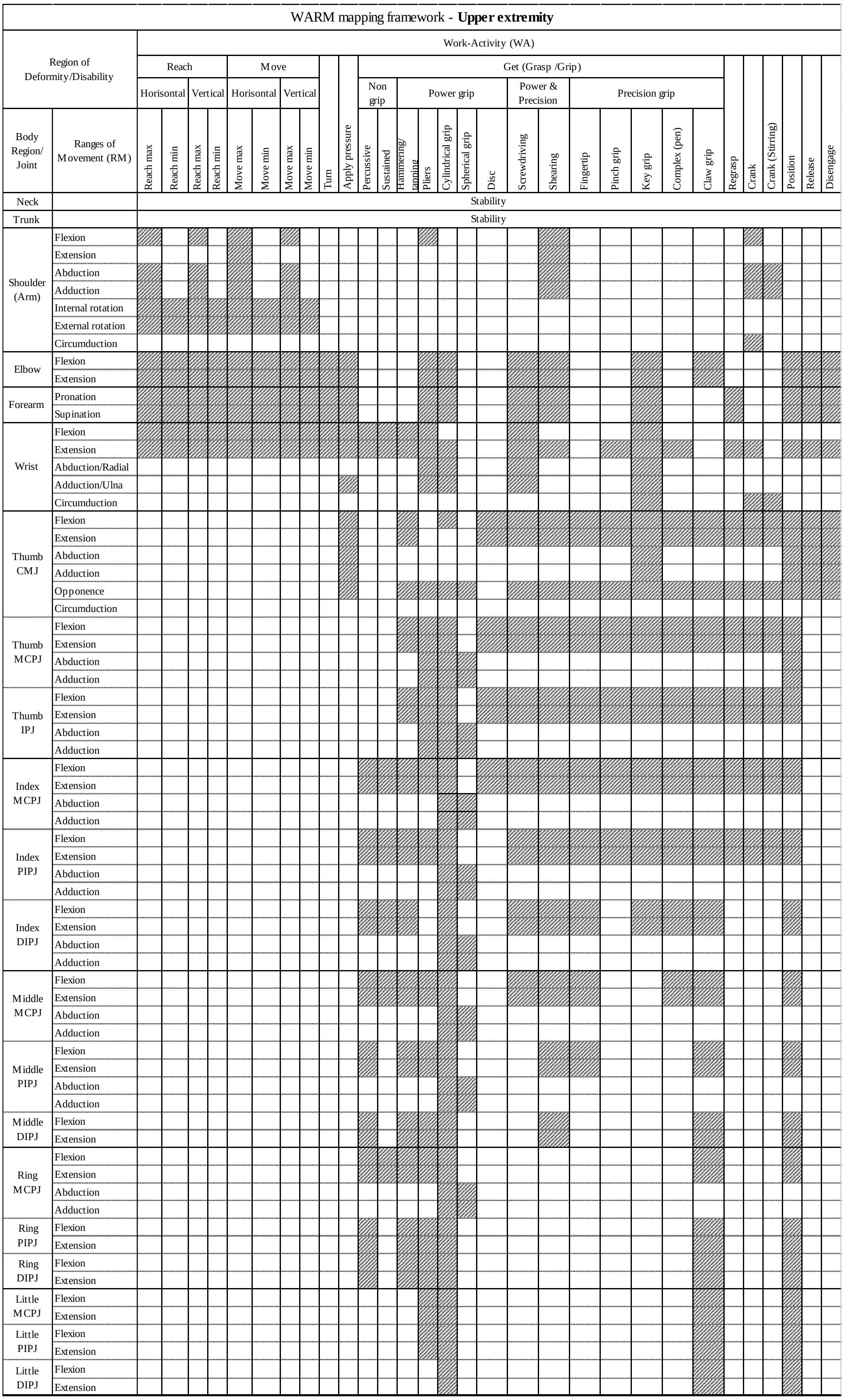

Figure 7.13: Work capability analysis of participant 6 (upper extremity)

Similarly, the work capability of the entire group of participants (n=92) was identified according to the WARM mapping framework and is shown in the Table 7.6 which summarises the disabilities that were present among the sample of PPDs and lists the corresponding WAs that can be performed with the residual disabilities.

For instance, there were 17 subjects with deformities in the shoulder. None of them were able to perform any activity, which required the shoulder since they all had limited or no shoulder RM. However, they were capable of performing manual WAs that do not involve the shoulder movement.

By further scrutinising collected data, it was found that out of the 92 PPDs that participated in the study, 16% were unable to perform any form of physical WAs, which means that 84% were capable of performing one or more manual WAs.

Table 7.6: Work capability analysis of participants

Deformed body region/joint	Frequency	Work capabilities (for upper and lower extremity)
Neck	1	None
Shoulder (arm)	17	Turn, apply pressure, percussive, sustained, hammering/ tapping, cylindrical gripping, spherical grip, disc grasping, screw-driving, fingertip gripping, pinch gripping, key grip, complex (pen), claw grip, re-grasp, position, release and disengage.
Elbow	23	Percussive, sustained, hammering/ tapping, spherical grip, disc grasping, fingertip gripping, pinch gripping, complex (pen), re-grasp, crank, stirring, position, release and disengage.
Forearm	23	Percussive, sustained, hammering/tapping, spherical grip, disc grasping, fingertip gripping, pinch gripping, complex (pen), claw grip, re-grasp, crank, stirring, position, release and disengage.
Wrist	30	Spherical grip, disc grasping, fingertip gripping, claw grip.
Thumb	35	Reach, move, turn, sustained.
Index finger	33	Reach, move, turn, apply pressure, release and disengage.
Middle finger	30	Reach, move, turn, apply pressure, disc grasping, pinch gripping, key grip, re-grasp, crank, stirring, release and disengage.
Ring finger	28	Reach, move, turn, apply pressure, disc grasping, screw-driving, shearing, fingertip gripping, pinch gripping, key grip, complex (pen), re-grasp, crank, stirring, release and disengage.
Little finger	25	Reach, move, turn, apply pressure, percussive, sustained, hammering/ tapping, spherical grip, disc grasping, screw-driving, shearing, fingertip gripping, pinch gripping, key grip, complex (pen), re-grasp, crank, stirring, release and disengage.
Lower extremity	235	Reach, move, turn, apply pressure, percussive, sustained, hammering/ tapping, cylindrical gripping, spherical grip, disc grasping, screw-driving, shearing, fingertip gripping, pinch gripping, key grip, complex (pen), claw grip, re-grasp, crank, stirring, position, release and disengage.

7.5 Discussion

“Study guide: Physical capability study” (Appendix 7.3 and 7.4) and the “Consent form” (Appendix 7.7 and 7.8) were prepared in English as well as Sinhala languages using structured formats allowing the participants to understand its content well because many of the participants could not use English. This is an inherent issue when working with non-native speakers of English [156].

Two main categories of disabilities were identified during the study namely, congenital disability and acquired disability [21], [46], [52], [157]. If a person has a born disability, it is termed as congenital disability and if the disability occurs after the birth due to an accident, burn, sickness or a disease, it is termed as an ‘acquired disability’. This aligns with the concepts of congenital and acquired disabilities in the literature [21], [46], [52], [157].

Causes of amputations are accidents, disease and birth defects. If the body part of an amputee cannot be reattached, the subject must learn to live with amputation or seek out for artificial devices [62]. There were 17 amputees found during the study. Amputations in the body regions that occur in the upper extremity are shoulder, above elbow, elbow down, below elbow and wrist down [62]. Since this do not give adequate information, 11 body regions/joints were introduced in this research. Similarly for the lower extremity, whole leg (from hip), leg above the knee (between hip and knee), leg below the knee (between knee and foot), whole foot (above ankle), whole toe (single or combination), tip/part of toe were identified as body regions [62] in the literature. Body regions/joints in the lower extremity were classified into four major groups as hip, knee, ankle and foot.

Therefore, while screening, the researcher met some PPDs with partial paralysis. They could perform work with the residual capability if they were given support to manage the paralysed body region. One participant with congenital disabilities had improvised some essential ADL and WAs that they were unable to perform according to the WARM mapping framework with the remaining body regions/joints and RMs. This was due to the adaptation of the body to carry out manual tasks they have been practising for a long time.

One participant with an acquired disability in the right side of the shoulder (arm) was unable to extend the arm and the forearm in a straight line due to permanent deformity. A surgery had been performed keeping the elbow in a fixed right angle position to each other, facilitating Activities of Daily Living (ADL). Now he is capable of for example eating with this hand.

WAs used in the Chapter 3 extracted from PMTS terminology were used in this research. The terms such as body regions, joints and RM that were referred to in this study were extracted from the medical terminology in general. Therefore, in terms of terminology, this study has been generalised. The deformities and disabilities explained throughout the research were also obtained from the literature and then reviewed by the medical experts. Thus the deformities and disabilities identified and discussed in this study are similar to those found in other populations in the world.

The subjects were selected from workplaces where they were employed, rehabilitated, and training for different vocations PPDs and at centres where artificial limbs and assistive devices are manufactured for PPDs. The researcher personally visited these places for data collection from the subjects by using walk-through, observation, and interviewing and measurement techniques. There is evidence in the literature that the techniques are used by research to collect data from PWDs or PPDs. Investigations were also carried out to understand the information that were unable to be captured in order to establish the residual capabilities of PPDs performing WAs using the framework.

Even though, the approval was obtained from the Director General of Health Services (DGHS) for data collection from the patients with permanent physical disabilities that were treated at hospitals, no subjects were found since the PPDs rarely stayed at the hospitals. In Homes, there were some PPDs who didn’t know how to explain their disability, their names, time of disability whether it was congenital or acquired. Some were found without knowing whether they can walk so they used to move on wheeled chairs. According to WARM mapping framework, they realised that they are able to walk.

During the study, two main categories of finger disabilities/limitations were also found: in one category, subjects were able to move only ring finger and the little finger while in the other category, the subjects could move only the other three fingers. Those who could move only the ring and little fingers have lower degree of work capabilities thus low competitive advantage at work.

When multiple physical disabilities are present, job accommodation is more difficult and each case often becomes unique [46]. Different occupations require differences in dimensions. For example, Truck drivers need to be taller and heavier than the general civilian populations. Underground coal miners had larger circumferences (torso, arms and legs) than did military personnel but not linear dimensions (heights and lengths). The level of detail need to be captured in order to select PPDs for specialised of jobs.

Methodological limitations

In case of applying the framework to identify the physical capability of performing WAs of the persons with congenital physical disabilities, firstly, the body regions/joints with limited RMs had to be identified. Some participants had dislocated joints, angularly rotated bones as well as amalgamated joints, and sometimes additional body regions with or without joints. Therefore, it was difficult to identify whether standard body regions/joints. The literature also suggests that disability is a complex phenomenon (Refer Section 1).

Slow-motion filming or videotape observations (Section 4.5 above) are determined to determine hand posture of PPDs [46]. Instead of these, direct observation method [85] was used in this research for data collection from PPDs and throughout the study, PPDs were observed by the researcher personally to identify their physical capability while they were at work. Therefore, the researcher had to visit the same organisation several times to complete the data collection. To reduce the disturbances and downtime of operators at workplace, this observation method was mainly used.

Observation methods constitute a practical solution in many ergonomic intervention and widely used to assess body postures [92], [143]. In this study too, the observation methods were used to assess the functionality of PPDs. The difficulties of PPDs even while during the study could therefore noticed.

It was sometimes difficult to identify body regions/joints of persons with congenital physical disability based on the deformity, limitations in angular rotation of bones and dislocation of joints. This was due to adaptation of the body to carry out manual tasks they have been practising for a long time. Therefore, measurement of the muscle power on top of the ROM [109], [158] for cumulative assessment of anatomical movements of the human body in order to fully judge a disability can be important. However, obtaining the muscle power needs specialised knowledge and can have practical difficulties. Thus, the parameters this multi-dimensional model included only anthropometric information (Refer Section 2.7.1) and RMs (Refer Section 4).

One other limitation of the study is the consideration of only PPDs. The assessment of the ability to engage in manual work of people with other forms of disabilities such as nervous, visual and auditory requires different test batteries and was considered as beyond the scope of this research. In addition, it was thought that employing people with other forms of disabilities to carry out manual WAs can be dangerous and give rise to health and safety related issues.

Muscle strength [46], [159], [160] is identified as an important parameter to identify the physical capabilities and limitations of PPDs. Since it was unable to measure the muscle strength of PPDs, "muscle power grading" [109] has been used by practitioners even though it is also said to be subjective by themselves.

Another limitation of the study is the consideration of only PPDs. The assessment of the ability to engage in manual work of people with other forms of disabilities such as nervous, visual and auditory impairment require further research and was considered as beyond the scope in this research project. It was found that employing people with other forms of disabilities to carry out manual WAs in industry can become dangerous and can also give rise to health and safety related issues.

It took a long time to understand whether a person was suffering from a nervous problem at the time of screening. Under ethical grounds, their performance limitations were not directly asked so that the researcher had to wait until the patients themselves explain/indicate the multiple disabilities since people only with physical disability/ disabilities (multiple disabilities) had been considered in this study.

7.6 Summary

This chapter discussed the study to evaluate the functionality of the framework, procedure of carrying out the study, limitations of the framework found during the study and validation of the study.

There were 63 subjects with acquired and 29 with congenital disabilities. Nine participants with congenital physical disabilities had disabilities in both upper and lower extremities. In the 92 participants, disabilities were found in 245 body regions/joints. Although they had 1819 limited or no RM useful for work, they are able of carrying out a part of typical WAs in industry with their residual capabilities. Out of the 92 participants, 84% were capable of performing one or more WAs carried out by the upper extremity. The findings provide impetus for further research to formulate guidelines for the employers to identify and evaluate capabilities of people with physical disabilities in performing specific jobs. However, other parameters such as social and psychological factors of PPDs also need to be researched in order to verify their ability to engage in manual WAs.

8 Discussion and future work

This thesis reports the development and evaluation of the WARM mapping framework to help enhance the employability of People with Physical Disabilities (PPDs). The procedures of obtaining ethical clearance, permission from organisations and participants, data collection, analysis of collected data has been described. This chapter presents a summary of all the chapters with an emphasis on strengths and weaknesses of this research compared to previous contributions and it gives suggestions for future work.

Employability of PWDs is a global need which has multi-fold benefits to PWDs themselves, their parents, volunteers and organisations that are looking to employ PPDs, and the Governments [20], [27], [89]. As explained in Chapter 1, PPDs who are a subset of PWDs have immense work potential [10], but their residual work performing ability of PPDs has not been studied [11], [12]. The WARM mapping framework discussed in this thesis facilitates to identify the work performing ability of PPDs in terms of industrial WAs prevalent in industry. This will help to clear the doubts of the colleagues, superiors, practitioners and researchers.

Even though there are different disabilities (Refer Section 2.4) and employment models (Refer Section 2.6) as explained in Chapters 1 and 2 are available, none support to identify the physical capabilities of PPDs to enhance their employability. Thus, it is evident from the literature that employers are reluctant to select PPDs for suitable jobs since they are unable to recognise the residual capabilities of PPDs at interviews [10] using any of these models. The importance of understanding the interaction between PPDs and the elements of work systems is expressed by [7], thus suggesting a multi-dimensional disability model to integrate the capabilities and limitations [11], [47] to perform work. Nevertheless, any indication of such multi-dimensional models was not found in the literature.

As explained in Section 2.4, PPDs are capable of performing work which are identified in terms of Activities of Daily Living - ADL [1]–[5]. The framework described in this thesis was developed in order to make PPDs ‘differently-abled’. This research suggests a method to identify of physical capabilities not in terms of ADL, but in terms of typical manual WAs that are prevalent in industry. Since WA is the lowest classification of work-units[84], [86], Hierarchical Task Analysis (HTA) [107] can be used to develop necessary ADL originating from the WAs as future work.

With reference to Chapter 2 and 3, hardly any literature could be found that identified the physical work capability of the PPDs. Nevertheless, in Pre-determined Motion Time Systems (PMTS) [84], [85], elements of work or the typical manual WAs in industry are available considering people without disabilities (people those who are not impaired in any way). Thus, identifying WAs using PMTS by means of an in-depth study was proposed. After analysing different PMTS demonstratives, some of the WAs that PPDs may perform in both upper and lower extremities were identified. In the study carried out with industrial engineers, the WAs were found to be specifically defined for people without disabilities. For example, all the WAs of ‘grip’ (‘get/ grasp’) is possible for people those without disabilities, but for people with different hand deformities/disabilities, a different definition of get’ was needed. Therefore, as explained in Section 3.4 and Table 3.5, WA 'get' was sub-divided as ‘no grip’, ‘power grip’, ‘power & precision grip’ and ‘precision grip’ [114] and thus PMTS was modified for this research to identify WAs in industry that can be performed by PPDs. This is a novel contribution to the body of knowledge.

As detailed in Section 4, the importance of assessing the residual physical capabilities of PPDs with respect to the movement of body regions is discussed [7], [46]. The study shows that the joints and body regions which are required to move and manipulate objects to perform manual work in general have not been studied in depth. It also highlighted that this gap has not been filled for a period of more than 30 years even though the significance has been identified long ago. Supporting this notion, it is declared by [27] that students with disabilities do not work in the areas of specialisation that they acquire during their vocational training.

Subsequently, to identify the physical capabilities of PPDs in order to perform manual WAs, the way that the PPDs manipulate their body regions and joints were needed to be studied. Thus, the second study was carried out to reveal which body regions and joints are essential to perform specific manual WAs. In general, physical capability of a person without disability/deformity is determined in terms of Range of Motion-ROM of a joint [74] and it was essential to identify the ROM needed to perform WAs. Joint ROM is described as a physiological parameter to determine the motion capability to perform manual WAs [72], [73], [75] and motion capability is evaluated according to the ROM they permit [59]. In this context, it was a pre-requisite to identify anatomical movements of human body in terms of joint ranges of motion. Thus, another study was carried out with medical experts to identify human motion capability, since there was no list available stating specific ROM to perform any WA. Experts suggested that, body regions such as arms and fingers together are needed in addition to joint ROM, in order to perform physical activities. Therefore, the motion of body regions/joint was identified as units that perform work. Motion capability of body regions/joints was named as range of movement (RM). Again this is novel contribution.

After finalising the WAs as well as RMs for necessary body regions/joints, another study (third) was carried out to map the WAs and RMs. The developed two-dimensional framework provides a novel philosophical contribution that will help the employers and physically disabled employees in the recruitment process. This will enhance the employability of PPDs with their residual capabilities.

To make sure that the PPDs are selected for employment successfully, the employers have to be able to understand the residual physical capabilities in terms of WAs at the time of interviewing. Simultaneously, the PPDs should be able to communicate about their potential residual physical capabilities in terms of WAs to the employer. Thus, to help both the employers and the PPDs to understand their requirements enabling necessary communication, the WARM mapping framework is proposed by mapping the physical capabilities with the typical WAs in industry. This is also a novel concept, which is not found in the literature.

For appropriate employment of PPDs in industry, physical capability in performing WAs is essential. Thus, a need was identified to prepare a standard document consisting 'human body regions/joints and their RM necessary to carry out manual WAs in industry' to help identify the residual capabilities of PPDs. The developed tool provides a vital two- dimensional approach to address the needs of both PPDs and their potential employers with respect to manual work tasks [7]. It relates the manual WAs to the RMs possible for the PPDs.

8.1 Benefits

With respect to the special employment programmes that are suggested such as subsidised, sheltered and supported [11], [14], [20], [50], [68], [69], to help employ PWDs, it is crucial to identify the eligibility requirement and assessment of disabilities in a consistent manner [68]. Supporting this notion, the proposed Work-Activity to Range of Movement (WARM) mapping framework provides support to select PPDs for employment. Further, each employment programme stated above can be benchmarked based on the WARM mapping framework. Even the PPDs themselves will be able to understand their eligibility in terms of their residual capabilities. Furthermore, the framework can be useful to determine the motion-assist devices [161] for example, supporting devices needed for pedalling by people with lower limb disabilities.

As researchers propose, the creation of sheltered work centres is a commonly adopted strategy [14], [68]. Even though the sheltered work centres [20] have been in practise for over 25 years, they do not provide a concrete solution for the proper selection to support employment of PWDs. In order to employ PWDs in the sheltered work centres or any other suitable workplace, principally, there is a need to understand the physical capabilities and limitations of PWDs. Thus, use of the WARM mapping framework for the selection of PPDs will provide support not only to the sheltered work centres, but also to the other organisations that offer employment for PPDs. Selecting PPDs for sheltered workplaces is critical as people with “too little” and “wrong type” of disabilities often tend to be selected [68] since there is no mechanism to determine the complexity of disability. As a result, sheltered employment, which mainly targets people with more severe disabilities is criticised for its inefficiency. This issue can also be addressed if the WARM mapping framework is used to select people with more severe disabilities and provide them only the WAs that they are capable of performing according to the WARM mapping framework. However, the long-term effect of the WARM mapping framework needs to be looked at to ascertain the benefits of using it.

A list of basic human activity limitations associated with upper and lower amputations is identified by [62], for example, grasping, lifting, pushing, pulling in the upper extremity and carrying, turning and kicking in the lower extremity. Some of the WAs however can be further decomposed into smaller work-units as explained in the

WARM mapping framework. For example, grasping can be sub-divided into four classes based on the complexity of work, i.e. 'no grip', 'power grip', 'power and precision grip', and 'precision grip' [84], [114] as explained in Section 3.4. Therefore, generalisability of the work carried out by [62] has limitations since the classification has not been started from the lowest level of work-units.

As per the work unit analysis of [84], [86], first order work-units are considered as the elementary human motions or the smallest work-units which are usually encountered in the study of work to facilitate job design and time study. Similarly, in the current research, the smallest work-units were renamed as Work-Activities. These allowed the WAs to be extended hierarchically to higher levels such as elements, tasks, intermediate products or components, end products, programs and gross output up to results [84], [86]. Therefore, the current research provides a greater level of generalisability. MTM is identified as the most common PMTS in the world and exhibits an internationally valid performance standard for manual tasks [110], thus establishing a worldwide uniform standard of planning and performance. The generalisability of the current research is further enhanced because it has used valid and accepted performance standards.

There is evidence in the literature where research has been carried out without giving due regard to the capabilities and limitations of PPDs [62], [65]. For example, they expect the employers to understand the limitations of employees that become amputees during their career and provide the necessary resources to overcome workplace limitations. They have also provided design guidelines to accommodate amputees. As an example, the design of technological aid and environmental accommodations that contribute towards the autonomy of PWDs are foremost emphasis of [65] without considering the nature of their impairments. The fields of their investigation include, for example, functional rehabilitation technologies (e.g., active orthoses, exoskeletons, robots and virtual environments applied for rehabilitation), individual substitution technologies (e.g., robotic prostheses, normal prostheses), adaptive or assistive technologies for PWDs [18]. To initiate this kind of supportive work for employing PPDs, physical capabilities and limitations needs to be known primarily. The WARM mapping framework will provide necessary information for designing technological-aid and environmental accommodations based on the essential RMs useful for performing WAs.

Even though some researchers believe that PWDs in general have great work-potential [10], only a small portion of them perform productive activities due to their supposed inability to facilitate their integration to the society [14]. In one attempt to integrate PWDs to the workforce, effectively a matrix which consists of rotation schedules is proposed to expose the workers to different tasks to evaluate the effect of job rotation with respect to PWDs at sheltered workplaces [14]. They expect all the employees to be equally efficient when executing the tasks. However, in reality, it will not be so, especially when PPDs are present among the workforce. Current research reveals that for the PPDs, the capabilities and limitations are primarily based on the physical ability of performing RMs. Some researchers [74] have identified body regions, joints and their corresponding ROMs and postures required for different tasks and jobs that exist within industries. For instance, typing posture while using the conventional keyboard requires arms abduction, pronation of forearms, and extension of wrists, ulnar deviation and finger extension in order to fit the keyboard [162]. In another research it has been revealed that wrist movements and muscle activity of the forearm muscles referred to as pronation and supination are highly prevalent in screw-driving tasks [74]. In the wood working industry, neck flexion/rotation and arm movements are involved [149]. Torque exertion involves the total normal grip force and the friction between the gloves and handle surface [149]. Therefore, it is essential to understand the physical capability of the PPDs in order to determine whether the given tasks can be performed by a person. The WARM mapping framework shows that different jobs require different RMs of body regions/joints and it is an attempt to conceptualise that the PPDs can also perform some of the WAs present in industry with their residual capabilities. This will enable the PPDs to be interrupted to the society and contribute towards economic development.

Furthermore, is identifying potential capabilities of PPDs since no proper sysstem of that people in wheelchair are as unproductive [22], [66] states literature available. This will identify WAs with residual capabilities changing the literature. These people can perform WAs using upper extremity even in wheel chairs. Otherwise work can be brought closer to these people allow them to be working.

There are numerous benefits can be expected by the employers who use this framework. At the interviews, PPDs do not have an idea of available WAs in organisations while the employer does not know about the physical capability performance of PPDs [10], [11]. Since two-way verbal communication is not facilitated between them at the job interviews, recruitment has not been possible even though the literature suggests that PWDs are willing to work, if they are recruited to organisations [15]. This framework provides an effective platform since both interviewer and interviewee can refer to the WARM mapping framework at the time of the interview. Thus, the interviewer can identify the capabilities and limitations of the PPDs while PPDs will have an understanding about the WAs in the organisation that he/she has to perform based on their residual ability. To ask questions related to residual motion capability of PPDs, the framework can be useful to understand the limitations in terms of WAs providing an ethical interviewing atmosphere to select suitable PPDs for employment. After selection, job assignments can be made according to the framework. It provides an idea about the workplace requirements [63], i.e. equipment, facilities, procedures and training as identified by [163], [164]. This will be helpful in providing them with opportunities to develop their skill inventory. However, in order to facilitate these, the framework needs to be extended to cover these additional aspects.

PPDs will also have many benefits that will lead to finding suitable jobs and workplaces based on their residual capabilities and limitations. They will be able to self-assess their own capabilities and limitations at specific work situations. These are all research needs, which have been frequently mentioned as gaps in literature [14], [17], [71], [74], [79], [149]. For instance, [74] state that in order to perform different tasks and jobs in industries different; body regions, joints and their corresponding ROMs and postures are required. This framework therefore acts as an appropriate communication bridge between the employer and PPDs, which has been repeatedly identified as a void in literature [7].

Explaining about the successful integration of the identified PWDs to work environments, those who have been off work due to impairment, managers are expected to make efforts to understand the capabilities of PWDs to employ them in organisations [17]. However, it has always been a grey area, with uncertainties when deciding the capabilities of PPDs. Unsuitable or harmful decisions of managers could even destroy the residual capabilities of PPDs and worsen the situation. The WARM mapping framework can potentially address this issue.

Research suggests that the work-related performance of individuals with finger disabilities is substandard to those with all fingers intact and fully functional [79]. However, published literature so far does not support to understand or quantify these substandard functional capabilities compared to normal individuals. For capture the disability in each finger, there is a position in the WARM mapping framework thus enabling facilities to identify capabilities in terms of different classes of 'get (grasp/grip)'. This can be used to evaluate the functional capabilities of PPDs with respect to the capacity of normal people. For example, the framework can be used to determine several WAs that PPDs with finger disabilities can perform. Out of the various grips that are needed 'no grip' activities can be achieved without the involvement of the RM of the fingers. PPDs with mild RM may perform 'no grip' activities while the 'precision grip' can be performed by PPDs with high RM capabilities. For example, the minimum RMs required to perform work with a screwdriver are quite different from those when using pliers or any other type of hand tool. Based on the capability of performing minimum RMs of different fingers, the work capability as well as limitations can therefore be identified using the WARM mapping framework extending the boundaries of employability of PPDs.

Employers need to provide amenities such as accessible pathways, auxiliary devices and safe and comfortable sanitary facilities if needed [15], [35], [36], but they are unable to predict the successes and failures of the outcomes of recruiting PWDs to their organisations. This research explores aspects of managing PWDs at work and proposes further research needed to categorise work-related needs of PWDs based on their physical capabilities and limitations to help design work tasks that could be carried out by them [20], [30], [31]. It is also argued that PPDs require more time to perform simple assembly and disassembly tasks than people with no disabilities [48] since the restricted or controlled movements of body regions inhibit the ability to freely move, manipulate objects and interact with the physical world [8], [24]. Based on this, another research area can be identified to study on the standardisation of time settings to provide 'personal allowances' for PPDs.

To perform walking, a pair of legs is essential [142]. The knee performs the main role during the whole gait cycle due to the fact that the knee joint sets the difference between a rigid leg, with one body from the hip until the ankle. However, [165] believe that in many occupational settings, walking is considered a job function when it is performed with a physical load. Therefore, muscular activity of PPDs must be studied in future research.

The human muscular power is the main source of energy for most of the work done in the world [119]. Voluntary muscles of human body are activated under one's conscious control [119] and therefore human beings can move. The forces concerned in making these movements are quantified using the muscle power grading (Refer Section 2.7.4). PPDs may not be fully supported by voluntary muscles. Supporting this, it is explained that all the muscles are attached at each end to bones, with one or more intervening joints. The basis for movement is the property of the muscles which contract, bringing the points of attachment closer together [119]. Therefore, traditional muscle power grading may not be feasible with PPDs and a novel way of quantifying their ability to work needs to be unveiled.

Methodological aspects

The advantage of snowballing sampling used in this research is that it keeps the sample size small, but the major disadvantage in the snowballing approach is that the second group of respondents suggested by the first group may be very similar to the first and therefore the study group may not be representative of the population [49]. However, with its inherent limitations, this method is being frequently used and proven successful in numerous occasions in achieving data saturation quickly and easily [49]. Furthermore, in the study, the moderator's comments were used to create the 'initial document 'and 'working document' in phases two and three. Therefore, it can be argued that the document is biased. However, in the subsequent refining of the document by the other experts, the dominant contribution of the moderator diminished. This can be considered as an inherent feature of the Delphi techniques [49].

Even though muscle strength [46], [159], [160] is identified as an important parameter used to identify the physical capabilities and limitations of PPDs for employment measuring, the muscle strength using available instruments such as the hand dynamometer was found to be difficult. Therefore, such instruments were not used in the study and the muscle strength was not measured. Therefore, further research is suggested to design a muscle strength measuring instrument which may be suitable to be used with the PPDs.

Finding a committee to apply for ethical clearance for the research was a challenging task. Researcher contacted approximately three other universities where there are ethical clearance committees, however they refused to accept the application for ethical clearance indicating that this research is novel for them. Finally, the Medical Research Institute (MRI) of ethical clearance and scientific committee accepted the application and it took about one-year to discuss the research in the 'ethical clearance granting meeting'. At the meeting, the researcher had to convince a team consisting of about 30 medical officers and Health Directors about the research. The main concern of the committee was regarding the terminology used by the researcher. They were different to medical terminology but they were more related to engineering terminology. Once these were clarified, the committee granted clearance.

Carrying out research in the health sector is not easy due to its frequently changing and the off-standard unavoidable practices within the hospital environment. Therefore, discussions, interviews and document-reviews with the health personnel and also finding a proper space for a discussion were challenging. The initial meeting with the Moderator was held in a corridor. Subsequent meetings were also held at the clinics at times in front of the other medical officers, nurses and guardians of patients. Therefore, notes were taken down by the researcher and sometimes the experts also made notes in their own hand-writing. However, note-taking in interview studies in research is not uncommon [49].

Future work

Even though it is difficult to quantify the costs of disability as explained in Section 1, a system can be developed to measure earnings of PWDs in the future. After finalising the cycle times for different industries based on this framework, earnings of the PPDs can be calculated in terms of Standard Allocated Hours (SAH). This performance measurement may lead to supporting all other measures such as planning, performance calculations, incentive schemes as similar to practices with the normal population. This is suggested as future work.

With reference to previous work, it is explained that individuals with finger disabilities require a substantially long time to perform simple assembly and disassembly tasks [71]. They reveal that the increase in time could be as much as one hundred percent more than what individuals without disability take. However, the WARM mapping framework suggests suitable work for individuals with finger disabilities, which may not involve assembly and disassembly tasks and involve only suitable tasks. Furthermore, with some extended future work, time measurements can also be integrated to the framework to substantiate the capability of PPDs. The findings of the research may also be used to develop research areas such as, listing out WAs for specific industries (e.g. General Sewing Data for people without disabilities in garment industry), timing such WAs and categorising work based on complexity.

Further work is also needed to integrate different jobs and work situations into the framework by studying the process times for PPDs. The research findings can be used as a foundation for many other research studies such as to develop WAs for specific industries, identify MTM-based work available in industry that PPDs can be mapped with, set Standard Minute Value (SMV) for different operations in specific industries and PPDs for different categories and innovate tools suitable for the disability or deformity.

To make the WARM mapping framework user-friendly further, a software can be developed by adding computer animation and made available in the worldwide web to upload capabilities and limitations of PPDs themselves which may be referred by employers. In addition, this framework has been developed to assess WAs carried out using a single side of the body. This is a limitation of the framework and it has to be extended to encompass WAs that essentially need both hands for example, driving and riding. Further, research also should be carried out to develop mechanisms to solve problems associated with employers when employing PPDs, such as the salary and identification of changes to be made to the workplaces.

When the developed framework is studied along with the aforementioned disability models, the philosophical contribution of the research seems to provide an extension to the embodied model with a strong methodological support to develop a work-related technical model to help employ PPDs in industry.

Since muscle strength is identified as an important factor to identify the physical capabilities and limitations [46], [160] and human strength capabilities change at different horizontal and vertical angles due to the interactions and orientation of the musculoskeletal system [120]. Thus, studying human strength capabilities in different work-planes is suggested. Additionally, the strength effects due to postural changes such as seated work and standing work also needed to be studied.

This research suggests only a two-dimensional framework to enhance employability of PPDs. In this research, the contribution to knowledge is certain. However, to make a wider acceptance within the society, more parameters are proposed to be added. As future work, it is suggested to study other important dimensions such as muscle strength, endurance of body regions, gender basis strength differences, influence of preferred/dominant hand or leg and cognitive behaviour of PPDs.

In the Physical capability study explained in Chapter 7, it was revealed that there are PPDs with many different types of disabilities especially in the inborn category. In order to employ them the need for a multi-dimensional model with many essential parameters as explained earlier in this chapter, has been suggested. However, the developed WARM mapping framework, has 30 WAs in upper extremity and four WAs in lower extremity. Meanwhile, this framework considers 21 main body regions/joints in the upper extremity while four in lower extremity. Moreover, for each body region/joint there are 2 -7 number of ROMs. Since this 2D model is also complex, simplification is essential for its best use. For simplification, using the science of algorithm has been suggested. In order to handle all these parameters effectively using ‘cluster analysis’ is suggested. In this light, several algorithms which have been developed for the clustering problem [166] may be helpful. K-means algorithm is very useful for handling large data sets of clustering since it’s easy implementation and fast working [167]. This type of grouping is essential to further develop the framework by adding a time measurement component. A standard data set of time for each work element may be defined for each WAs to enhance the user-friendliness of the framework.

At this stage, the terminology used in the framework is suitable only for a limited community. This restriction can be avoided by developing a visual or non-descriptive form of the WARM mapping tool for easy understanding and to enhance user-friendliness. Such visual and non-descriptive forms are used in applications such as REBA and RULA [80], [81]

Before initiating the application process, it is expected to study the effects of Standard Minute Value (WMSD) [163], [164]. However, in order to help improve the workplace accommodation to a high percentage of the industrial population with and without low back disability, sound ergonomic principles for redesigning of Manual Materials Handling (MMH) tasks are suggested [168] using ergonomic redesigning strategies, lifting, lowering, and carrying tasks can be changed for pushing and pulling tasks. For example, they suggest a well-designed cart to transfer heavy weights with forces that are acceptable to a high percentage of males and females. In the same manner, some typical manual WAs may be converted to easy tasks using ergonomic redesigning strategies and identification of these WAs is suggested to be carried out in the future.

In addition, researchers propose a wider approach of ergonomic intervention for the design of assistive technologies, including functional needs, accessibility, social acceptability [18] and workplace adjustments [7], [63] to help PWDs. Since categorisation of PPDs is possible according to the physical capability of PPDs to perform WAs using the WARM mapping framework, the necessary assistive devices can be identified for manufacturing to help PPDs. Thus, the integration of the science of ergonomics, may boost the usability of the WARM mapping framework further.

CHAPTER 9

9 Conclusion

This thesis addresses the development of a framework to increase the ability of PPDs to work in industry. Ethical clearance was granted from Medical Research Institute (MRI), Sri Lanka to carry out this study. Mainly, five major studies were carried out to develop this two-dimensional framework. The conclusions made in each of these studies lead to the ultimate result of the WARM mapping framework. The elements of the framework provide generality since this uses the same WA as stated in PMTS mapped with body regions/joints used in the orthopaedic medical field. The two-dimensional approach provided by this framework adds universality to it since all other contributions made to employ PPDs in this arena so far have been in single dimension.

Having observed that there were passive approaches to assist the employability of PPDs by adopting policies such as sheltered, subsidised, designated and supported employment, the motivation to this research came from the observation that there is a need to positively rate the performance of PPDs in defined work types in order to facilitate their employment in industry. Even though, policies have been in practice to provide for the employment of PPDs, identifying residual capabilities to perform WAs have been a problem. There was a research gap in this respect for matching their motion capability and major work elements that constitute industrial work for assessing their residual physical capability to perform certain identified WAs.

Manual work elements that the humans employ in performing work using the upper torso have been identified and validated in the study and these are in Tables 3.2, 3.3 and 3.4 while that those for lower torso are in 3.5. Body regions/joints that are used for performing industrial work have been identified and validated. These are shown in Tables 4.1 and 4.3. Thus this research fulfilled the need for the assessment of the work performance capability of PWDs by producing this research result which is the WARM mapping framework.

Sections of the WARM mapping framework developed for upper and lower extremities are shown in Figures 9.1 and 9.2 while the full-scale framework are in Figures 5.3 and 5.4.

WARM Mapping Framework - **Upper Extremity**									
Region of Deformity/Disability		Work-Activity (WA)							
		Reach				Move			
		Horizontal		Vertical		Horizontal		Vertical	
Body Region/ Joint	Ranges of Movement (RM)	Reach max	Reach min	Reach max	Reach min	Move max	Move min	Move max	Move min
Neck		Stability							
Trunk		Stability							
Shoulder (Arm)	Flexion	▨		▨		▨		▨	
	Extension					▨			
	Abduction	▨		▨		▨		▨	
	Adduction	▨		▨		▨		▨	
	Internal rotation	▨	▨	▨	▨	▨	▨	▨	▨
	External rotation	▨	▨	▨	▨	▨	▨	▨	▨
	Circumduction								
Elbow	Flexion	▨	▨	▨	▨	▨	▨	▨	▨
	Extension	▨	▨	▨	▨	▨	▨	▨	▨
Forearm	Pronation	▨	▨	▨	▨	▨	▨	▨	▨
	Supination	▨	▨	▨	▨	▨	▨	▨	▨

Figure 9.1: A section of the WARM mapping framework- upper extremity

WARM mapping framework - **Lower extremity**				
Region of deformity/disability		WA		
		Step climbing		
Body region/joint	Ranges of Movement (RM)	With one hip, knee & ankle	Both hips, knees & ankles	Step walking
Hip	Flexion	▨	▨	▨
	Extension	▨	▨	▨
	Abduction		▨	
	Adduction		▨	
	Internal rotation	▨	▨	▨
	External rotation	▨	▨	▨
	Circumduction			

Figure 9.2: A section of the WARM mapping framework- lower extremity.

The results of the usability assessment of the framework was enriched by its user-friendliness and the clarity. The comprehensive functionality assessment results showed that out of the 92 participants, 84% were capable of performing one or more WAs carried out by the upper extremity.

The developed framework was expected to be used by the practitioners who are involved in recruitment, selection for vocational training of personnel for jobs, training and retraining in industry, designing of jobs, designing and manufacturing assistive devices and wheeled-chairs for the use of PPDs and for training programmes for developers' of PPDs globally. To decide on the equipment, facilities, procedures and training for effective performance of PPDs, this framework may be used as a platform.

As further work, the framework of WARM mapping tool needs to be extended to cover both left and right sides of the body.

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Appendices

Appendix 3.1: Consent form in English language

UNIVERSITY OF MORATUWA

Consent form

Name :
Participant Identification Number : 201 / /....../.......... ./..........

Please initial box

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have 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. ☐
3. I understand that any information given by me may be used in future reports, articles or presentations by the research team. ☐
4. I understand that my name will not appear in any reports, articles or presentations. ☐
5. I agree to follow the instructions. ☐
6. I agree to allow making any measurement and tests required by the study. ☐
7. I agree to take part in the future studies. ☐

_______________	_______________	_______________
Name of Participant	Date	Signature
_______________	_______________	_______________
Researcher	Date	Signature

Appendix 3.2: Consent form Sinhala language

මොරටුව විශ්ව විද්‍යාලය

එකගතාව කායික හැකියාවල වෙනස්කම් සහිත වූවන්ගේ හැකියා අධ්‍යයනය

සහභාගිවන්නාගේ නම :

සහභාගිවන්නාගේ අනු අංකය : 201 /...../....../.........../............

අදාල කොටුවේ කතිරයක් දමන්න

1. පර්යේෂණය පිළිබඳ විස්තර සහිත "සහභාගිවන්නන් සඳහා තොරතුරු පත්‍රය කියවා/ අසා දැන/ තේරුම් ගත් බව සහතික කරමි. පර්යේෂණය පිළිබඳව තොරතුරු විමසීමට හා ප්‍රශ්න ඇසීමට ඉඩ ලද අතර ඒ සියල්ලටම පැහැදිලි උත්තර ලැබුනි. ☐

2. මේ පර්යේෂණය සඳහා මම කැමැත්තෙන්ම සහභාගි වන අතර, මට අවශ්‍ය විටෙක හේතු නොදක්වා ඉවත් විය හැකි බවත් දනිමි. ☐

3. මෙහිදී රැස් කරගන්නා කරුණු පර්යේෂක කණ්ඩායමට අවශ්‍ය පරිදි ලිපි ලේඛනවල සඳහන් කිරීමට හැකි බව මම දනිමි. ☐

4. මගේ නම කිසිම ලේඛනයක සඳහන් නොකරන බව මම දනිමි. ☐

5. මට ලබාදෙන උපදෙස් පිළිපැදීමට එකග වෙමි. ☐

6. පර්යේෂණයට අදාළ ක්‍රියාකාරකම්වල යෙදීමටත් අවශ්‍ය මිනුම් ගැනීමටත් කැමැත්ත දෙමි. ☐

7. ඉදිරි පර්යේෂණ සඳහා ද සහභාගි වීමට මම කැමැත්ත දෙමි. ☐

______________	______________	______________
සහභාගිවන්නාගේ නම	දිනය	අත්සන
______________	______________	______________
පර්යේෂකගේ නම	දිනය	අත්සන

Appendix 3.3: Demographic data form

UNIVERSITY OF MORATUWA

Demographic Information – Expert study

Participant no: 201 / ………… /………… /………… /

1	Name (if willing)			
2	Designation/ Speciality			
3	Workplace			
4	Address (Work)			
5	Qualification	1	2	3
6	Training/Country			
7	Speciality			
8	Professional Membership			
9	Experience in the position			
10	Posts held (previous)			
Please fill the following information if you would like to receive a copy of the final format of the framework				
1	Contact number			
2	E-mail address			

Appendix 6.1: Consent form in English for usability study

UNIVERSITY OF MORATUWA

Consent form - Usability study

Name :
Participant Identification Number : 201 / /....../.......... ./..........

Please initial box

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have 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. ☐
3. I understand that any information given by me may be used in future reports, articles or presentations by the research team. ☐
4. I understand that my name will not appear in any reports, articles or presentations. ☐
5. I agree to follow the instructions. ☐
6. I agree to allow making any measurement and tests required by the study. ☐
7. I agree to take part in the future studies. ☐

______________________	______________	______________
Name of Participant	Date	Signature
______________________	______________	______________
Researcher	Date	Signature

Appendix 6.2: Consent form Sinhala for usability study

මොරටුව විශ්ව විද්‍යාලය

එකඟතාව

සහභාගිවන්නාගේ නම :
සහභාගිවන්නාගේ උපන් දිනය : 201 /...../...../.........../...........

අදාළ කොටුවේ සලකුණක් දමන්න

1. [illegible] ☐

2. [illegible] ☐

3. [illegible] ☐

4. [illegible] ☐

5. [illegible] ☐

6. [illegible] ☐

7. [illegible] ☐

සහභාගිවන්නාගේ නම	දිනය	අත්සන
පරීක්ෂකගේ නම	දිනය	අත්සන

Appendix 6.3 Demographic data collection form for usability study

UNIVERSITY OF MORATUWA

Demographic Information - Usability study

Participant no: 201 / ………… /………… /………… /　　　　Date:

1	Workplace			
2	Address (Work)			
3	Qualifications			
4	Professional Memberships			
5	Designation			
6	Experience in the position (years)			
7	Previous experience			
Please fill the following information if you like.				
1	Name (if willing)			
2	Contact number			
3	E-mail address			

Appendix 6.4: Questionnaire of usability study (page 1)

UNIVERSITY OF MORATUWA

Work- Activity and Range of Movement Mapping (WARM) for People with Physical Disabilities (PPDs)

Participant No: 201 / ..../............/............

Put an 'x' in the relevant choice.

1. What do you think of the usefulness of the WARM format?

   Identify RM ☐ Identify activities ☐

   Link RM and activities ☐ No idea / can't say ☐

2. Who do you think this format is intended for?

   PPDs ☐ Employer ☐ Government ☐ Vocational trainers ☐ Other ☐ None ☐

   If other, specify ☐

3. What do you think are the purposes of this format? (Put an x in relevant boxes)

a. Select PPDs for vocational training		f. Other (if other, specify)
b. Select PPDs for recruitment/ employment		
c. Select for on-the-job training		
d. Select for re-training		
e. Design workplaces ergonomically		

4. Have you ever seen a format like this before to help recruit/employ People with Physical Disabilities (PPDs)? Yes | No

5. Please give me your initial impression about the layout of this WARM format.

   No use; unable Even to further develop ☐ Little use; can further develop ☐ Vague; need To further improve ☐ Clear; easy to understand ☐ Good; effective format ☐

6. What are the three things you like about this format?

7. What are the three things you dislike about this format?

8. If you could make one significant change to the WARM format, what would you do?

   ....

Questionnaire of usability study (page 2)

Work- Activity and Range of Movement Mapping (WARM) for People with Physical Disabilities (PPDs) (Page 2 of 2)

1. Are there data information you would like to see added to the WARM format? If so, specify.

   ……………………………………………………………………………......................

2. Would you use the WARM format on your own in the future? Why/why not?

   ……………………………………………………………………………………

3. Would you recommend the WARM format to a colleague or to a friend?

Yes	No

4. Please rate the following statements with regard to the WARM framework

No	Statement	Strongly disagree	Disagree	Moderate	Agree	Strongly agree
a.	This format has a clear purpose.					
b.	The content of this format Interests me.					
c.	This format has characteristics that makes it attractive.					
d.	The shading used throughout this format are attractive.					
e.	The typography (lettering, headings and titles) is attractive.					
f.	The format has a good balance of activities versus ROM.					
g.	I can get to information quickly.					
h.	Information is easy to read.					
i.	Information is written in a style that suits me.					
j.	Descriptions have the right amount of information.					
k.	The information is relevant to my professional needs.					
l.	This format is designed with users in mind.					
m.	This format is well-suited to first-time users.					
n.	The content makes me want to explore the format further.					

5. Do you have any other comments about this format?

……………………………………………………………………………..........................

Appendix 7.1: Covering letter for organisations for PCS

UNIVERSITY OF MORATUWA

Cover letter for organisations

To: Mr. Dinal Peiris, Head - HR department, MAS Holdings (PVT) LD.,

From: Kokila Wijewickrama Abeykoon

Subject: Request for permission for data collection – Physical capability study

Data:

Dear Sir,

As per the "Participation request" attached, we are very appreciative if you could kindly grant permission for data collection from the currently employing people with physical disabilities (physically differently abled) at MAS Holdings (PVT) Ltd. for this research. We need contact details of sub – business - units where these are employing. The signed copy of "Participation request" will be handed over to you at the first visit.

Thank you,

Kokila Wijewickrama Abeykoon

Appendix 7.2: Participation request for PCS

UNIVERSITY OF MORATUWA

Participation request - Physical capability study of differently abled people

Reference number

This research is being carried out by a team of researchers from the Department of Mechanical Engineering, Faculty of Engineering, University of Moratuwa. The aim of this study is to help people with physical disabilities (physically differently abled) to increase their ability to work efficiently in industry.

A framework will be developed by adopting work tasks and procedures according to principles of ergonomics and PMTS (Pre-determined Motion Time Systems) to suit people with disabilities enabling them to successfully carryout work tasks in industry. By facilitating their work, they can be used to effectively support the economy of the country.

Since the number of people with disabilities is in an increasing trend, employing people with physical disabilities is a global need. The task performing ability of people with physical disabilities may differ due to the disabilities themselves and their severity. However, employers may not be empowered to identify the requirements of the physically disabled to provide adequate facilities for their effective employment. Thus, employers need to be provided with necessary information to help adapt work tasks and procedures to suit people with physical disabilities for higher productivity, and thereby help increase the employability of them.

Initially, we will distribute a "Participant Information Sheet" stating general information. Then, we will conduct a short interview with them to check the suitability to stay in our study-sample. We select them if they are within the age group of 18 – 55 years and having only physical, non-developing debilitating conditions. Then, consent of participants will be obtained for the study. We will collect additional data according to a set format (attached herewith) only from those who are selected using the interview. Finally, relevant anthropometric measurements of part/ parts of body with disability will be obtained. Strength measurements and endurance times will also be recorded.

All gathered information will be kept in strict confidence. Any information indicating their identities will be removed and will not be linked to their responses. Any information they provide will be valuable for the future development of this study. The session will take 1-2 hours of their time.

Therefore, we humbly request your fullest support to successfully carryout this research study and request your kind permission to participate the people with physical disabilities currently employed in your organisation.
Thank you,

....
Signature
Kokila Wijewickrama Abeykoon (Researcher) — Date
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Appendix 7.3: The study guide in English language for PCS

UNIVERSITY OF MORATUWA

Study guide- Physical capability study

The aim of this research is to help classify people with different types of physical disabilities as a means of developing a framework using ergonomic principles and modified Pre-determined Motion Time Systems (PMTS) to increase the ability of physically disabled population to work in industry.

Initially, we will distribute a "Participant Information Sheet" stating general information. Then, we will conduct a short interview with you to check the suitability to stay in our study-sample. We select you if you are within the age group of 18-55 years and having only physical, non-developing debilitating conditions. Then consent of participants will be obtained for the study. We will collect data according to a set format (attached herewith) from those who are selected using an interview. Finally, relevant anthropometric measurements of part/parts of body with disability will be obtained. Strength measurements and endurance will also be recorded.

All gathered information will be kept in strict confidence. Any information indicating your identity will be removed and will not be linked to your responses. Any information you provide will be valuable for of this study. The session will take 1-2 hours of your time.

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Appendix 7.4: The study guide Sinhala for PCS

මොරටුව විශ්ව විද්‍යාලය

පර්යේෂණයට ඔබ පොළඹවීම : කායික ආබාධ සහිතවූවන්ගේ හැකියා අධ්‍යයනය

කායික ආබාධ සහිතවූවන් (කායික හැකියාවල වෙනස්කම් සහිත වූවන්) ගේ හැකියාවන්ට ගැලපෙන සේ රැකියාවල යෙදීමට උදවු කිරීම පර්යේෂණයේ මූලික අරමුණ වේ. 'මානව සාධක හිතාමික' සහ 'වැඩ කිරීමේ සම්බන්ධ ක්‍රමවේදයන්ට ගතවන කාල අධ්‍යයනය' සඳහා දැනට පවතින ක්‍රියාවලීන් කායික ආබාධ සහිතවූවන් රැකියාවල යෙදවීමට සුදුසු පරිදි වෙනස් කිරීමෙන් ඔවුනට සාර්ථකව වැඩ කිරීමට ඉඩ ලැබෙනු ඇත.

සලකුණුවෙන්ම පර්යේෂණයේ අරමුණු සඳහන් කර ඇති "සහභාගිවන්නන්ගේ තොරතුරු පත්‍රය" ඔබ අතට ලැබෙනු ඇත. පර්යේෂණයට සහභාගිවීමට කැමති අය කෙටි අධ්‍යයනයකින් පසුව ඉදිරි කටයුතු වලට තෝරාගනු ලැබේ. වයස අවුරුදු 18-66 ත් අතර වර්ධනය නොවන කායික ආබාධ සහිතවූවන් මේ පර්යේෂණය සඳහා තෝරා ගනු ලැබේ. පර්යේෂණයට සහභාගිවීමට කැමති බව ලිඛිතව ලබාගැනීමෙන් පසුව ඔබගේ පුද්ගලික තොරතුරු සටහන් කරගනු ලැබේ. අවසාන වශයෙන් කායික අපහසුතා ඇති අවයව සහ සන්ධි පර්යේෂණයට අදාළ පරිදි මැනගනු ඇත.

අප ලබාගන්නා සෑම තොරතුරක්ම රහස්‍යභාවය සහතික කරන අතර කිසිම ලේඛනයක ඔබගේ නම සඳහන් නොකරන බව ද සහතික කරමු. ඔබ සපයන සෑම තොරතුරක්ම මේ පර්යේෂණයට ඉතා ප්‍රයෝජනවත් වන අතර එම තොරතුරුවල රහස්‍යභාවය සහතික කරමු. මේ සියලු කටයුතු සඳහා පැය 1-2 ක කාලයක් ගතවෙනු ඇත.

කෝකිලා විජේසිංහ අබේකෝන් (පර්යේෂක) දිනය
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පර්යේෂණ අධීක්ෂණ නිලධාරී මණ්ඩලය

ආචාර්ය හිමන් පුංචිහේවා
ජ්‍යෙෂ්ඨ කථිකාචාර්ය
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Appendix 7.5: Participant information sheet in English for PCS

UNIVERSITY OF MORATUWA

Participant information sheet- Physical capability study

This study is being carried out as postgraduate research in the Department of Mechanical Engineering, Faculty of Engineering, University of Moratuwa. The aim of the study is to help people with physically disabled (physically differently abled) and employers to adapt work tasks and procedures to suit to people with physical disabilities enable them to successfully carryout work tasks in industry helping the economy.

The task performing ability of the people with physical disabilities may differ due to the disabilities themselves and their severity. However, employers may not be empowered to identify the requirements of the physically disabled to provide adequate facilities for their effective employment. Thus, employers need to be provided with necessary information to help adapt work tasks and procedures to suit people with physical disabilities for higher productivity, and thereby help increase the employability of the physically disabled.

Thank you very much for agreeing to participate in this study. You can any time withdraw from this research. The information that you give me is invaluable. You will be interviewed and your relevant body parts will be measured. The study will take approximately 1 - 2 hours. The information you give will be treated in strict confidence.

At the end of the study also please indicate whether you will be interested in participating in future studies. Please feel free to contact us at any time if you have any questions.

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Appendix 7.6: Participant information sheet Sinhala for PCS

මොරටුව විශ්ව විද්‍යාලය

පර්යේෂණයට සහභාගිවන්නන්ගේ තොරතුරු පත්‍රය: භාගික ආබාධ සහිතවූවන්ගේ හැකියා අධ්‍යයනය

මෙම පර්යේෂණය සිදු කරනුයේ මොරටුව විශ්ව විද්‍යාලයේ, ඉංජිනේරු පීඨයේ, යාන්ත්‍රික ඉංජිනේරු අංශයේ, පශ්චාත් උපාධි පර්යේෂණ කණ්ඩායමක් විසිනි. භාගික ආබාධ සහිතවූවන් රැකියාවල යෙදවීමට සුදුසු ක්‍රියාවලියක් යෝජනා කිරීම පර්යේෂණයේ මූලික අරමුණ වේ. එමගින් භාගික ආබාධ සහිතවූවන්ගේ හැකියා සඳහා ගැළපීමට ආයතන සූදානම්වීමද ඉඩ සැලසෙන අතර තමාට සුදුසු පරිසරයක වැඩ කිරීමට භාගික ආබාධ සහිත වූවන්ට ඉඩ ලබාදීමට ඉවහල් වනු ඇත.

භාගික ආබාධ සහිතවූවන් සුදුසු රැකියාවල යෙදවීමෙන් ඉහළ මට්ටමේ ඵලදායිතාවයක් ලබා ගත හැකි වන අතර රටේ ආර්ථිකය ශක්තිමත් කිරීමට භාගික ආබාධ සහිතවූවන්ට ද උදවු විය හැකිය. නමුත් ඔවුන්ගේ වැඩ කිරීමේ හැකියාවන් සඳහා ගැළපීමට ආයතන සූදානම්වීමද අසහසු නිසා ඔවුන්ට අදාළ වන ආකාරයේ රැකියා සැකසීම මෙන්ම වැඩ කිරීමට සුදුසු පරිසර නිර්මාණය කිරීමද ගැටලු සහගත වී තිබේ.

භාගික ආබාධ සහිතවූ තැනැත්තෙකු වැඩිපුර යෙදෙන ආකාරය, ඔහුගේ වැඩ කිරීමේ හැකියාව, ආබාධයේ සම්පූර්ණත්වය හා ස්වභාවය මත රඳා පවතී. එකිනෙකාට වෙනස් වන මේ හැකියාවන් ගැන අවබෝධයක් ලබා ගැනීමට මෙන්ම ඔවුන්ට ගැළපෙන [illegible] කුමන ආකාරයේ රැකියාවන්ද යන්න පිළිබඳවත් අවබෝධයක් ලබා ගැනීමට අපේ රටේ ආයතන සූදානම්වී [illegible] අවස්ථාව සැලසී තිබේදැයි යන්න ගැන සැලකිය [illegible]. මේ අනුව භාගික ආබාධ සහිත අයට මෙන්ම ආයතන සූදානම්වීමද මේ පර්යේෂණයේ ප්‍රතිඵල ප්‍රයෝජනවත් වනු ඇත.

ඔබ මේ පර්යේෂණයට සහයෝගය දැක්වීමට එකඟවීම ගැන ස්තූතිවන්ත වෙමු. ඔබට අවශ්‍ය ඕනෑම වේලාවක හේතු නොදක්වා මෙම පර්යේෂණයෙන් ඉවත් විය හැකිය. ඔබ සපයන සෑම තොරතුරක්ම මේ පර්යේෂණයට ඉතා ප්‍රයෝජනවත් වන අතර එම තොරතුරුවල රහස්‍යභාවය සහතික කරමු. මේ සඳහා කටයුතු සඳහා පැය 1 - 2 ක කාලයක් ගතවනු ඇත.

අවසාන වශයෙන් ඉදිරි පර්යේෂණ සඳහා සහභාගිවීමට ඔබ කැමති නම් ඒ ගැන සඳහන් කරන්න. මේ සම්බන්ධව ඔබට ගැටළු තිබේනම්, කරුණාකර අපගෙන් විමසන්න.

කෝකිලා විජේවික්‍රම [illegible] (පර්යේෂක)
kokila@mech.mrt.ac.lk ; 0777 574 651

දිනය

පර්යේෂණ අධීක්ෂණ කමිටුවේ සාමාජිකයන්

ආචාර්ය හිමාන් පුංචිහේවා මහතා
ජ්‍යෙෂ්ඨ කථිකාචාර්ය
himan@mech.mrt.ac.lk
0112 640 475

ආචාර්ය ජූලියන් [illegible] මහතා
ජ්‍යෙෂ්ඨ කථිකාචාර්ය
julian@kln.ac.lk
0112 914 482

Appendix 7.7: Consent form in English for PCS

UNIVERSITY OF MORATUWA

Consent form: Physical capability study

Name :
Participant Identification Number : 201 / /....../......... /..........

Please initial box

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have 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. ☐
3. I understand that any information given by me may be used in future reports, articles or presentations by the research team. ☐
4. I understand that my name will not appear in any reports, articles or presentations. ☐
5. I agree to follow the instructions. ☐
6. I agree to allow making any measurement and tests required by the study. ☐
7. I agree to take part in the future studies. ☐

____________________	____________________	____________________
Name of Participant	Date	Signature
____________________	____________________	____________________
Researcher	Date	Signature

Appendix 7.8: Consent form in Sinhala for PCS

මොරටුව විශ්ව විද්‍යාලය

එකඟතාව - කායික හැකියාවල වෙනස්කම් සහිතවූවන්ගේ හැකියා අධ්‍යයනය

සහභාගිවන්නාගේ නම :

සහභාගිවන්නාගේ අනු අංකය : 201 /...../...../.........../...........

අදාල කොටුවේ කතිරයක් දමන්න

1. පර්යේෂණය පිළිබඳ විස්තර සහිත "සහභාගිවන්නන් සඳහා තොරතුරු පත්‍රය කියවා/ අසා දැන/ තේරුම් ගත් බව සහතික කරමි. පර්යේෂණය පිළිබඳව තොරතුරු විමසීමට හා ප්‍රශ්න ඇසීමට ඉඩ ලද අතර ඒ සියල්ලටම පැහැදිලි උත්තර ලැබුණි. ☐

2. මේ පර්යේෂණය සඳහා මම කැමැත්තෙනම් සහභාගී වන අතර, මට අවශ්‍ය විටෙක හේතු නොදක්වා ඉවත් විය හැකි බවත් දනිමි. ☐

3. මෙහිදී රැස් කරගන්නා කරුණු පර්යේෂක කණ්ඩායමට අවශ්‍ය පරිදි ලිපි ලේඛනවල සඳහන් කිරීමට හැකි බව මම දනිමි. ☐

4. මගේ නම කිසිම ලේඛනයක සඳහන් නොකරන බව මම දනිමි. ☐

5. මට ලබාදෙන උපදෙස් පිළිපැදීමට එකඟ වෙමි. ☐

6. පර්යේෂණයට අදාළ ක්‍රියාකාරකම්වල යෙදීමටත් අවශ්‍ය මිනුම් ගැනීමටත් කැමැත්ත දෙමි. ☐

7. ඉදිරි පර්යේෂණ සඳහා ද සහභාගි වීමට මම කැමැත්ත දෙමි. ☐

සහභාගිවන්නාගේ නම	දිනය	අත්සන
පර්යේෂකගේ නම	දිනය	අත්සන

Appendix 7.9: Screening form for PCS

UNIVERSITY OF MORATUWA

Screening form: Physical Capability Study

Form No:	201 / / / /

1	**Age limit**	Working age		Non - working age		Remarks
2	**Type of disability**	Physical		Non physcal		Remarks
3	**Condition of disability**	Developmental		Non developmental		Remarks

Notes:

Appendix 7.10: Demographic data sheet for PCS

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Demographic information - Physical capability study

No:	

1	Name (if willing)		
2	Gender		
3	Age		
4	Height (cm)		
5	Weight (kg)		
6	Date of birth		
7	Address		
8	District		
9	Circumstance of disability	(Birth/ Accident/ War/ Other)	
10	Highest educational qualification		
11	Previous work experience	Yes	No
		Duration if yes	
12	Previous training	Yes	No
		Type if yes	
13	Current workplace and Occupation		

Appendix 7.11: Possible deformity/disability conditions in upper extremity of PCS

Deformity/disability condition (Upper extremity)

	Body part	Condition		Circumstance		Remarks
		Deformed	Missing	Congenital	Amputee	
1	Whole arm from shoulder RIGHT					
2	Whole arm from shoulder LEFT					
3	Arm above the elbow (between shoulder and elbow) RIGHT					
4	Arm above the elbow (between shoulder and elbow)LEFT					
5	Arm below the elbow (between elbow and wrist) RIGHT					
6	Arm below the elbow (between elbow and wrist) LEFT					
7	Whole hand below the wrist RIGHT					
8	Whole hand below the wrist LEFT					
9	Whole thumb RIGHT					
10	Whole thumb LEFT					
11	Tip part of thumb RIGHT					
12	Tip part of thumb LEFT					
13	Finger (index/middle/ring/pinky; single or many) RIGHT					
14	Whole finger (index/middle/ring/pinky; single or many)					
15	Tip/ part of finger RIGHT					
16	Tip/ part of finger LEFT					
17	Other					

Appendix 7.12: Possible deformity/disability conditions in lower extremity of PCS

Deformity/disability condition (Lower extremity)

	Body part	Condition		Circumstance		Remarks
		Deformed	Missing	Congenital	Amputee	
1	Whole leg from hip Left					
2	Leg above the knee (between hip and knee) Right					
3	Leg above the knee (between hip and knee) Left					
4	Leg below the knee (between knee and foot) Right					
5	Leg below the knee (between knee and foot) Left					
6	Whole foot (below ankle) RIGHT					
7	Whole foot (below ankle) LEFT					
8	Whole toe (single or combination) RIGHT					
9	Whole toe (single or combination) LEFT					
10	Tip/ part of toe RIGHT					
11	Tip/ part of toe LEFT					
12	Other					
	Notes					

Appendix 7.13: Anthropometry data of PCS

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Anthropometric data collection

No.	Disabled body part	Measurement (mm)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Appendix 7.14: Musculoskeletal functioning of PCS

Appendix 7.14: Musculoskeletal functioning 1 (page 1)

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Neck	Flexion						
	Extension						
	Abduction						
	Adduction						
	Twist						
Body part	**ROM**	**Ability**			**Angle**	**Endurance**	**Remarks**
		Limited	**No**	**Yes**			
Upper arm RIGHT	Extension						
	Abduction						
	Adduction						
	Circumduction						
	Twist						
Upper arm LEFT	Flexion						
	Extension						
	Abduction						
	Adduction						
	Circumduction						
	Twist						

Musculoskeletal functioning of PCS (page 2)

Musculoskeletal functioning 1 (page 2)

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Lower arm RIGHT	Flexion						
	Abduction						
	Adduction						
	Twist						
Lower arm LEFT	Flexion						
	Abduction						
	Adduction						
	Twist						
Body part	**ROM**	**Ability**			**Angle**	**Endurance**	**Remarks**
		Limited	**No**	**Yes**			
Wrist RIGHT	Flexion						
	Extension						
	Radial deviation						
	Ulna deviation						
Wrist LEFT	Flexion						
	Extension						
	Radial deviation						
	Ulna deviation						

Musculoskeletal functioning of PCS (page 3)

Musculoskeletal functioning 3

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Hand RIGHT	Flexion						
	Extension						
	Gliding						
	Supination						
	Pronation						
Hand LEFT	Flexion						
	Extension						
	Gliding						
	Supination						
	Pronation						

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Fingers RIGHT	Flexion						
	Extension						
	Gliding						
	Abduction						
	Adduction						
Fingers LEFT	Flexion						
	Extension						
	Gliding						
	Abduction						
	Adduction						

Musculoskeletal functioning of PCS (page 4)

Appendix 7.14: Musculoskeletal functioning 4

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Trunk	Flexion						
	Extension						
	Lateral flexion RIGHT						
	Lateral flexion LEFT						
	Dorsiflexion						

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Upper leg RIGHT	Flexion						
	Extension						
	Abduction						
	Adduction						
	Twist						
Upper leg LEFT	Flexion						
	Extension						
	Abduction						
	Adduction						
	Twist						

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Knee RIGHT	Flexion						
Knee LEFT	Flexion						

Musculoskeletal functioning of PCS (page 5)

Appendix 7.14: Musculoskeletal functioning page 5

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Ankle RIGHT	Abduction						
	Adduction						
	Plantar flexion						
	Dorsiflexion						
Ankle LEFT	Abduction						
	Adduction						
	Plantar flexion						
	Dorsiflexion						

Body part	ROM	Ability			Angle	Endurance	Remarks
		Limited	No	Yes			
Foot RIGHT	Inversion						
	Eversion						
	Plantar flexion						
	MPJ						
Foot LEFT	Inversion						
	Eversion						
	Plantar flexion						
	MPJ						

Appendix 7.15: Procedure of Ethical clearance

UNIVERSITY OF MORATUWA

Procedures of ethical clearance and scientific evaluation

There were 04 investigators in the study where the Research Scholar was the Principal Investigator (PI) and all 03 Mentors acted other Investigators. After compiling all necessary formats, an application was lodged on to Medical Research Institute (MRI) Colombo, Sri Lanka under the registration number 36/2014 for obtaining ethical clearance, before commencing the study. Two sets of applications were sent to the Chairperson of Ethical 'Ethical clearance and scientific evaluation committee' for 'Ethical clearance' and the 'scientific evaluation' as prerequisites and the details are given below. In order to apply for ethical clearance the information on the title, duration and planned starting date of the project and budget for the full period were provided. Personal details like designations, current workplaces, academic and professional qualifications and contact details of PI and three other investigators were too enclosed. The copies of "Participant information sheet" (Appendix 7.5) and "Consent form" (Appendices 7.6 is the English version and 7.7 is its Sinhala translation) which were prepared for data collection from PPDs were also attached in English, Sinhala and Tamil languages. The questionnaire prepared to be used for data collection was also attached. Soft copies of all these documents were submitted in a compressed disk.

For scientific evaluation, another set of application was lodged, which consisted a summary of the project, detailed description of research design and data analysis, methodology, literature review and the list of references prepared according to Vancouver citation format. The original signatures of all the four (04) investigators were placed in both sets of applications as a prerequisite.

During the time of submission applications, the researcher was informed to prepare "Participant information sheet" and "Consent form" in Tamil language also since it was only prepared in English and Sinhala languages. The other comment received from MRI was to add that the participant can withdraw from the research any time in the 'Participant Information Sheet: Physical capability study', and this was too added.

It was taken 01 year to grant 'Ethical clearance and scientific evaluation' for the study and this was critically affected the commencement of the research.

Appendix 7.16: The letter granting ethical clearance

Research Committee

Medical Research Institute

Chairperson
Dr.Sunil de Alwis
- DDG (ET & R),
Ministry of Health

Secretary
Dr. Geethani Galagoda

Assistant Secretaries
Ms.Apeksha Warunavithana
Ms. Kaushalya Hewavitharana

Members
Dr.Sumith Ananda-D/MRI
Dr. Anil Samaranayake-DD/MRI
Dr. Janaki Abeynayake
Dr. Dharshan De Silva
Dr. Rajiva de Silva
Dr. Nishali Ekanayaka
Dr. Sunethra Gunasena
Dr. Priyanka Herath
Dr. Jude Jayamaha
Dr. Primali Jayasekera
Dr. Lilani Karunanayake
Dr. Malika Karunaratna
Dr. Gaya Katulanda
Ms. Kumudu Kulatunga
Dr. Dulmini Kumarasinghe
Ms.Geethani Kuruppuarachchi
Dr.Kanthi Nanayakkara
Dr.Sujatha Pathirage
Ms. Devika Perera
Dr. Ramani Karunakaran
Mr. R. Ramesh
Dr.Champika.Rathnayaka
Dr. Sagarika Samarasinghe
Dr. M. Thammitiyagodage
Dr.D.Sanath.Thuballage
Ms. W.A.S. Wijendra

31.04.2015

Director/ MRI

Project No: 36/2014

A framework developed using ergonomic principles and modified Pre-Determined Motion Time Systems (PMTS) to increase the ability of physically disabled population to work in industry

The above project was approved by the Research Committee of MRI on 07th April, 2015.

The funds are not allocated from MRI.

The researcher is expected to inform the following to the Research Committee.

1. Any deviations that you are planning to carry out during the conduct of the research for prior approval
2. Progress reports at 3 month intervals
3. Final report prior to the publication

....
Dr. Sunil De Alwis
Chairperson
DDG (ET & R), Ministry of Health

Copies – File R/C
Accountant / MRI (for necessary action)
Principal Investigator – Ms. KMW Abeykoon, Senior Lecturer, University of Moratuwa

Medical Research Institute, Danister de Silva Mawatha, P.O. Box 527, Colombo 08
Phone: 011 2696234 E mail :rc.ec.mri@gmail.com
Fax :011 2691465 Web: http://www.mri.gov.lk

Appendix 7.17: The letter granting scientific evaluation

Research Committee

Medical Research Institute

21.04.2015

Director/ MRI

Project No: 36/2014

A framework developed using ergonomic principles and modified Pre-Determined Motion Time Systems (PMTS) to increase the ability of physically disabled population to work in industry

The above project was approved by the Research Committee of MRI on 07th April, 2015.

The funds are not allocated from MRI.

The researcher is expected to inform the following to the Research Committee.

1. Any deviations that you are planning to carry out during the conduct of the research for prior approval
2. Progress reports at 3 month intervals
3. Final report prior to the publication

....
Dr. Sunil De Alwis
Chairperson
DDG (ET & R), Ministry of Health

Copies – File R/C
Accountant / MRI (for necessary action)
Principal Investigator – Ms. KMW Abeykoon, Senior Lecturer, University of Moratuwa

Medical Research Institute,
Danister de Silva Mawatha,
P.O. Box 527, Colombo 08

Phone: 011 2696234 E mail :rc.ec.mri@gmail.com
Fax :011 2691465 Web: http://www.mri.gov.lk

Appendix 7.18: The letter granting permission for data collection by DGHC

Telephone

Fax

e-mail

website) www.health.gov.lk

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சுவசிரிபாய

SUWASIRIPAYA

My No.) DGHS/Universities/2015

Your No.)

Date) 03/06/ 2015

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சுகாதாரம் மற்றும் சுதேசவைத்தியஅமைச்சு

Ministry of Health & Indigenous Medicine

Director/NHSL
Director/T.H., Kandy,
Director/CSTH, Kalubowila
Director/CNTH, Ragama,
Director/TH, Anuradhapura,
M.S., B.H. Gampaha

Data Collection – Physical capability study of differently abled people

A research has been carried out by a team of researchers from the Department of Mechanical Engineering, Faculty of Engineering, University of Moratuwa on ability of people with various physical disabilities to work in industry. The aim of this study is to help people with physical disabilities (physically differently abled) to increase their ability to suit them to successfully carryout work tasks in industry, so that they can be used to effectively support the economy of the country.

To initiate this study, researchers are expecting to collect data from the patients with physical disabilities currently being treated at government hospitals, and your institution has identified as one of the data collection centre.

As the ethical clearance has been obtained for this research from Medical Research Institute and this study would be an advantage for the employing population with physical disabilities in the country to uplift their employment effectively and to suit them with higher productivity, I hereby grant permission to conduct this research at the above medical institutions, without disturbing the patients or day today activities in the hospitals.

Therefore, please furnish your fullest support for the research team to collect the necessary data to carry out this research successfully.

Dr. P. G. Mahipala
Director General Health Service
Ministry of Health & Indigenous Medicine
385, "Suwasiripaya"
Baddegama Wimalawansa Thero Mawatha,
Colombo 10.

Dr. P. G. Mahipala
Director General of Health Services

Cc:

1. Dr. H.K. G. Punchihewa & Dr. LDJF Nanayakkara, Department of Mechanical Engineering, University of Moratuwa
2. Ms. Kokila Wijewickrama Abeykoon, Researcher

} Please make a note to keep the gathered information in strict confidence.

Sp/-

Appendix 7.19: The letter issued by Additional Director of Social Services

DEPARTMENT OF SOCIAL SERVICES

MINISTRY OF SOCIAL SERVICES, WELFARE & LIVESTOCK DEVELOPMENT

SSD/2/1/30/01

2015.08.

"WE SHALL TOGETHER BUILD A NATION OF HUMANS WITH MERIT HAPPINESS AND PRIDE"

[illegible] UM/ME/PhD/2015/2 [illegible] 2015.05.07 [illegible]

02. [illegible]

03. [illegible]

[illegible] - 0112253503 / 0716257730

[illegible] / Address

02 nd Floor, Stage II, Sethsiripaya, Battaramulla.

[illegible] / Website : www.socialservices.gov.lk

[illegible] / Telephone

[illegible] / Office : 0112187050

[illegible] / Director : 0112187040

[illegible] / Fax : 0112186276

[illegible] / E-Mail : [illegible]