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Barriers to gardening for older women and methods to overcome them

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Barriers to gardening for older women and methods to overcome them.

by

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Abstract

This thesis investigates the difficulties older women experience, to aid in the development of more suitable gardens, gardening interventions and tools, enabling older women to continue participating successfully. As women age, health and wellbeing can be improved and maintained through gardening. However, many older women have to reduce time spent on horticultural activities or modify the activities or tools used, thus reducing the positive effects of the activity. A mixed method sequential research design identifies and hones in on barriers for the older women.

To understand gardening participation among older women, an online survey was held. Through statistical analysis, older women were found to be more driven by experiential motivators than men, showing gardening has potential to serve as a sustainable means of keeping up physical activity, provided the activities can be successfully completed. A correlation between enjoyment and perceived difficulty of gardening tasks was found. Enjoyment of most tasks was high and perceived difficulty low, with moving heavy objects the least enjoyed and most difficult.

As moving heavy objects was found to often be left to others but a supporting task to other garden activities, it was further investigated. In focus groups, it was found that moving compost bags presented a clear and concrete problem for older women, along with moving potted plants and carrying and moving heavy tools. Environmental factors specific to the garden environment were mentioned frequently as providing challenges to move heavy objects across them, along with tool characteristics.

The task was further explored through observations in gardens, which were analysed using Rapid Entire Body Analysis. One of the results of this investigation was that navigating steps and height differences whilst carrying loads or manoeuvring a sack truck created situations of high musculoskeletal injury risk.

The impact of navigating steps on the older woman's body was evaluated through a biomechanical analysis using motion capture in combination with the Biomechanics of Bodies software to identify impact within specific joints whilst using different assistive movers (wheelbarrows, garden trolley,

sack truck, step climber sack truck). Increased obstacle height led to increased forces required and even with limited loads, impact in shoulder and lower back joints was high. Tools were not used in the most efficient manner and recommendations for design improvement were made for all tools.

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First and foremost, I would like to express my gratitude towards the women who participated in the studies presented in this thesis. Thank you for helping me understand your experiences and conveying your challenges with, and enthusiasm for, gardening. You have awoken an interest in gardening in me I expect will sustain.

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I dedicate this thesis to my grandmothers, who both loved their gardens.

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Chapter 1 Introduction

"If you're not hauling heavy rocks, you're pushing a wheelbarrow, toting tools, dragging the hose or whacking weeds." (Barbara Pearlman, 1999)

Gardening is a peculiar leisure activity: why do so many older people in the United Kingdom, and older women in particular, exert themselves again and again though activities that require bending, kneeling, reaching and a multitude of other postures all the while wielding heavy equipment? In a recurring battle with nature, what in these gardening activities is being enjoyed, what is being avoided and what poses problems for older women? How does this impact their bodies? And can and should gardening be made easier? These questions are investigated in this thesis. Gardening is an activity with established health and wellbeing benefits, and as the population ages in the UK, it may also provide method for reducing health care cost. As such, ensuring older women can successfully participate by removing any barriers is key. Therefore, the aim of this thesis has been to investigate the motivators to participate for older women, influences on this motivation and the challenges experienced with gardening activities, moving heavy objects in the garden in particular.

1.1 Context of research

The population is ageing. This is happening nearly all over the world, but in Western countries like the United Kingdom in particular (Cracknell 2010). The number of people aged 60 or over is expected to more than double by 2050 compared to the population of 2013 (United Nations Department of Economic and Social Affairs 2013). The life-expectancy has steadily increased for the last decades and there is no sign that life-expectancy is approaching a limit (Oeppen 2002). In the United Kingdom, it is estimated that by 2039 24.3% of the population will be over 65 years old, compared to 2014 when it was 17.7% (Office for National Statistics 2015a). Because women tend to outlive men, this older population is predominantly female (United Nations Department of Economic and Social Affairs 2013).

In the UK, the increasing number of older people has an impact on welfare spending, the NHS resources and social services expenditure whilst the proportion of the population in employment, and hence supporting the older population is decreasing (House of Commons Library 2015). Poor health will impact on wellbeing not just directly but also because it affects independence, resilience and having a role in society (Age UK 2012).

Though people live longer, these years are often lived in poor health (Hochlaf and Franklin 2009). The healthy ageing of the growing group of predominantly women is important, as healthy ageing can help to reduce pressure on the health systems (House of Commons Library 2015). Successful ageing can be defined as "the maximisation of positive (desired) outcomes and the minimisation of negative (undesired) outcomes" (Freund and Baltes 1998: 531). An active lifestyle is one of the most effective ways to maintain good health and wellbeing (King and King 2010) and it has been established that leisure gardening can positively affect physical and mental wellbeing as well as quality of life of older adults (Wang and MacMillan 2013).

There are no fixed definitions of when a person becomes an older person, though commonly the designation 'older people' in the Western countries tends to be used for people aged 60 or over (United Nations Department of Economic and Social Affairs 2013) or aged 65 and over (World Health Organisation 2002). There are two 'waves' of ageing people due to hit the UK (Office for

National Statistics 2015b). The younger group in this wave is currently in their 50s, and as such strictly speaking fall outside the common definitions of older people. However, it was decided to include them in the studies regarding motivations within this thesis as they will form in large part the ageing population of the near future. All participants for studies considering physical aspects were over 60, though this was driven by individual abilities rather than age, as ageing affects each individual in varying degrees and speed (Dionigi 2015). As such, when mentioning older people in this thesis, this should be considered within the context of the study discussed.

About 75% of Britons have a garden and 59% of those with a garden indicate they enjoy gardening a lot or a little (The Horticultural Trades Association 2011). It was found that 38% of people over the age of 65 chose gardening as the activity that gives them the most pleasure in life, making it the most enjoyed pastime for this group (Age UK 2013). Gardening becomes a significant leisure activity for older adults between 55 and 75 years old, and that this is especially true for women (Bhatti 2006). There is a clear change in people's attitudes toward gardening as they age. Whereas the younger age group of 15-24 year olds is mainly 'not keen' or 'hostile' towards gardening, this changes gradually until the 65+ age group see themselves mainly as 'very keen' or 'quite keen' gardeners (The Horticultural Trades Association 2011). Of people over 65, 33% indicate they garden at least once a week, compared to only 12% of 16-24 year olds (MINTEL 2018), and the average number of hours spent gardening increases as people get older, going up to 5.3 hours per week in the main gardening season for the people of over 65 (The Horticultural Trades Association 2011). Women's appreciation of gardening is higher than men's and women are also more likely to be interested in gardening than men, with around one in six women considering themselves a keen gardener, compared to one in eight men, though there is little difference between hours spent working in the garden between men and women (The Horticultural Trades Association 2011, MINTEL 2018). As such, gardening is an activity that a substantial portion of older women enjoy and though it may not appeal to all ageing women, ensuring those with an interest are supported and encouraged to continue or increase participation would be beneficial.

Figure 1.1: Woman gardening. Image downloaded from https://www.maxpixel.net/The-Old-Lady-Apple-Tree-Harvest-Grandma-Garden-3503684, September 2018.

This research focuses on the older female leisure gardener and the role gardening has in her life (Figure 1.1). As with any leisure activity, the voluntary nature of the activities mean only those with some interest in gardening will be motivated to undertake gardening tasks and those are therefore the ones included in the research. This is consistent with the definition of (leisure) gardeners coined by the United States Bureau of the Census (1998) and used by Ashton-Schaeffer and Constant (2006):

> *A gardener is a person who likes or enjoys working with plants. This includes any aspect of gardening, such as lawn care, house-plants, flower gardening, vegetable gardening, landscaping, bulbs, fruit trees, container gardening, raising transplants, herb garden-ing, ornamental gardening, and water gardening.*

Inherent to this definition, only those with an interest in gardening are included.

Though hard numbers on the decline in participation are not available, it has been found that for those over 75 years old, problems in looking after the garden become more pronounced due to both a decline in physical ability and changes in circumstance such as the passing of a partner (Bhatti 2006). Still, it was found that gardening activities are enjoyed by physically disabled and able-bodied women similarly (Pachana et al. 2000).

Whilst the benefits of gardening are well-known, and the intensities of the activities have largely been measured (Ainsworth et al. 2011a and several authors after), the challenges experienced by older women and the ways in which older women cope with these challenges have been touched

upon by few researchers (Bhatti 2006, Scott et al. 2015, Gross and Lane 2007). It is argued more research is needed in order to identify the factors motivating or inhibiting older women in gardening to allow older women to successfully participate and reap the benefits of horticultural leisure activities. This research therefore focuses on the older woman and her experiences with gardening, aiming to positively influence continued participation by considering both the reasons for participating and the challenges experienced.

1.2 Aims and objectives

The aim of this thesis is to investigate the motivators for older women to participate in gardening, influences on this motivation and the challenges experienced with gardening activities and use this knowledge to formulate recommendations for tool manufacturers, policy makers so that they may continue their horticultural activities more successfully as they age.

As moving heavy objects in the garden was found during the research to warrant further examination, the problems associated with moving heavy objects are investigated in detail.

To this end, focusing specifically on older women (age 50+) the objectives of the research are:

1. To explore motivation to undertake gardening as an activity.
2. To understand factors affecting motivation to garden.
3. To investigate perception of specific gardening tasks.
4. To identify specific challenges that may act as barriers to moving heavy objects in the garden.
5. To determine the impact of navigating environmental obstacles in the garden on the body.

1.3 Overview of the thesis

To investigate the overall aim, the perspective of the older woman on her gardening experience is key throughout this thesis. The thesis investigates gardening on several levels: gardening as a whole, comparison of individual gardening tasks, a detailed investigation of the gardening task of moving heavy objects and the impact of the specific challenge of navigating height obstacle in the garden (Figure 1.2).

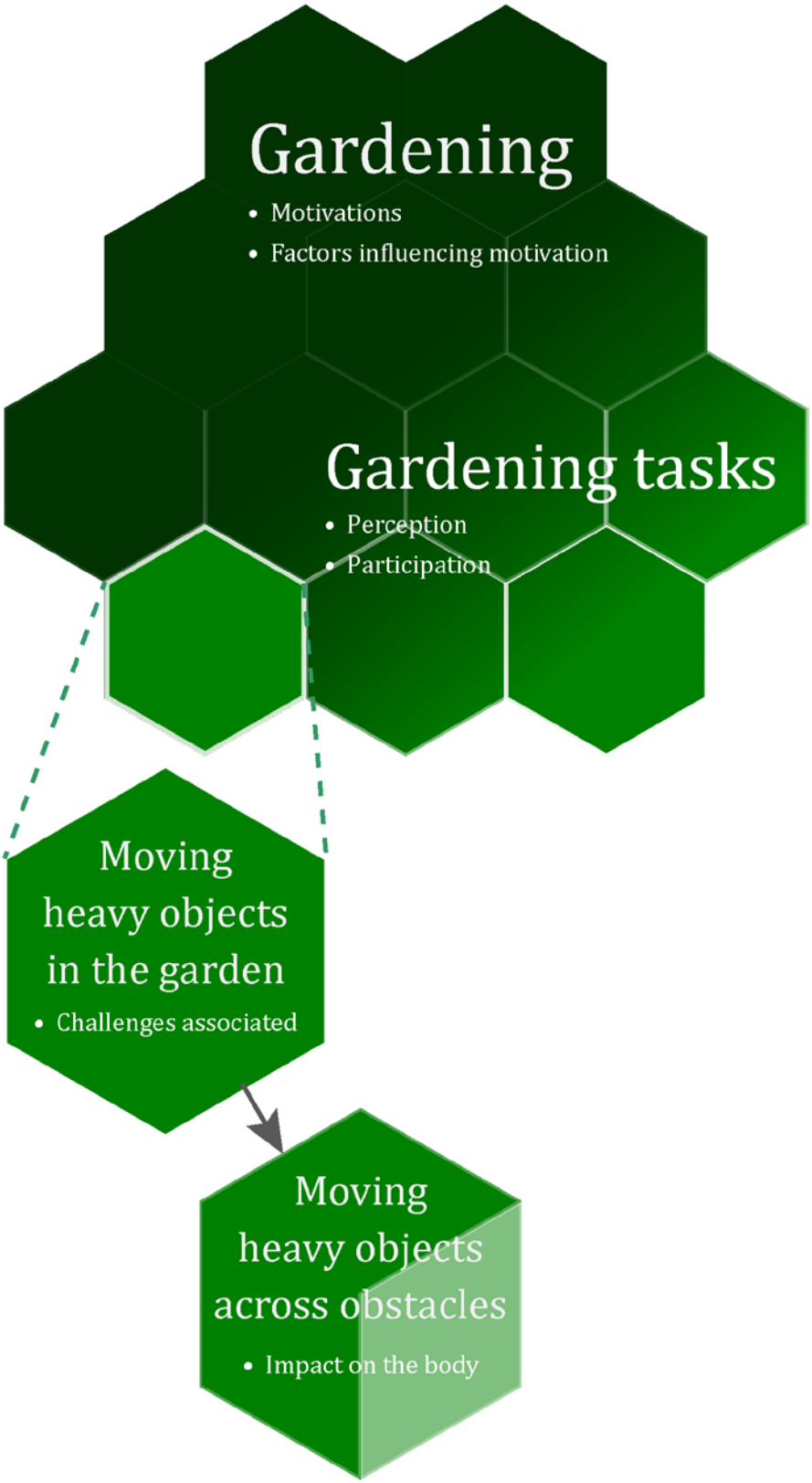

Figure 1.2: Funnel approach of the thesis, considering gardening as a whole, as a collection of tasks and directing focus towards the task of moving heavy objects, ending with a thorough analysis of moving objects across obstacles.

In **Chapter 2**, a literature review is presented on the effects of ageing on the older woman, the benefits of exercise, and in particular gardening for the older woman, and the existing knowledge on reasons and barriers to garden. Evidence for the potential of gardening as a means of exercise and green therapy for the older person was found. Other research has found gardeners in general to be mostly intrinsically motivated to participate in horticultural activities, but the specific reasons for older women to participate in gardening in the UK have not been investigated. Furthermore, barriers to gardening for older women have been neglected and as such it is unknown whether older women perceive barriers and if and how they overcome them to successfully continue gardening.

Additionally, the literature survey of Chapter 2 demonstrates that gardening in most research has been viewed as a single task and comparison of individual gardening tasks have been neglected. The research done has suggested that tasks like chopping wood, digging, mowing the lawn and pushing a large garden cart or wheelbarrow are the tasks with the highest intensity, but the perception of the older woman of gardening tasks has not been considered.

Also in Chapter 2 is an evaluation of the current state of research regarding one specific gardening task: moving heavy objects in the garden. Moving of objects has been researched primarily in industrial settings, using professional mechanical movers and men of working ages. Gaps in knowledge were identified relating to lack of inclusion of older people and older women in particular, the impact of obstacles as encountered frequently in the garden on the execution of the task and the tools used within this context.

Chapter 3 discusses the mixed-method approach applied to address the gaps identified in the literature survey. Four studies were executed sequentially, and were increasingly focused on more specific topics (Table 1.1). The order of the studies reflected the generic-to-specific format, starting with a quantitative large scale online survey, and followed subsequently by a series of focus groups, observations in older women's garden and ending with an in-depth quantitative evaluation of the specific challenges associated with moving heavy objects across height differences as commonly found in gardens. This provided validity through large participant numbers in the first two studies, and allowed for in-depth investigation in later studies. Furthermore, the different perspectives

applied in the thesis provide an all-encompassing overview of the gardening experience of older women, combining psychological, experiential and physical perspectives.

In **Chapter 4**, an online survey study is reported in which motivators and de-motivators to undertake gardening activities are explored in order to identify factors making gardening a popular pastime among this group and make recommendations on how best to avoid demotivating older women. Furthermore, comparison of gardening tasks on participation, enjoyment and perceived difficulty is made in order to identify those tasks that older women may need some form of assistance with. This resulted in a ranking of tasks based on these two parameters, with the lowest scoring task on all parameters being moving heavy objects in the garden.

Table 1.1: To achieve the objectives, research questions are answered.

Objectives	Research questions	Method
To explore motivation to undertake gardening as an activity.	What motivates older women to do gardening?	Online survey
To understand factors affecting motivation to garden.	Which factors influence whether older women are motivated to undertake gardening tasks?	
To investigate perception of specific gardening tasks.	Which gardening tasks are perceived as the most difficult and least enjoyed by older women and have the lowest participation?	
	Which factors contribute to enjoyment of gardening tasks: why are some gardening tasks enjoyed more than others?	Focus groups
	Which factors contribute to perceived difficulty of gardening tasks: why are some gardening tasks perceived as more difficult than others?	
To identify specific challenges that may act as barriers to moving heavy objects in the garden.	Which problem scenarios and associated challenges do older women identify in their experiences with moving heavy objects in the garden?	
	How do factors relating to the task, tools, person and environment impact on the ability of older women to successfully move heavy objects in their gardens?	Observations in older women's garden
To determine the impact of navigating environmental obstacles in the garden on the body.	What is the impact on the body of older women when using mechanical aids to move loads across varying height differences?	Biomechanical analysis in lab setting

In **Chapter 5**, a focus group study is discussed in which the reasons behind the differences in perception of gardening tasks are explored in more detail to clarify the results of the survey and provide more insight into the perceived challenges with gardening for older women. The problem

scenarios relating to moving heavy objects were analysed by asking participants to recollect instances of moving heavy objects in the garden and provide their perceived challenges with the activities.

Chapter 6 details observations in the garden, undertaken to analyse issues associated with performing the problem scenarios in more detail. The established REBA method (Hignett and McAtamney 2000) was applied to this garden context to identify the risk of musculoskeletal injury in these problem scenarios. The observations indicated several problems, for example with height differences in the garden and resulting steps; an external influence that makes moving in the garden different from moving in most industrial settings.

In **Chapter 7**, a biomechanics study is reported. This study was devised to evaluate systematically the impact of steps on the body whilst using a selection of different common manual movers in the garden and identify those tools and tool aspects requiring modification. The Biomechanics of Bodies software was used in conjunction with motion capture and force plate data to analyse the impact of external forces on various joints of the older woman.

Chapter 8 concludes the thesis, summarising the work, discusses key findings and contributions, providing recommendations for further work and drawing final conclusions.

1.4 Original contributions

The resulting key contributions, applicable to women over 50 in the UK are:

- An overview of the motivators to gardening, demonstrating the significance of both inner directed experience and results driven motivators, to guide development of gardening based exercise interventions with high adherence.
- A mapping of the factors affecting motivation to garden, showing that in conjunction with weather conditions, garden tool characteristics are important to older women. This finding demonstrates to tool manufacturers the significance of their products to this target group.
- A task based study of gardening, which demonstrated perception and participation in various gardening tasks varied and a link between enjoyment and perceived difficulty was

established. This knowledge may benefit those developing gardening interventions or tools.

- An overview of the particular challenges experienced during moving heavy objects in the garden which were a function of the garden environment, characteristics of the task, the tools used and personal factors. These findings may be used to ease the completion of this task through improved garden or tool design.
- A quantified biomechanical analysis of the physical impact of the task of moving heavy objects across obstacles, demonstrating high forces occurring in various joints and some inefficiency in use of the different tools. The results provide grounds for practical recommendations for improvement of assistive devices, which can be applied by tool manufacturing industry.

Chapter 2 Literature review

In an ageing population it is important for the individual and the populace to maintain a healthy society. As this ageing population is predominantly female, addressing their needs is key. It is shown in this chapter that participation in physical exercise is an effective rationale for achieving this objective, but compliance with a long term exercise regime is problematical for the section of society who would most benefit, i.e. the older women who tend to outlive men. However many older women have access to gardens, which could provide the necessary physically demanding tasks and would also provide structure. This chapter reviews research that has been undertaken into the mental and physical benefits of gardening for the older woman, the reasons for participating as well as the challenges with gardening.

2.1 The ageing female population

This section aims to outline the impact of aging and particularly on women to provide the background context to the research.

The longer a person lives, the more their body will start to show signs of ageing. Ageing is the progressive deterioration of virtually every bodily function over time (Austad 1997): the biological processes underlying ageing affect every aspect of our being: cognitive, sensory and physical, though for every individual in various degrees and speeds. This normal ageing, or primary ageing, is

the process that happens to all of us, independent of disease or trauma, whereas secondary ageing describes disabilities arising from disease or trauma (Moody 2002).

Sarcopenia is the age-related loss of muscle mass, strength and functional decline (Berger and Doherty 2010). Strength decline in lower limbs is typically 20-40% for those in their 60s and sarcopenia reportedly affects over 20% of 60- to 70- year olds (Berger and Doherty 2010). Furthermore, power (product of force and velocity) is said to reduce both faster and stronger than isometric strength (Berger and Doherty 2010) and as such, impacts on ability to do physical activities (amongst which gardening tasks) at older age. Both strength and power can be regained through exercise (Berger and Doherty 2010).

Leading causes of death are heart disease, cancer and stroke (Moody 2002), but more important to consider within the context of this thesis are those chronic illnesses that are more likely to occur in older people than younger and that reduce healthy-life expectancy. As life-expectancy has risen quickly, healthy life-expectancy has not kept up (Hochlaf and Franklin 2009); people live longer, but those extra years are often lived in poor health. The most common chronic health conditions for older persons are (in order of frequency of occurrence): arthritis, hypertension, hearing loss, heart disease, orthopaedic impairment, cataracts, diabetes, chronic sinusitis, visual impairment and cerebrovascular disease (Moody 2002). Dementia, and in particular old age related Alzheimer's disease afflicts 1 in 12 people over 65, but 1 in 3 persons over 80 and causes confusion and memory impairment initially, and incontinence, loss of speech and inability to walk by the final stages (Moody 2002).

2.1.1 The ageing woman

Life-expectancy is expected to remain higher in women than men over the next decades, though slowly narrowing to an estimated 5.8 years in developed countries in 2045-2050 (United Nations Department of Economic and Social Affairs 2013). Meanwhile, the gap between the end of healthy years and end of life for women has reportedly risen to 9.6 years, compared to 8.1 years for men (Hochlaf and Franklin 2009). This means there is a significant proportion of the older population that is female and affected by health conditions.

Arthritis affects nearly half of all persons over 65 (Moody 2002). Because of the inflammation of joints, 78% of sufferers experience pain most days (Arthritis Research UK 2017). Osteoarthritis is the most common form of arthritis, which occurs more in women than men and for which risk of development increases with age (Arthritis Research UK 2017). It occurs most in knees, followed by hips and hands.

About 25% of women over 65 develop osteoporosis (Moody 2002), a weakening of the bones, which increases likelihood of breaking and can have serious consequences (Moody 2002, Lin and Lane 2006). In gardening, there is risk of injury due to falls or handling of equipment (The Royal Society for the Prevention of Accidents 2002), which is likely to affect the older woman with osteoporosis to a greater extent.

Depressive symptoms occur in 17% of women over 65, versus 11% of men (Albert and Freedman 2010).

2.1.2 Successful ageing

Successful ageing consists of three components: survival (longevity), health (lack of disability), and life satisfaction (happiness)(Bowling 2007). To age successfully, three processes can be applied: selection, optimisation and compensation (Freund and Baltes 1998). Selection is the active or passive reduction of the number of goals to be able to focus energy towards those goals that are more important (Baltes and Lang 1997). Optimisation is the refinement of the means necessary to achieve the goals and compensation is searching for other means to achieve the goal. These processes can be applied by ageing individuals and their caretakers to access both the latent reserve it is argued older adults still possess, and the best state possible within the limitations of genetic effects (Baltes and Baltes 1993).

2.1.3 The benefits of being active

An active lifestyle is one of the most effective ways to positively influence one's health and wellbeing. For older women, an active lifestyle has been found to have numerous positive health effects. Physical activity for older women has been found to:

- Increase motor strength and gait speed (Liu and Latham 2009).
- Retain cardiovascular health (Shephard and Balady 1999, Bassuk et al. 2005, Wessel et al. 2004) and reduced cardiovascular disease risk and stroke mortality (Bijnen, Fransje C. H. et al. 1998)
- Be a precursor to decreased severity of disability through the increased motor strength associated (Rantanen et al. 1999) and increases the likelihood of dying without disability (Leveille et al. 2009).
- Reduce risk of stroke (Gillum et al. 1996).
- Maintain functional ability (Brach et al. 2003) and avoid and reduce sarcopenia (Harber et al. 2009).
- Positively influence successful completion of Activities of Daily Living for those with osteoarthritis (Penninx et al. 2001) and general frailty (Chou et al. 2012).
- Reduce pain for those with osteoarthritis (Liu and Latham 2009).
- Lower mortality rate (Sherman et al. 1994, Nicklett et al. 2012).
- Reduce incidence of falls (El-Khoury et al. 2015), which affect older women disproportionally when they occur (Stevens and Sogolow 2005).
- Provide weight loss, decreasing mortality for overweight persons (Christmas and Andersen 2000). Obesity is more likely to occur in older women than men (Public Health England n.d.)
- Improve bone mineral density (Christmas and Andersen 2000), mitigating the age related decline of bone mineral density (BMD) of the spine and walking is effective in stabilising the BMD of the hip (Bonaiuti et al. 2002). Exercise increases the effects of medications to counter osteoporosis (Lin and Lane 2006).
- Relieve symptoms of menopause: sleep quality, insomnia and depression (Sternfeld et al. 2014).

For older people in general, regular exercise decreases decline in musculoskeletal function (Galloway and Jokl 2000), delays onset of dementia and Alzheimer's disease (Larson et al. 2006, Sobow and Liberski 2006) and reduces the risk of developing metabolic syndrome, cancer,

hypertension, coronary artery disease and other chronic diseases (Roberts and Barnard 2005, U.S. Department of Health and Human Services 1996) and in many cases can actually reverse Type 2 diabetes (Boulé et al. 2001, Bassuk et al. 2005). Exercise reduces the risk of developing depression in older adults (Strawbridge et al. 2002, Taylor et al. 2004, Brosse et al. 2002), improves quality of life (U.S. Department of Health and Human Services 1996) and is associated with mental wellbeing (Lampinen et al. 2006). Long term physical activity is associated with reduced cognitive decline and improved cognitive function (Weuve 2004).

To achieve the health benefits of exercise as stated above, guidelines for physical activity have been developed for older adults. These guidelines generally state a combination of moderate intensity aerobic activities (e.g brisk walks for at least 30 min on five days of the week) (Haskell et al. 2007, Nelson et al. 2007), muscle strengthening (twice a week 8-10 exercises containing 10-15 repetitions), flexibility training (twice a week for ten minutes) and balance exercises to reduce risk of falling (Nelson et al. 2007, Cress et al. 2004).

Many people think they know the recommendations for physical activity when in fact they do not and many have unrealistic views of their own levels of activity (Chaudhury and Shelton 2010). Ashe et al. (2009) looked into leisure-time physical activity and found that only 30% of adults over 65 years old met the recommended guidelines. Furthermore, only half of people that start an exercise training programme complete it (Dishman and Buckworth 1997).

To encourage people's adherence to physical activity Chao et al. (2000) state that there is no 'one-size-fits-all recipe'. Whilst behaviour change is often characterized as merely a change in physical activity, omitting the accompanying behaviours that lead to such change, a person will have to be motivationally ready for lasting self-regulatory behaviour (Brawley et al. 2003). Chao et al. (2000: 214S) argue that 'without motivation, effort is not forthcoming'. Dacey et al. (2008) found that intrinsic enjoyment of physical activity is an important factor for older adults' adherence to the activities. It is therefore imperative to understand the factors that motivate people when wanting to design effective physical activity interventions. Gardening may provide a source of intrinsic enjoyment for many, as it becomes a significant leisure activity for older women in the UK (Bhatti 2006).

2.2 The role of gardening for health and wellbeing

As a popular leisure activity, the potential role for horticultural activities in the health and wellbeing of the ageing population has been investigated. Though existing literature on the effects of gardening activities on physical health has been limited (Nicklett et al. 2016), several health and wellbeing benefits have been identified.

Several of the more vigorous gardening tasks (e.g. lawn mowing and digging) have been classified as moderate intensity physical activities using the Metabolic Activity of Task scale (Ainsworth et al. 2011b), see also section 2.2. High-demand leisure activities like gardening are associated with higher physical health (Everard et al. 2000). In reviewing the overall evidence regarding the benefits of gardening it was found that gardening can promote overall health and quality of life, as well as physical strength, fitness and flexibility, cognitive ability and socialisation (Wang and MacMillan 2013) and in a meta-analysis the conclusion was drawn that gardening can improve public health (Soga et al. 2017).

Participants of a Master Gardener program (a program providing volunteer gardeners gardening knowledge and skills to pass onto others) were found to have increased scores on quality of life in regards to perception of social and physical activity, self-esteem and nutrition (Boyer et al. 2002). Regular gardening can help meet physical activity recommendations and additionally can aid in development and maintenance of hand strength, pinch force and overall physical health (Park et al. 2009). If undertaken correctly, gardening could contribute to both hand and body strength and flexibility through the activities that require lifting and stretching, although care should be taken to limit the loads so as not to risk injury and pain (Park and Shoemaker 2009).

Gardening can also contribute to the prevention of falls and the improvement of balance and gait speed (Chen and Janke 2012). Lifting and stretching while gardening can contribute to body strength and flexibility, and the activity can improve cardiorespiratory fitness (Park et al. 2009). Long-term regular physical activity undertaken as leisure can contribute to significantly better cognitive function and reduced cognitive decline for older women (Weuve 2004). Similarly, it was found that horticultural therapy benefitted individuals with Alzheimer's disease in that loss of

recent memory and lack of concentration was reduced (D'Andrea et al. 2008) and gardening was found to be enjoyable and stimulating for individuals with advanced Huntington's disease (Spring et al. 2014). Community gardening was found to decrease depression scores and improved level of function (Austin et al. 2006). Gardening was found to help breast cancer sufferers and gave them renewed strength to face their illness again (Unruh et al. 2000). Roberts and Barnard (2005) stress the potential benefits of combining exercise and healthy diets in warding off chronic disease, to which gardening can contribute both by doing the activity and consuming the fruits and vegetables that are grown.

Though some argue against any form of 'green therapy' (Fitzpatrick 2006), some benefits have been found associated with contact with or presence in nature. Viewing pictures of nature can improve cognitive functioning (Berman et al. 2008). Presence of natural elements within the view from a window increases neighbourhood satisfaction and aspects of sense of wellbeing compared to built elements (Kaplan 2001). Having a window view of a natural setting rather than urban has positive influence on speed of recovery (Ulrich 1984, Ulrich et al. 1991). It was found that pleasant rural imagery whilst exercising increased self-esteem whilst unpleasant rural imagery produced a negative effect on three measures of mood (Pretty et al. 2005). Experience in natural environments can both mitigate stress and aid in stress recovery (Kaplan 1995) and it was found that visiting a botanic garden can reduce stress levels (Kohlleppel et al. 2002). Maller et al. (2006) stress the importance of nature to health and wellbeing mainly relating to mental ill health. More broadly, in a review, leisure activities were found to benefit wellbeing of older adults (Betts Adams et al. 2011).

According to Freeman et al. (2012) gardens are important to people for physical and psychological health and wellbeing, relating to others and to connect with nature. Older gardeners obtain high levels of leisure satisfaction from gardening, mainly related to relaxation, psychological and physiological aspects (Cheng et al. 2010) and the perception of life satisfaction is higher among gardeners than non-gardeners (Sommerfeld et al. 2010). Cheng et al. also found that the deeper the level of engagement, the higher this level of satisfaction is.

The benefits of gardening for the older woman thus extend to retaining and improving physical fitness, alleviating symptoms of various ailments and psychological wellbeing. Continued or

increased participation in gardening therefore can have all aforementioned benefits to the older woman.

2.3 Motivations to garden

Whilst the advantages of an active lifestyle for both longevity and quality of life are clear, adherence to exercise programs can be difficult to achieve and despite reported benefits of exercise, activity levels of people decrease with age (Milanovic et al. 2013, Verbrugge et al. 1996, Bijnen, F. C. H. et al. 1998, Caspersen et al. 2000, Pantelić et al. 2012). This is where gardening may provide a means of sustained participation.

The benefits of gardening for older adults are clear and the role it can play in keeping the older population healthy is well-established (Section 2.1) and it is also clear many older women enjoy gardening (Section 1.1). However, understanding their motivations is imperative to ensure continued participation. The reasons behind why older people and women in particular participate in gardening are examined and gaps in this knowledge identified.

Motivation is commonly defined by the combination of beliefs, values and goals that drive a person to action or behaviour (Eccles and Wigfield 2002). As such, it is made up of a complex set of internal and external forces and processes and therefore understanding motivation has been complicated; it cannot simply be observed, however it can be inferred from behaviour. This is however not straightforward as it involves (in most cases) a combination of interacting and even contradictory needs, wants and desires. Intrinsic motivation is defined as wanting to do something for its inherent satisfactions rather than for a separable consequence, whilst extrinsic motivation is the drive when an activity is undertaken to attain a separable outcome (Ryan and Deci 2000). Dacey et al. (2008) found that an increase of intrinsic and self-determined extrinsic motivation has a positive association with increased physical activity of older adults, whilst weight management and influencing one's appearance are least likely to produce behaviour change.

Within the field of leisure motivation, no unified theory has been agreed upon to explain motivations (Webb and Karlis 2017). Perhaps due to the diverse nature of leisure activities, researchers over time have found different, though somewhat overlapping categories of

motivations contributing to overall leisure motivation. Dillard and Bates (2011) summarised and compared these motivations to their own model in an attempt to develop a unified theory. Their model comprised of four categories: escape, enhancing relationships, mastery and winning, whereby the four categories were quadrants on a dual axis system: inner versus outer directed and experience versus results driven. The escape quadrant contains motivations such as 'relaxing', 'getting away from one's busy life', but also 'intellectual stimulation' and 'enjoying nature'. Enhancing relationships includes social interactions, e.g. 'meeting new people', 'bonding with friends' and 'family activity'. Mastery relates to the effort required and contains e.g. 'becoming better at activity', 'exercising' and 'building self-confidence'. Finally, winning relates to e.g. 'pushing one's personal limits', 'competing' and 'keeping score'. Earlier research (Tinsley and Kass 1978, Rosenthal et al. 1982, Iso-Ahola 1982, Beard and Ragheb 1983, Unger and Kernan 1983, Tinsley and Eldredge 1995, Manfredo et al. 1996) was found to map fairly well to this four-quadrant theory.

In gardening, few studies have explicitly looked into motivation to participate and fewer still explicitly applied a theory of leisure motivation. In an attempt to further clarify and compare motivations to garden, the categories or factors of gardening motivation found in other research were mapped in the dual axis grid developed by Dillard and Bates (2011) (Table 2.1). As one might expect, winning was not an element of relevance in any of the studies. Although there are those that compete in growing competitions, it turns out (keen) leisure gardeners are not generally comparing and seeing whether the 'grass is greener on the other side of the fence'. Most of the research in home gardens (Wang and Glicksman investigated community gardeners) suggests limited evidence for a significant role for enhancing relationships, though some mention of people propagating plants to give to friends and family has been made (Chen et al. 2010). The results of many of the studies show that the physicality of gardening is an important aspect of gardening motivation. The aches and pains associated with gardening are thus not necessarily seen as deterrents. The results of this literature review show a strong inner directed focus for those participating in leisure gardening, whereby result of the effort is important, but the experience of doing gardening even more so.

Table 2.1: Mapping gardening motivators as found by other researchers to the four quadrant, dual axis model for leisure motivation proposed by Dillard and Bates (2011). Mapping has been done by evaluating each factor or category found onto the two axes to find corresponding factors.

		Quadrant axes directions	**Corresponding factor**
Chen et al. (2010) Taiwan, N=99, 15+	Increase positive mood	Inner directed/experience	Escape
	To improve the environment	Inner directed/result	Mastery
	As a way to spend time	Inner directed/experience	Escape
	To improve social relationships	Outer directed/experience	Enhancing relationships
	To escape from the worries of daily life	Inner directed/experience	Escape
Ashton-Shaeffer and Constant (2006) USA, N=303, 60+	Intellectual	Inner directed/results	Mastery
	Stimulus-avoidance	Inner directed/experience	Escape
	Friendship building*	Outer directed/experience	Enhancing relationships
	Social interaction*	Outer directed/experience	Enhancing relationships
	Physical fitness	Inner directed/results	Mastery
	Skill-development	Inner directed/results	Mastery
	Creativity	Inner directed/experience	Escape
Scott et al. (2015) Australia, N=324, 60+	Aesthetics with the ever changing nature on display in the gardens	Inner directed/result	Mastery
	Deep attachment and emotional bonds with the garden	Inner directed/experience	Escape
	Growing and tending to plants	Inner directed/experience	Escape
	The connection with nature	Inner directed/experience	Escape
	Homemaking	Inner directed/experience	Escape
	Pleasure	Inner directed/experience	Escape
	Produce	Inner directed/result	Mastery
	Identity relating to achievements	Inner directed/result	Mastery
	Work relating to the physical work required	Inner directed/result	Mastery
Gross and Lane (2007) UK, N=18, 18-85	Means of escape	Inner directed/experience	Escape
	Creating an aesthetic that	Inner directed/result	Mastery

	reflected one's personality both through effort and achievement		
	Connection to nature	Inner directed/experience	Escape
	Need to control or at least guide the garden's growth	Inner directed/result	Mastery
Bhatti (2009)	Cultivating the garden	Inner directed/result	Mastery
UK, N=797, ages unknown**	Cultivating the mind	Inner directed/experience	Escape
	Cultivating relationships with friends, family	Outer directed/experience	Enhancing relationships
	Cultivating the flora and fauna	Inner directed/result	Mastery
	Pleasurable or painful physical nature of the activities/stress relief	Inner directed/result	Mastery
	Literally being in touch with nature	Inner directed/experience	Escape
Wang and Glicksman (Wang and Glicksman 2013)	Mental health benefits	Inner directed/experience	Escape
USA, N=20, ages unknown, older adults**	The end product (fruits and vegetables)	Inner directed/result	Mastery
	Continuation of a past life	Inner directed/experience	Escape
	Something to do/responsibility	Inner directed/experience	Escape
	Beauty and connection to growth	Inner directed/experience	Escape
	Connecting with others	Outer directed/experience	Enhancing relationships
	Physical health	Inner directed/result	Mastery
	Learning something new	Inner directed/result	Mastery
	Helping each other out	Outer directed/experience	Enhancing relationships
Clayton (2007)	Spending time outdoors	Inner directed/experience	Escape
USA, N=126, ages unknown**	Observing nature and natural processes at work	Inner directed/experience	Escape
	Relaxation	Inner directed/experience	Escape
	Controlling the appearance of the garden	Inner directed/result	Mastery
	Exercise	Inner directed/result	Mastery
Freeman et al. (2012)	Health benefits	Inner directed/result	Mastery
	Relaxing and escaping from everyday life	Inner directed/experience	Escape

New-Zealand, N=55 households, 25+	Social participation	Outer directed/experience	Enhancing relationships
	Connection with nature	Inner directed/experience	Escape
Kiesling and Manning (2010) USA, 466, 18+	Creation of beauty	Inner directed/result	Mastery
	Engagement in a soothing hobby	Inner directed/experience	Escape
	Connecting with nature	Inner directed/experience	Escape
	Food production	Inner directed/result	Mastery
	Exercise	Inner directed/result	Mastery

* Friendship building and social interaction were found to be the least significant components to gardening motivation (Ashton-Shaeffer and Constant 2006).

** Ages were not reported.

These results point to a real potential for gardening as a means of sustainable, persistent physical activity for older people; one where participants can get the benefits of exercise whilst intrinsically enjoying the activities. However, no agreement has been reached on the motivations for gardening which may be down to the different cultural backgrounds, age and gender groups investigated. For the UK, research has been limited, with none focusing specifically on the older person's motives to garden. As such, the prior research has served as input to create a survey in which motivations to garden for older women in the UK are examined.

2.4 Horticultural activities

In above sections gardening has been discussed as a single activity, and this is the manner in which it has been seen in the majority of research. However, in practice the activity of gardening consists of a large collection of tasks, whose required frequency and intensity vary depending on the flora present and the season. When someone indicates they enjoy gardening for e.g. connecting with nature or health benefits, they can be thinking about e.g. mowing the lawn, pruning the bushes or planting. It can be expected that the reasons for doing these different activities would vary: it is unlikely that the act of cutting down a branch with a motored chainsaw would be considered on the same level of being in touch with nature as having ones hands in the ground to plant. To really have an understanding of gardening, the spectrum of different activities has to be considered.

2.4.1 Gardening tasks

Few researchers have looked at the impact of gardening by considering the individual tasks. Most of this research quantifies various gardening tasks according to their intensity, as per the metabolic equivalent units (METs) of an activity. MET data related to gardening is summarised by Ainsworth et al. (2011b) for data up to 2011, data from 2011 onwards is summarised in Table 2.2. Vigorously chopping wood, digging, felling large trees, laying crushed rock or gravel and in some studies mowing the lawn, raking, shovelling, hoeing and pushing a large garden cart or wheelbarrow were found to be high intensity (MET >6) tasks, but the majority of gardening tasks were found to be medium intensity (MET 3-6). Light intensity tasks (MET <3) according to some studies were fruit or flower picking tasks, weeding, raking, planting, operating a snow blower, lawn mowing, sowing, harvesting, soil mixing, filling containers, washing produce and mulching. The context of determining the MET scores has proven determinant, with most notably the difference in tool used, e.g. a sit-on mower versus a hand-pushed type. Furthermore, age differences account for much of the variation, with older adults generally generating lower MET than younger adults and children. This is most likely due to the self-selected speed and thus intensity of working. Finally, lab versus home settings have been found to make a difference, though whether a lab setting increases or decreases METs depended on the task under investigation (Gunn et al. 2002, 2005, Withers et al. 2006).

Table 2.2: Overview of MET values reported for various gardening tasks. This table contains data from 2011 onwards, as prior data is summarised by Ainsworth et al. (2011b).

	Park et al. (2011)	**Knaggs et al. (2011)**	**Park et al. (2012)**	**Park et al. (2013)**	**Park et al. (Park et al. 2014)**	**Hawkins et al. (2015)**
N	20		17	17	15	18
Age (mean+SD)	67.3 ±2.7		66.9 ±2.7		24.7 ±1.4	
Age (range)				11-13		62-70
Gender	Mixed		Mixed	Mixed	Mixed	Mixed
METs						
Digging	4.5 ±1.2			6.6 ±1.6	6.3 ±1.2	5.7 ±1.0
Hoeing				5.3 ±0.7	4.4 ±0.8	
Fertilising	4.0 ±1.9					
Making a vegetable garden			3.7 ±0.7			
Mixing growing medium				4.3 ±0.6	3.6 ±0.5	
Planting transplants				4.3 ±0.5	3.5 ±0.5	
Raking	3.4 ±0.8	2.86 ±0.67		6.2 ±1.5	5.4 ±1.0	4.6 ±0.8
Weeding	3.4 ±0.6			5.8 ±1.1	5.0 ±0.8	4.6 ±1.0
Mulching	3.3 ±0.8			5.5 ±1.3	4.5 ±0.6	
Tying plants to stakes	3.0 ±1.0					
Planting seedlings	2.9 ±0.9					
Watering with watering can	2.8 ±0.9					
Filling and carrying plant pot (5m), planting plastic flowers		2.53 ±0.75				
Watering with hose	2.4 ±0.8			4.6 ±1.1	3.9 ±0.4	
Sowing	2.7 ±0.6			5.0 ±1.1	4.3 ±0.8	1.9 ±0.5
Harvesting	2.7 ±0.6			4.8 ±0.6	4.2 ±0.6	
Transplanting plants			2.7 ±0.5			
Propagating herb plants			2.4 ±0.5			
Mixing soil	2.4 ±0.7					3.2 ±0.5
Pruning	2.5 ±0.7					
Filling containers with soil						2.3 ±0.6
Washing harvested produce	1.7 ±0.4					

Note: Due to different populations and varying definitions of tasks, MET values for tasks are not the same.

Other comparisons on a gardening task level have related to body postures, which were observed for various gardening tasks (Park and Shoemaker 2009) and showed bending and gripping postures occurred in nearly all of the gardening tasks, and lifting as a part of nearly half of the tasks observed. Finally, gardening tasks have been compared on their ratings of perceived exertion (RPE), with most tasks investigated perceived to be moderate intensity tasks by the participants, whilst some tasks (e.g. planning garden, flower arranging and planting) received mean scores close to or lower (<8) than the resting score of the scale (7) (Park et al. 2017). The task with the highest perceived exertion was sowing seeds (15.0 ±1.2) followed by making garden plots (13.3 ±1.2), but some of the tasks with high METs (e.g. digging, mowing, raking) were not included in the study or only as part of another task.

2.4.2 Gardening tools

Aside from considering and comparing tasks, some research has evaluated a specific tool and task setting, with the aim of improving ergonomics. Some focused on the evaluation of a specific tool used within a horticultural or farming related task by professionals: arborist hand saw (Mirka et al. 2009), traditional spade (Khidiya and Bhardwaj 2010), axes (Päivinen and Heinimaa 2009), secateurs (Leppänen et al. 1998) and hand-powered pruning shears (Roquelaure et al. 2004). Others considered specific tool qualities to optimise design: handle types on several gardening tools (Rok Chang et al. 1999) or reducing muscle fatigue, ergonomics of the upper extremity and reducing vibration caused by string trimmers (Tudor 1996). Finally, two studies were found that were focused on the experiences of female (leisure) gardeners, both considering the design of gardening trowels (Zinnecker 2011, Tebben and Thomas 2004). Though these studies benefit the improvement of very particular tools and as such improve the working conditions of those using them, they do not aim to generate data that allows for the comparison across tasks.

The data regarding comparison of gardening has been very limited, and the perception of (leisure) gardeners and older women in particular towards different gardening tasks has not been investigated. It could be expected that while people thoroughly enjoy gardening, they (come to) dislike or avoid certain tasks. If these tasks then become inhibitors for older women to continue gardening, these should be addressed. With age, gardening becomes more challenging and it is

likely selection, optimisation and compensation will take place, but it is unclear which tasks this affects and how this in turn affects continued motivation. Where continued successful participation is the aim, it is imperative to understand the perception of and participation in the various different tasks. This gap is a missing link in the research in the field, as with this knowledge motivations for gardening could be narrowed to more specific tasks and thus focus could be directed to those tasks most in need of improvement. As insufficient research was found on the comparison of gardening tasks this was addressed in this thesis through an online survey study followed by focus groups, in which perception of and participation in gardening tasks among older women was evaluated.

2.5 Barriers to garden

As people age, this has various effects on their bodies (section 2.1) and consequently, on their ability to successfully do various activities. Health problems and pain have been found to be most significant barriers for older people to no longer participate in exercise (Cohen-Mansfield et al. 2003, Booth et al. 1997, Lee et al. 2008).

In addition to health problems, other potential barriers to exercise in older adults are an environment that keeps them from doing exercise or does not encourage, poor physician advice, lack of knowledge on the relation between exercise and health and whether they were active in their childhood (Schutzer 2004). The barriers can also be the motivators: deteriorating health can be a barrier to do exercise, but also a motivator: Newson and Kemps (2015) found that health concerns were also the strongest motivators for older Australians to take up exercise, showing how barriers and motivators can be intertwined within the older population (Schutzer 2004).

However, lack of motivation also proved significant for older women. It was found that 'inertia' was the main barrier to those already undertaking exercise, followed by time, health and social constraints (Lees et al. 2005). Inertia was also found to be an important barrier to those not taking part in exercise, though fears of injury or falling were even more important for this group. Those inactive older adults also had lower expectations of the benefits of exercise (Costello et al. 2011). Perceived discomfort and mood disturbances had a strong negative influence, whilst access, previous participation, perceived health and social influences were found to have strong positive

influences in a review of factors contributing to whether older people would undertake leisure-time physical activities (Dishman 1988). External barriers were mentioned mostly by those in relatively good health, and those who were married (Cohen-Mansfield et al. 2003). Even if a person has the intention of doing exercise or is already active, contemporary barriers in their environment, most clearly weather conditions but also convenience and cost, could keep them from doing so (Dishman et al. 1984).

Gardening could provide an activity that motivates and provides structure. Research on how participation in gardening and more specifically in various gardening tasks is affected by (perceived or actual) barriers has been limited, with only scattered mentions on the influence of physical difficulties, knowledge or lack of time (Bhatti 2006). According to The Royal Society for the Prevention of Accidents, 11.1% of the accidents in and around the home happen in the garden (The Royal Society for the Prevention of Accidents 2002). The tools most responsible for accidents requiring a visit to the hospital in order of descending cause of injury are lawn mowers, flower pots, secateurs or pruners, spades or shovels, electric hedgetrimmers, plant or flower tubs or troughs, shears and garden forks.

In a survey amongst older people, the majority indicated they had had to adjust or limit their gardening activities since first gardening (Scott et al. 2015). Most adjusted or limited because of an awareness that if they engaged in a similar way it could be detrimental to their physical health, and some indicated particular problems, e.g. arthritis, hip or back problems. A few participants instead stated not adjusting their activities despite health issues or discomfort, ignoring these to achieve the aim of gardening.

2.5.1 Successful ageing strategies applied to gardening

It was found that among those that adjusted or limited their gardening activities, most sought paid or voluntary help, modified the activities or limited time spent or amount of sessions (Scott et al. 2015). Some downsized, indicated planning differently and some indicated using modified tools to enable them to continue. 13% of gardeners over 65 in UK employ a paid gardener (The Horticultural Trades Association 2011), though some thought allowing another into the space one

has cultivated themselves for some time was not easy (Gross and Lane 2007). Downsizing was also mentioned as a strategy in other research (Bhatti 2006, Gross and Lane 2007). Furthermore, initiatives like the Carry on Gardening website by gardening charity Thrive give advice and practical tips on how to continue gardening through disability and old age (Thrive 2018). For some however, the garden becomes a 'lost space', where older people are confronted with their own inability to cope (Percival 2002 in Bhatti 2006) and a cause for frustration (Gross and Lane 2007, Bhatti 2006).

Both knowledge about the (perceived) barriers to gardening and the way to overcome them has been limited. It is the aim of this thesis to contribute to this knowledge and through increasing awareness of the challenges enable older women to continue gardening successfully.

2.6 Moving heavy objects in the garden: existing knowledge on the barriers associated

In the survey-based study reported in Chapter 4 it was found that moving heavy objects in the garden was perceived by older women as both the most difficult and least enjoyable task in the garden. In the sequential study design reported in this thesis, this knowledge was used in subsequent studies investigating this gardening task in detail. As such, the existing knowledge on barriers and factors of influence relating to moving heavy objects in the garden has been reviewed and it was shown that there were several gaps in the knowledge of manual lifting, pulling and pushing by older women within the garden.

Moving heavy objects in the garden falls under the category of manual materials handling. Within manual materials handling, several types of tasks are included: lifting, carrying, pushing and pulling tasks, either with or without use of mechanical aid. Mechanical aids tend to be made of a sturdy frame with a platform to support the load and have wheeled base to ease moving loads, e.g. skids, platform trucks, sack trucks and dollies (Canadian Centre for Occupational Health and Safety 1997). When using a mechanical aid, usability of this tool is described as: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO/TR 16982:2002(en) 2002). The usability of a tool is

not determined by the tool alone, but instead is dependent on the context of use. Within manual materials handling, several researchers (Mack et al. 1995, Jung et al. 2005, Todd 2005) have devised overviews of all relevant contextual factors that together determine the usability of a manual materials mover such as a sack truck (Figure 2.1). These contextual factors were grouped in similar ways by all, though the characteristics included and grouping names used varied somewhat (Table 2.3).

Within this thesis, some of the contextual factor groups received different names: environmental, tool, task and personal factors. The words 'user' and 'operator' were deemed less appropriate for the older women in the study, and replaced with 'personal'. Furthermore, 'design characteristics' or 'design factors' might cause confusion in relation to garden design. 'Tool factors' was used instead as it brought the manual movers in the same category as other gardening tools, leading to the four categories as presented in Figure 2.1.

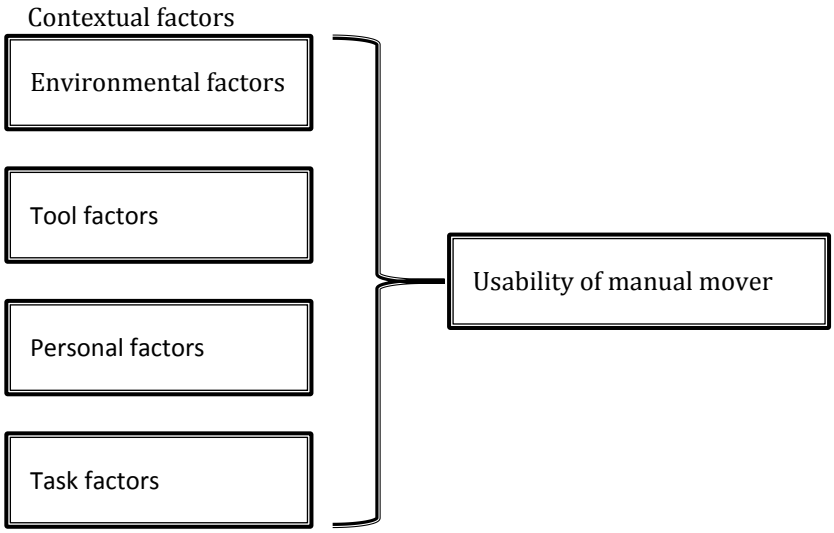

Figure 2.1: The contextual factors together determine the usability of the manual moving vehicle.

Table 2.3: Overview of factors and characteristics underlying usability of manual materials movers. The final category of performance aspects / usability contains the factors that form the output of the configuration of input based on the environmental, design, task and user characteristics.

	Mack et al. (1995)	**Jung et al. (2005)**	**Todd (Todd 2005)**
Environmental conditions / Environmental factors	Compatibility with workplace and other equipment	Floors	Surface friction
	Space available	Obstacles	Obstacles
	Obstacles	Slope, stairs, curbs	Slope, stairs, curbs
	Terrain - floor surface	Congestion	Congestion
	Surface friction	Maintenance	Maintenance
	Slopes or ramps		
	Steps, stairs		
	Maintenance condition		
	Lighting		
	Vibration		
User characteristics / operator factors	Age	Age	Age
	Sex	Gender	Gender
	Anthropometry	Anthropometry	Anthropometry
	Strength	Strength	Strength
	Training and task knowledge		Aerobic capacity
	Motivation		
Operational conditions / task factors	Frequency and duration of task	Load	Load
	Speed of work	Direction of motion	Load distribution
	Required load per trip	Motion phases	Direction of motion
	Work pressure	Frequency	Motion phases
	Availability of assistance	Distance	Frequency
	Type of load*	Speed	Distance
	Size*	Coworkers	Speed
	Weight*		
	Weight distribution (centre of gravity)*		
	Shape*		
Design characteristics / design factors	Interface (handle type, height, orientation)	Superstructure	Superstructure
	Size	Wheels	Wheels

	Weight	Handles	Handles
	Platform height and dimensions	Shelves	Shelves
	Load securing system	Brakes	Brakes
	Wheelbase	Load securing system	
	Wheel type and size		
	Castoring of wheels		
Performance aspects / usability	Forces required	Posture	Posture
	Steerability	Force requirement	Force requirement
	Stability	Physiological demand	Physiological demand
	Field of view	Psychological demand	Psychological demand
	Physiological energy demands	Efficiency	Efficiency
	Ease of loading/unloading	Steerability, stability	Steerability, stability
	Efficiency (e.g. load capacity)	Safety	Safety
	Safety		

* Mack et al. used a separate category 'Load characteristics', however for clarity these factors have been added to the operation / task factors.

2.6.1 The impact of manual materials handling for the older woman

Moving loads within the context of the garden and by the older female leisure gardener has not received any attention in research before. However, valuable lessons can be learned from research regarding moving loads in other contexts: a variety of carts can be found in industry settings. Research has been undertaken to evaluate impact on the body when using cylinder trolleys (Okunribido and Haslegrave 1999, 2003), aircraft trolleys (Glitsch et al. 2007), four-wheeled distribution centre carts and waste containers (Kuijer et al. 2007), two-wheeled waste containers (Schibye et al. 2001), medicine carts (Xu et al. 2013), catering carts (Jung et al. 2007a) and luggage trolleys (Jung et al. 2007b). Furthermore, pushing and pulling tasks have been researched in lab settings. None of the research found related to gardening, whether by professional or leisure horticulturalists. However, although in different settings, many of the same factors still apply and relevant research in other contexts is discussed.

2.6.2 Environmental factors

The garden provides an environment hardly comparable to most manual handling situations: whilst natural obstacles may occur, other factors present on factory floor do not, e.g. lighting, vibration and congestion.

Several studies considered the incline on which manual moving occurred. Moving nursing carts upwards on an incline increased muscle activation (Kao et al. 2015) and force required to push or pull an airline cart was found to increase with increased slope, exacerbated by increased weight on the trolley (Glitsch et al. 2007).

Furthermore, the ground or floor surface material was found to be influential. Postural changes were seen on floors with varying friction coefficients, i.e. trunk extension and knee flexion, suggesting participants modified the way they exerted force to cope with the change in flooring (Boocock et al. 2006). For single and two-wheeled (construction) wheelbarrows, asphalt, grass and gravel and varying load weights were compared on muscle forces required in the upper extremity, perceived exertion and hand force required (Lin 2014). Though only links between hand force required and load weight could be established, the upper extremity muscles were also negatively affected by the surface material, with grass requiring the highest muscle force and asphalt the lowest. Surface friction was also found to influence shoulder joint moment when pushing and pulling medicine carts (Xu et al. 2013).

The effect of obstacles or steps was researched only in two studies. Pulling an empty 21 kg container onto a pavement (0.13 m high) was found to generate shoulder moments comparable to or higher than starting to pull or push a loaded container (40-74 kg) (Kuijer et al. 2003), with average shoulder moments around 20-40 Nm for two different container designs. In pulling sack trucks with varying characteristics up a flight of stairs, it was found that a sack truck with the tri-star system generated the lowest peak forces, though it performed similar to the other models in average force (Young et al. 1997).

2.6.3 Tool design and loading factors

The tool variables considered related to the wheels, handles, the overall structure and the method of securing loads. The latter was not studied extensively, however in a study on medicine carts, load stability was found to significantly influence shoulder joint moments (Xu et al. 2013).

On luggage trolleys, bigger wheels were found to reduce joint contact forces (JCFs) and joint torques (JTs) in the walking direction, whilst increasing forces in the sideways direction (Jung et al. 2007b). With increasing wheel size and especially with increasing tyre size, average force required for pull a hand truck up a flight of stairs decreased, though this could not be seen for the peak force (Young et al. 1997).

A two-wheeled container design in which the wheels were not located at the very edge of the container was found to generate significantly higher shoulder moments when pulling it up onto a pavement (Kuijer et al. 2003). The location of the wheel seemed to reduce shoulder and low back moments and shoulder contact forces somewhat during level ground moving but did not impact compression forces in the low back. The addition of a fixed direction wheel to a catering cart reduced required manual forces to go around corners (Jung et al. 2007a). Harder wheels required less pushing or pulling force and the makings of the wheels itself, i.e. ball-bearings versus sleeve bearings, influenced the force required as well (Garg et al. 2014).

Handle orientation affects the maximal push/pull strength and can be a cause of awkward postures, which could make the occurrence of injury more likely. During seated push exertion, handle rotation, handle tilt and between-handle width were all found to affect radial/ulnar deviation (Young et al. 2013) and push strength (Lin et al. 2012) for bimanual pushing. Vertical handle orientation during pushing and pulling was found to decrease moments in shoulder and low back for the same manual force exertion (Chow and Dickerson 2016). However, handle orientation requiring either supination or pronation of the lower arm did not affect shoulder muscle activation (Di Domizio and Keir 2010). A handle oriented at 50° in the sagittal plane was found to produce the best postural angles in the upper extremity while pushing cylinder trolleys (Okunribido and Haslegrave 2003). Reducing effort required and retaining or increasing stability were found to create conflicting recommendations for handle design, with the advice given that adjustability for

individual users might provide the most optimal solution for different people (Okunribido and Haslegrave 1999).

Several studies have considered the optimal handle height of manual moving vehicles of different types. Handle height for pushing was found to be optimal at around elbow height and for pulling at around shoulder height (Lee et al. 1991), though others found shoulder height to be the best for both pushing and pulling (Al-Eisawi et al. 1999, Chow and Dickerson 2016). Both pushing and pulling at shoulder height was seen to generate lower back compression and shoulder moments than pulling or pushing at hip height (Hoozemans et al. 2004). In one-handed pulling, increased handle height up to shoulder level decreased the maximal pull strength and sideways pulling generated the highest pull strength, followed by front and across the front of the body (Lin et al. 2013). They did not include pulling whilst facing forward, as would be done with some sack trucks and luggage trolleys. Handle height for pulling luggage trolleys was found to be insufficient at 110 cm for tall participants, creating larger moments in shoulder and low back than shorter participants (Jung et al. 2007b). In pulling hand trucks up a flight of stairs, no clear difference was found in average or peak force required with regards to handle height (Young et al. 1997), though in their study the handles were all between 122-151 cm.

Though for various manual moving aids recommendations can be made for the optimal wheel and handle sizes to suit different contexts, the isolated evaluation of wheels or handles rather than whole tools means that comparison between different types of tools is hard to make. As such, it is impossible based on the information available to identify the optimal tool to use in the garden environment, by the older woman. More research is required to identify the tool best suited to aid the older woman in moving heavy objects in her garden.

2.6.4 Task factors

It is thought that in an attempt to reduce the impact of manual lifting and carrying, pushing and pulling of industrial carts has become more widespread (Todd 2005). However, it is argued that although force required for pushing and pulling generally is lower than lifting, the use of carts does not necessarily lower the impact on the body, but instead shifts location and direction of forces

within the body (Resnick and Chaffin 1995, Woldstad and Chaffin 1994). Pushing and pulling of loads have been associated with 9-18% of cases of lower back pain (Garg et al. 2014). Furthermore, shoulder complaints have been linked to pushing and pulling (Hoozemans et al. 2002, Harkness 2003).

Push force was found to be close to horizontal for pushing at shoulder height and pushing heavier loads, whilst it was directed more downward when pushing at hip height and with lighter loads (Hoozemans et al. 2007). For pushing or pulling in the horizontal direction it was found that participants (on an instrumented rig) pushed or pulled upward when the handle was at elbow height (Hoffman et al. 2011). At different heights, the results of Hoffman et al. were less clear, but it is suggestive of a natural tendency to exert forces not necessarily in the most optimal direction when considering the cart's needed directional change, but instead an inclination of people to exert forces in a direction more suited to their own body positions.

Whether pushing or pulling is to be preferred in terms of impact on the body has been a topic of research for some time. No clear agreement existed whether overall pushing or pulling should be preferred (Garg et al. 2014). Pushing was found to generate higher manual force but lower low back and shoulder moments than pulling (Chow and Dickerson 2016). Kao et al. (2015) found that pushing required generally lower muscle activation than pulling and perceived exertion was also lower when young women were moving nursing carts. Pushing was found to generate lower lower-back loading than pulling (Lee et al. 1991). With loads of 25 and 50 kg, pushing and pulling a two-wheeled container was found to generate relatively low lower back and shoulder torques (Schibye et al. 2001). Low back compression forces were found to be higher during pulling (whilst walking forwards) than pushing. Compression force of L4-L5 during pushing and pulling of a two-wheeled container with loads 25 and 50 kg was found to be between 605-1445 N (not close to the 3400 N safe limit). Shoulder torques were up to 38Nm. The erector spinae muscles were strongly activated during both pushing and pulling of varying loads using a pallet jack, suggesting the lower back may be at risk of injury or pain (Bennett et al. 2011). It was found that people often exert forces above the recommended limit, not in the optimal way when pushing or pulling carts, and thus that the

reduction of force that is expected from a manual handling device may not be provided (Woldstad and Chaffin 1994).

One-handed pulling was found to require high levels of muscle activation in the shoulders, thus suggesting the shoulders as a risk for injury or fatigue (Bennett et al. 2011). Single-handed pushing as opposed to bimanual pushing resulted in higher vertical torque and if combined with asymmetrical foot stance of the opposite foot forward the effect is more profound (Lee and Aruin 2015).

Cart and load weight for pushing and pulling have an effect on the hand forces (Al-Eisawi et al. 1999), the loads in the joints (Hoozemans et al. 2004) and the shoulders (Jung et al. 2007b) and lower back in particular (Lett and McGill 2006). Pushing heavy loaded carts (>225 kg) horizontally lead to low back compression forces over the recommended limit of 3.4 kN (Resnick and Chaffin 1995). With heavier loads, the upper body has been seen to deliver the bulk of the additional force required (Bennett et al. 2011). Higher loads required higher manual force when pulling sack trucks onto steps (Young et al. 1997). The relationship between weight and force required is expected to be strongly present when moving loads onto steps or across obstacles, as the vertical displacement requires the person to lift (part of) the load, whilst in horizontal pulling or pushing this is not the case.

Though some older women employ a paid gardener (The Horticultural Trades Association 2011, Scott et al. 2015), many older women are expected to move the heavy items by themselves when help is not around. Though it is clear that weight of the load and method of moving matter in terms of the impact on the body and effort required, lack of research with older women makes it unclear which loads they are able to move and in which manner they can best move these.

2.6.5 Personal factors

As the final component forming the context of usability of manual movers, personal factors are of significance and the existing research regarding the influence of personal factors is discussed. Personal factors such as experience, gender, bodyweight and age were part of some of the studies. Women's pulling strength was found to be approximately 70% of men's (Lin et al. 2013). For

women the safe limits for lifting, carrying, pushing and pulling are lower than for men (Liberty Mutual Insurance 2012).

It was found that higher bodyweight increased lower-back loadings for both pushing and pulling, but more for pulling than for pushing (Lee et al. 1991). Difference in technique was found to influence the muscles in the upper extremity and the shoulders more than muscles in the lower part of the body (Bennett et al. 2011). Bennett et al. (2011) recommend changing strategies might reduce overall chance of fatigue or injury in a workplace setting where repetition and duration are important factors to consider.

Although lifting and carrying capabilities were not seen to decrease significantly with age, reduction in isokinetic and isometric strengths mean that for older women lifting should be undertaken with caution (Wright and Mital 1999a, Mital et al. 2000). Interestingly, though in general strength is found to decline with age, older participants sometimes outperformed younger groups in pulling exercises (Lin et al. 2013). No explanation was found for this phenomenon. However, experience was found to significantly reduce spinal compression and shearing forces for pushing and pulling (Lett and McGill 2006). Perhaps the older person knows their strengths and limitations better than the younger person and as such is better at approaching this limit.

Age and gender have an impact on lifting, carrying and pushing and pulling capacity of an individual, experience may negate some of this impact. However, overall there is very little research involving older women in these types of exercises and as such more research into the capabilities of the older woman for manual materials moving is required.

2.7 Conclusions

It has been argued that gardening as a form of exercise with high adherence has the potential to play an important role in the continued health and wellbeing of the ageing woman. Encouraging continued or increased participation in gardening would therefore benefit this group. This is only possible if the barriers to gardening as women age are clear and gardens and gardening interventions are tailored to the needs and wishes of older women. The literature review has demonstrated that most gardeners seem intrinsically motivated to do gardening, but research

regarding motivations of the older women in the UK has been limited. Furthermore, barriers to gardening have not been extensively researched.

Gardening in most research has been viewed as a single task, with few researchers having compared the various gardening tasks in order to determine their impact on the older woman and none having considered perception of gardening tasks. This knowledge is needed to identify those tasks that cause problems for the older woman, so that efforts can be made to improve the older woman's gardening experience.

Moving heavy objects in the garden is one task further investigated within this thesis. Several factors influence usability of a manual mover within this task, and for each of these factors, gaps were identified, as there has been limited research regarding older women, obstacles as encountered in the garden and the tools used for moving in the garden. More knowledge on the combination of these factors would benefit in the (re)design of appropriate tools, taking into account the scenarios in which these tools are used.

To address the aforementioned deficiencies of knowledge, several studies will be required, as these questions require various methods of investigation and this research, together with the sequitur conclusions will form the basis of this thesis.

Chapter 3 Methodology

Having identified a lack of research exploring the motivators and challenges to gardening, this research aims to take inventory of the challenges and to understand the motivations for older women to participate in horticultural activities, in order to provide recommendations to ensure continued successful participation. This is achieved through a mixed methods approach outlined that involves both qualitative and quantitative data gathering and a range of methods in a structured methodology to identify the challenges from the broad collection of tasks that gardening comprises to a focus on the specific and practical challenges of moving heavy objects within the garden environment. The methods included are an online survey, focus groups, observations in the garden and a biomechanical analysis of moving heavy objects across height differences.

3.1 Research philosophy

The focus of the research is on the experience of the older woman; her perspective on gardening. The literature survey demonstrated older women have had a limited voice in bringing across their opinions. Therefore the research seeks to explore experience and perceptions in order to identify where gardening can be improved to enable women to successfully continue participating as they get older. A pragmatists' perspective is applied: this allows for flexibility in views and theories and is concerned more with applicable outcome rather than absolute truth. Pragmatists believe that truth is relative: what seems truth today might be false tomorrow and definite truth might be a final

opinion, at the end of time, but until then absolute truth is not the goal; the provisional truth we can obtain right now is what matters (Creswell 2003). This principle applies to the research; the perception of the older woman on the gardening experience may not concur with the measurable facts, but their truth is considered equally or even more important than objective measurement.

To investigate the experience of older women with gardening, a mixed methods approach was deemed the most suitable as it allowed the experience to be investigated in the most applicable ways for each objective. Through the application of mixed methods, research approaches are *"[…] mixed in ways that offer the best opportunities for answering important research questions"* (Johnson and Onwuegbuzie 1990). In the case of this research, application of mixed methods enabled the gardening experience to be investigated on both broad and detailed levels, through application of an online survey, focus groups, observations and a biomechanical analysis sequentially.

3.2 Research approach

As this research makes use of a mixed methods approach, driven by the pragmatist nature of the design research, a combination of inductive and deductive related methods (Walsh and Wigens 2003) are used throughout the research. The studies centre on establishing what inhibits older women in their leisure gardening and the findings lead to recommendations for change to take away barriers in their horticultural experience. The approach therefore was largely inductive for the first phases of the research, whereby the studies were used to identify and narrow down problems with the gardening experiences. The final study used a deductive approach; the problem was clearly defined, and the biomechanics study was used to establish the influence of several known variables.

3.3 Research strategy

A pragmatic research strategy was chosen for this research and with that, a mixed methods approach was most appropriate. Mixed methods allows for each research question to be investigated in the way that is most suited to that question, rather than experiencing the limitations in choice given by explicitly committing to purely qualitative or quantitative research strategies (Creswell 2003). Johnson and Onwuegbuzie argue: *"By utilizing quantitative and qualitative*

techniques within the same framework, mixed methods research can incorporate the strengths of both methodologies" (Johnson and Onwuegbuzie 1990: 23). Henwood and Pidgeon emphasize that "the researcher should always bear in mind that methods are not so much valid in and of themselves, but rather will be more or less useful for particular research purposes" (Henwood and Pidgeon 1993: 17).

3.4 Research design

To take into account the different levels of challenges older women can experience with gardening, a converging perspective was applied, in which different methods of research are combined to explore user's needs from different sides (Sanders 1992). Within this research, the combination of what people say and what they do was used to obtain a more all-encompassing perspective of the needs of older women (Olsen and Welo 2011).

Within the research, the results of each study informed the following studies; a sequential research design, through which a deeper understanding of the barriers to gardening experienced by older women was obtained (Table 3.1). Furthermore, rather than capturing a change or development of a target group or variable over time in a longitudinal study (Bryman 2005), a cross-sectional research design was applied to create an overview of problems occurring currently.

To narrow down the problems with horticultural activities for older women, the research design incorporated a broad to focused study design; the research started with a survey to establish the main tasks in need of improvement and discover any significant differences between the target group and other groups in relation to their reasons and motivators for gardening. In a sequential explanatory strategy (Creswell 2009, Robson and McCartan 2016), the following qualitative studies were informed by the initial quantitative study. In focus groups, the next step was to delve deeper into the gardening task considered the least enjoyed and most difficult: moving heavy objects in the garden. This exploration was done to discover the specific problem scenarios for this task as well as the main factors of significance. These problem scenarios were then observed in participants' own gardens to further investigate the factors underlying the problem scenarios. Finally, in a sequential exploratory

Table 3.1: Overview of the methods applied in the thesis.

Objective	Research method	Type of data	Analysis	No. of participants	Chapter
To explore motivation to undertake gardening as an activity.	Online survey	Quantitative	Statistical analysis	83	4
To understand factors affecting motivation to garden.					
To investigate perception of specific gardening tasks.					
To identify specific challenges that may act as barriers to moving heavy objects in the garden.	Focus group	Qualitative	Content analysis similar to Krueger and Casey (2015)	29	5
	Observation	Qualitative	Rapid Entire Body Assessment (Hignett and McAtamney 2000)	8	6
To determine the impact of navigating environmental obstacles in the garden on the body.	Biomechanics study	Quantitative	Modelling and estimation of loads in the bodies using Biomechanics of Bodies (Shippen and May 2016)	3	7

strategy (Creswell 2009, Robson and McCartan 2016), a biomechanics study was developed to test elements discovered in the qualitative phase. The specific factors found in the previous studies were isolated and relevant variables were investigated separately to discover their influence. From these studies, recommendations and requirements for tool design were extracted and summarised.

3.4.1 Study 1: Online survey of motivations to garden and comparison of gardening tasks

The initial objectives related to exploring motivations for gardening, factors affecting motivation and comparing the perception of different gardening tasks. These objectives were best addressed through an online survey as it would allow a broad range of participants to be reached (Birnbaum 2004) and comparisons could be made between groups to identify what makes older women unique to other gardeners. Through this approach large amounts of data could be collected in a flexible manner from a large population sample (Baber et al. 2013) and the practical advantages of quicker execution and availability of advanced functions (e.g. skip patterns) ensured participants

were only answering those questions relevant to them (Robson and McCartan 2016). An obvious downside is that although online participation of the population has increased rapidly since the creation of the internet (Wright 2005) the sample was limited to those with internet access. Internet usage among older adults is linked to socio-economic status, which in turn influences health status and as such, those online tend to be in somewhat better health than those that are not (Gracia and Herrero 2009). The sample thus was skewed somewhat towards healthier women of relatively higher socio-economic status. Furthermore, no (direct) explanation could be given if participants misunderstand (Birnbaum 2004, Wright 2005) and therefore the survey was piloted.

3.4.2 Study 2: Focus groups on enjoyment and difficulty of gardening tasks and exploring issues with moving heavy objects in the garden

Through the survey, the gardening task of interest had been focused to 'moving heavy objects in the garden'. To understand the problems with this gardening task and to identify the factors contributing to the problems, and to further understand differences in perception of enjoyment and difficulty of the different gardening tasks, focus groups were held. Focus groups were chosen to interpret the results of the online quantitative survey and provide depth (Stewart and Shamdasani 2014). *"Questionnaires are more appropriate for obtaining quantitative information and explaining how many people hold a certain (pre-defined) opinion; focus groups are better for exploring exactly how those opinions are constructed"* (Kitzinger 1995: 302). The advantage of applying focus groups over interviews in this research comes from the direct interaction with participants and the added insights created by the interaction between participants (Langford and McDonagh 2003, Bruseberg and McDonagh-Philp 2002, van Kleef et al. 2005). Although the interaction can result in reduced control on the contents discussed, the group setting provides the moderator with the opportunity to probe and observe non-verbal responses (Krueger and Casey 2015, Stewart and Shamdasani 2014). However the main advantage for this setting was the opportunity for participants to analyse their shared experiences (Kitzinger 1995), because the group setting allows for participants to build upon other participant's responses (Stewart and Shamdasani 2014). As the perception of the older woman was key, focus groups were the most appropriate means of obtaining their views as they can create excitement to share among the participants, can give them a sense of security that

their views are acceptable and gave participants the flexibility to answer only to those questions that they have an opinion on (Stewart and Shamdasani 2014).

3.4.3 Study 3: Observation of moving heavy objects in gardens

To observe the problems identified with the task of moving heavy objects in the garden in more detail, observation sessions in participants' own gardens were held. Because the results of the focus groups and online survey clearly pointed to moving heavy objects, but people may lack vocabulary or palate to explain what is wrong or missing in a situation (Kelley and Littman 2001), observations were seen as the most appropriate means of obtaining any information that could not be articulated by the participants. Through observations, physical problems that the older women may not have realised could be seen and thus provide real-life insight into this activity within the complex system (Baber et al. 2013, Robson and McCartan 2016). Also, whilst the research is concerned with the gardening experience from the perspective of the older woman, the objective information that could be gathered was deemed useful to contrast and combine with the findings of the focus groups and survey. The observations were used to identify risky postures during the problem scenarios, specify the situations within which problems occurred and identify the factors underlying the scenarios.

Rapid Entire Body Assessment (Hignett and McAtamney 2000) was used to identify high risk postures. There are many methods designed to analyse real life or video based participants whilst working, e.g. Quick Exposure Check (David et al. 2008) and RULA (Mcatamney and Corlett 1993), with some incorporating subjective participant evaluations and others being suitable for evaluating part of the body only or for static situations (Takala et al. 2010). Some also focus more on repetition, which makes them suitable for working situations but less so for the infrequently occurring tasks relating to moving heavy objects. REBA is suitable for dynamic and changing postures, incorporates the whole body in the review and is easy to use on video data, as it does not require precise measurements of postural angles and forces, but instead scores points for postures within ranges. It is not as precise as other methods might be, but it is practical and does not require interference with behaviour of participants during a trial nor does it require participant evaluations and as such was deemed the most appropriate for this research.

3.4.4 Study 4: Biomechanical analysis of loads on the body when moving heavy objects over steps

As found in the focus groups and observations, one of the issues with moving heavy objects in the garden relates to the garden environment: the occurrence of steps or other height differences in many participants' gardens or on the way to their gardens. To identify the influence of obstacle height and use of different assistive devices, a lab-based biomechanics study was conducted. The impact on the body was seen as the best objective measure to test this. Motion capture allows for the digitisation of movement and the subsequent data can be combined with force sensor data to estimate forces occurring in various parts of the body and thus was seen as the most appropriate method of assessing the impact on the body of the older woman. Motion capture has been used in previous research to evaluate postural deviations (Nissen et al. 2007), estimate muscle forces (Erdemir et al. 2007) and musculoskeletal loading (Shippen and May 2010). In horticultural setting, the method has been applied to evaluate the impact of digging with a good versus bad technique (as classified by a team of horticulturalists and physiotherapists) (Shippen et al. 2017), however it had not been applied to this setting before and was used to quantify and compare impact of obstacle height and different tools on the older woman's body.

3.5 Validity and reliability

Whilst certain disciplines have clear rules to determine validity and reliability, this has proven challenging when applying mixed methods (Kanis 2014, Vink 2014, Hignett and Stanton 2014, Kanis et al. 2014). Triangulation, though often used, is met with hesitation in regards to increasing validity of findings as combinations of inappropriate methods do not lead to greater certainty of outcome (Kanis 2014, Hignett and Stanton 2014) and instead appropriate use of methods to accurately answer individual research questions can be preferred. The latter approach has been used in this thesis; each study explores different but related research questions, to provide an overall perspective of the experiences of gardening for older women.

3.5.1 Validity

The manner in which validation of the research has been achieved is detailed below. From the types of legitimation of mixed method research that have been distinguished according to Onwuegbuzie and Johnson (2006), those applicable to this research are discussed: sample integration, inside-outside, weakness minimisation, conversion, and multiple validities.

To check the **sample integration** (the extent to which samples of the qualitative and quantitative studies match and as such the findings are comparable) between the survey and the focus groups, participants within the focus groups were asked to check whether they would change anything about the order for the enjoyment and difficulty task ordering as resulted from the survey. Some did reorder some of the tasks but the majority agreed to the order as generated from the survey and as such, the sample integration was deemed sufficient. For both the observation study and the biomechanical analysis, participants were selected. In the case of the observations, the selection was based on their individual situations and as such they were meant to cover the relevant situations. The biomechanics participants were selected to be healthy representatives, and as such are consciously not representative of the larger target group of older female leisure gardeners in the UK.

Within this research, the researcher was not an active participant. The researcher was not part of the target group and within both qualitative studies, the position of interested novice was taken and as such, all studies were seen through the lens of an outsider. Through this approach, issues of a clashing **inside-outside** perspective, as often encountered when mixing qualitative research and quantitative research, were avoided.

Surveys have the advantage of retrieving input from larger participant groups, but the explanation of the answers is very limited and interpretation of the answers can be problematic. The focus groups were used to provide this further depth and exploration to the survey where needed. The focus groups provided a range of problem scenarios, but were limited to participant's recollection and description. The observations were used to analyse the problem scenarios and provide information that was not mentioned but could be observed. The observations were not controlled,

and the biomechanics study provided a means to control the relevant variables. In this way, the **weaknesses of the individual methods** were minimised.

To use the findings of the online survey in the focus groups, the order of tasks in terms of enjoyment and difficulty was presented to the participants by spacing them on an A3. Though this **conversion of data** made the data easy to understand, it was not an entirely accurate depiction of the findings as participants in the survey were not asked to rank the tasks but instead score each individual task. As such, there is a discrepancy between the way in which the survey compared tasks to the way in which this was done in the focus groups. As the research questions asked differed this was not seen as problematic.

Multiple validities legitimation relates to the validation of individual qualitative and quantitative methods used; each method should conform to the validity standards for their type of method. Four aspects of validity that apply to both qualitative and quantitative research are construct validity, internal validity, external validity and reliability (Yin 2013, Robson and McCartan 2016).

Construct validity comes from the application of appropriate measures for the research questions. For the survey, this was sought through the use of metrics similar to other, validated research metrics. For the focus groups, asking questions that would logically lead to the answers to the research questions provided face validity. The observations were an extension of the focus groups by seeing the problem scenarios in real life settings. Though the aim was to see all chosen problem scenarios in the observations, not all participants were willing or able to demonstrate them. As such, the observations that were seen have face validity, but they did not include all relevant problem scenarios. The biomechanics study made use of standardised methods for the retrieval of the motion capture data and the analysis.

Internal validity is achieved when the outcome is demonstrably caused by the intervention or when various threats have not been an influence on the outcome (Robson and McCartan 2016). Gardening is a seasonal activity. This somewhat influenced internal validity for the focus groups, observations and likely the survey, as the answers to which tasks are considered difficult or enjoyable likely vary with these tasks have been performed; during the focus groups one participant mentioned doing a lot of watering around that time of the year and also thought

watering was very relevant task to focus the research on. Furthermore, during the observations one of the participant's gardens was full of autumn leaves and she was preoccupied with clearing those away. Although the overall score of tasks might have changed somewhat for the survey if it had been conducted in the autumn or winter, the task of moving heavy objects is unlikely to not be considered the least enjoyable or difficult, as it is required as a supporting task to other horticultural activities. Although there was a limitation in relation to using relatively healthy participants compared to the general target users no threats to internal validity were identified for the biomechanical study.

External validity relates to the generalizability of findings beyond the boundaries of a study (Bryman 2005). Issues relating to participant sampling are discussed in section 3.6. In spite of these issues, it is asserted that the results are reasonably generalizable to the larger group of older female leisure gardeners in the UK. Physical aspects of ageing are various and the participants included in the studies have had different abilities and difficulties. Gardens across the UK are various too, but a variety of gardens was included in the observations.

3.5.2 Reliability

Temporal reliability is limited to the context of the current state of product design, gardens and medical advances. The methods have all been applied meticulously, and some additional measures were taken to increase inter and intra researcher reliability of findings. In the focus group sessions an assisting researcher was present to take notes. In the observations, a second analyst evaluated the postures based on the video data and both researchers re-evaluated the data weeks later to check for inter and intra-researcher reliability. During the motion capture sessions, one additional researcher was present to check the accuracy of measurement and another to check the quality of recording as the session went along.

3.6 Participant sampling

The focus of this research was on the ageing population. This ageing is mainly caused by both the generations born post World War Two and the baby boom of the 1960s (Office for National Statistics 2014). At the time of writing, the first group is reaching their late sixties. The second

group reaches retirement age in about ten to fifteen years. This meant that the research is focused on a group that has not yet experienced much of life after retirement. Two approaches were considered to deal with this problem: include current older adults or include the group that will be the older adults in the future. With the first, an issue could be that there are relevant generational differences with later generations, whereas with the other, an issue could be that they will have to think of what their future self might want and need, leading to theoretical scenarios that might not happen as expected. The logical solution for this was to combine the two, so that the input of the current generation regarding ageing and the future generation regarding their views was taken up. Therefore, the target group throughout the research was female gardeners of 50+ years old.

To reach the target population for the online survey it was advertised to leisure gardeners through the monthly RHS gardening magazine The Garden, online gardening forums and the RHS twitter feed. This multi-outlet approach was chosen because different groups of gardeners were expected to frequent different sources of information and participants in the whole of the UK could be reached. Online surveys are inherently only suitable for those with an active internet connection and as such those without internet access were not included. Internet activity and horticultural interest were not expected to correlate, and as such the bias induced by excluding those without internet was expected to be very small. There is a self-selection bias in survey studies (Wright 2005), and thus a sample is always biased with those eager to join. Motivation to participate in a survey on gardening will likely only be present in keen gardeners, whilst less keen gardeners may not be willing to join. Because part of the survey related to motivation for gardening, it was expected that this motivation was therefore somewhat biased towards those more interested in gardening. The task selection was not expected to be affected by this bias to the same degree, as tasks enjoyed and considered difficult were not expected to correlate with motivation to participate in a survey on gardening experience.

To reach the target group for the focus groups, several channels of contact were used, among which three gardening organisations and five non-gardening related events or organisations. From the potential participants gathered initially, snowball recruiting led to several additional potential participants. Potential bias in the selection of participants was reduced by including non-gardening

organisations; through gardening organisations it would be expected only very keen gardeners would be reached, whilst through non-gardening organisations less keen gardeners were also included. All participants were residents in the West Midlands, which may mean they encountered different climate, soil and terrain than other older women in the rest of the UK. The terrain was expected to impact on the individual experience of moving heavy objects in the garden. The participants were therefore asked to describe their gardens and variety was great (e.g. steep versus flat, types of surfaces, presence of steps). Though not representative of every garden encountered in the UK, it is expected the overall bias of local participants was limited.

Participants were handpicked from the focus group participants to represent a variety of garden environments, those that had presented very specific problem scenarios and two participants that during the focus group sessions had appeared to be lead users; those that see problems with existing solutions and thus come up with their own solutions (Steen et al. 2007). The focus groups were used as a selection pool, through which the participants most of interest were selected. The bias of such an approach is obvious; the same participants are re-used, thus reaffirming any data given in focus groups instead of being a source of triangulation. However, the aim of these observation sessions was to see some of the more extreme situations first hand and to identify the postures contributing to these situations. As such the goal was not to see other, alternative problems, but instead specify the problems more. The benefit of this approach was that the researcher knew prior to the sessions approximately what would be seen and the observations were targeted to these scenarios or environments.

For the biomechanics study, participants were contacted from the list of interested potential participants generated ahead of the focus group sessions. Participants were emailed and those interested were evaluated for suitability based on their physical health using the PHQ-15 (Kroenke et al. 2002). Those that that identified no chronic ailments other than mild arthritis were selected. With age a variety of physical problems can occur, and selection was driven by health and safety; risk of physical harm should be reduced as much as possible. Potential bias with this approach is that the women were likely in better shape than the overall population of older female leisure gardeners. Less physically fit members of the target group might have had more trouble moving the

tools across different obstacles and perhaps even would have been unable to. However, the potential bias of including women with various chronic diseases or injuries would have skewed data as well. Though the women were all of similar height (158-162 cm), they differed significantly in weight (41-83 kg). Though certainty about the influence of these individual factors was limited due to the small sample size, variation in technique was seen and gave indications for further research.

3.7 Ethical issues considered

Central to this research were the older women. Ethics approaches of each individual study are described in the method section of each study chapter (Chapter 4 to 7), however some overarching considerations are described here. Although to an extent every person is frail and could endure harm, this is more the case as people age. The ability to give consent and the way in which the consent is obtained are both important, as well as their safety during the study. Furthermore, data handling and anonymization (and safety after the study) should be taken into account. For every study (survey, focus groups, observations and biomechanics), ethical approval was obtained through the Coventry University process and the aforementioned factors were considered (Appendix A, Appendix B, Appendix C and Appendix D).

In regards to consent, participant information was provided prior to the studies and participants were given contact details to get in touch if they had any questions (survey) or phoned prior to the session to ask whether there were any questions and taken through the document verbally on the day of the session prior to signing (other studies). For the focus groups, the emphasis of the verbal explanation was on the use of the video and audio data, the use of their comments in publications and thesis and the anonymity or possible lack thereof when using these comments. For the observations, the increased potential lack of anonymity for participants due to gardens or participant postures being recognisable were discussed and again the use of the video and audio data in publications. For the biomechanics, the potential risks of bodily harm were emphasized and the use of the multi-media recorded data and how this was anonymised was explained.

Risk factors for the observations and biomechanics were higher than for the survey and focus groups, as for the first participants had a reasonable risk of bodily harm due to the physical nature of the activities, whilst for the survey and focus groups the only potential harm identified was from the content of the questions or discussions upsetting the participants. As these studies were about leisure horticulture, the overall risk of emotional distress was seen as small. However, it was considered that discussions on reduced capabilities or failing to complete tasks might upset the participants. The discussions started with positive questions relating to enjoyment and finished on constructive questions relating to changing problem scenarios to improve them. No participants were visibly upset in any of the focus group sessions.

During the observations, priority was given to the prevention of bodily harm of the participants, at the cost of the research findings. Participants were not forced to demonstrate the problem scenarios they had offered up in focus groups and this meant not all participants ended up showing all their problem scenarios, with some merely describing on scene or gesturing how they would execute or fail to execute a task. Because of the potential frailty of the older women, there was no way around this; their safety was paramount.

During the biomechanics study, participants were asked repeatedly throughout the study and in different ways to indicate whether they wanted a break, a drink or to seize participation, or whether they felt any pain. Though sessions should not go on too long with an older target group, abundant time was pencilled into the schedule to allow for additional breaks if needed.

Participants in the focus groups and biomechanics studies were compensated for their time and the travel costs, but not given any other incentive to avoid coercion or pressured overexertion during the physical studies (observations and biomechanics). The compensations were given at the start of the session to avoid participants continuing participation when no longer wanting or able to.

The consent forms and other identifying data was stored in a lockable cupboard in a restricted access room. The digital data was kept on a password protected laptop and stored on OneDrive, the approved cloud storage service of Coventry University. A calendar alarm has been set to destroy the personal identifying data (the files linking participant names to participant numbers) on 1st October 2019, if they have not been destroyed before.

3.8 Conclusions

A mixed methods research design is applied, through which an overview of the perception of gardening is established and the task found to be most critical for further consideration, moving heavy objects in the garden, is explored in detail. Through the research, several methods with established validity that were never or scarcely applied to gardening before were used to obtain answers to research questions in a layered structure from general to specific.

In the next chapter the results of an online survey on the motivations to garden and perception of gardening tasks is presented.

Chapter 4 Survey of motivations to garden and comparison of gardening tasks

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Parts of the data and analysis within this chapter are featured in:
Kolk, E., Moody, L., Shippen, J., and Alexander, P. (2016) *'Getting to the Root of the Problem: Informing Design through the Exploration of the Gardening Experience of Older Women'. in Desmet, P., Fokkinga, S., Ludden, G., Cila, N., and van Zuthem, H. (eds.) Celebration & Contemplation: Proceedings of the Tenth International Conference on Design and Emotion held 2016 in Amsterdam*

4.1 Introduction

In Chapter 2, it was established that gardening can contribute to the health and wellbeing of older women. It can provide sufficient exercise to meet the recommended level of activity for older people (Park et al. 2008) and benefits to quality of life, cognitive ability and socialisation have also been found (Wang and MacMillan 2013). Whilst adherence to exercise regimes has been problematic for older women (Chao et al. 2000), the leisurely pursuit of horticultural activities may present an opportunity as a favourite pastime for many elderly women (Sommerfeld et al. 2010).

However, if horticultural activities are to contribute to the health and wellbeing of older women, an understanding of their motivations and potential barriers is required, to ensure older women can continue this leisurely pursuit successfully. Furthermore, an understanding of the differences in their needs and preferences in comparison to other leisure gardeners is required to determine

where older women differ in what motivates them about gardening and how they perceive and participate in gardening activities. This knowledge would help focus those developing products, gardening interventions and policy makers on the tasks and attributes of gardening most important to the older woman.

In the literature review (Section 2.3) it was identified that some existing research has explored motivation of older adults to participate in gardening activities. This prior research suggested results from horticultural activities were important, but the experience of participating in gardening even more so. However, it was also established that more specific reasons varied for each study and as such, no agreement has been reached on the most important motivations for gardening as different cultural backgrounds, age and gender groups have been investigated. In the UK, the older woman's reasons for gardening have not been investigated and it is not known if and to what extent older women differ from older men or from younger women.

Furthermore, research on the external influences on motivation to participate in leisure horticultural activities was absent from the literature, and though research has been undertaken to compare physical exertion required for specific gardening tasks (Section 2.4), previous research generally considered gardening as a single activity or considered only one specific activity. Comparison of gardening tasks has thus been very limited and no research was found comparing perception of different gardening tasks for older female leisure gardeners.

This chapter outlines a survey-based study, to investigate motivation to participate in horticultural activities, influences on this motivation and a comparison of gardening tasks on enjoyment, difficulty and participation. To see the extent to which the older women present unique views, older men and younger women were included in the survey. As the end goal of the research is to enable continued or increased participation in gardening, the survey was undertaken in order to identify tasks requiring change, i.e. tasks that are considered (too) difficult, not enjoyable or are not participated in, as well as attributes of gardening that would need to be considered when developing gardening interventions, programmes or tools.

4.1.1 Research questions

The study sought to explore:

1. What motivates older women to undertake gardening activities?
2. Which factors influence whether older women undertake gardening tasks?
3. Which gardening tasks are perceived as the most difficult?
4. Which gardening tasks are least enjoyed?
5. Which gardening tasks have the lowest participation?

Older men and younger women were included in the survey to determine whether the views and perceptions of the older women were unique.

4.2 Method

An online survey was developed and run using Qualtrics online survey platform (Qualtrics 2015). The survey ran from 25 July 2015 to 1 October 2015. The online survey method was selected to enable reaching a large participant pool located throughout the UK and to provide quantitative data that would be comparable across different groups. Ethical approval for the survey was obtained through Coventry University's ethics process (project number P35136,Appendix A). All participants provided informed consent at the start of the survey.

4.2.1 Study design

The survey comprised of 34 questions. It contained 2 general demographic questions (age and gender) and 1 open text box for additional comments at the end of the survey. Other questions related to horticultural demographics (6 questions), reasons for gardening (1 question), extrinsic influences on gardening motivation (8 questions), comparison of gardening tasks (4 questions) and tool use per task (12 questions).

Horticultural demographics

Gardening related demographics were type and size of garden, persons responsible for the horticultural activities, features present in garden, time spent on horticultural activities and health conditions affecting ability to garden. The format for these questions included multiple choice with

multiple selection and single selection. If participants indicated health conditions they were asked in an open text field to specify (optional). The answers to the gardening related demographic questions were used to compare the samples of older women versus older men and younger women and help identify whether differences in motivations and influences on motivation could be traced back to differences in garden and gardener between the three participant groups.

Reasons for gardening

The reasons for participating in horticultural activities were developed based on prior research applying the Leisure Motivation Scale (developed by Beard and Ragheb 1983) to gardening (Ashton-Shaeffer and Constant 2006). This was combined with other work qualitatively looking into gardening motivators (Scott et al. 2015, Clayton 2007, Freeman et al. 2012, Chen et al. 2010, Kiesling and Manning 2010) leading to 19 statements and an open text 'other reason' additional statement. Unidirectional Visual Analogues Scales (VAS) were adopted (Aitken 1969) to allow participants to record their degree of agreement to each statement (Figure 4.1). It was found by Funke and Reips (2012) that with these scales participants in online surveys adjust their answers to provide more nuance than for example the often-used Likert scale (Likert 1932) and more accurate comparisons of multiple items can be made.

Extrinsic influences on gardening motivation

Task and ergonomic specific factors, environmental conditions (including social conditions), physical factors and characteristics of the tools used were considered and in several iterations a list of external influences was developed, consisting of 43 items, for which VASs were applied (8 questions containing 43 statements). As these potential influences could in many cases not be defined as unambiguously positive or negative influences, strength of influence was asked without direction whether this was positive or negative.

Comparison of gardening tasks and tools used

Gardening tasks were selected based on a systematic evaluation of the tasks occurring throughout the horticultural season as described on the RHS monthly advice calendar (Royal Horticultural Society 2015). The tasks included were frequently occurring tasks, seasonally required tasks and

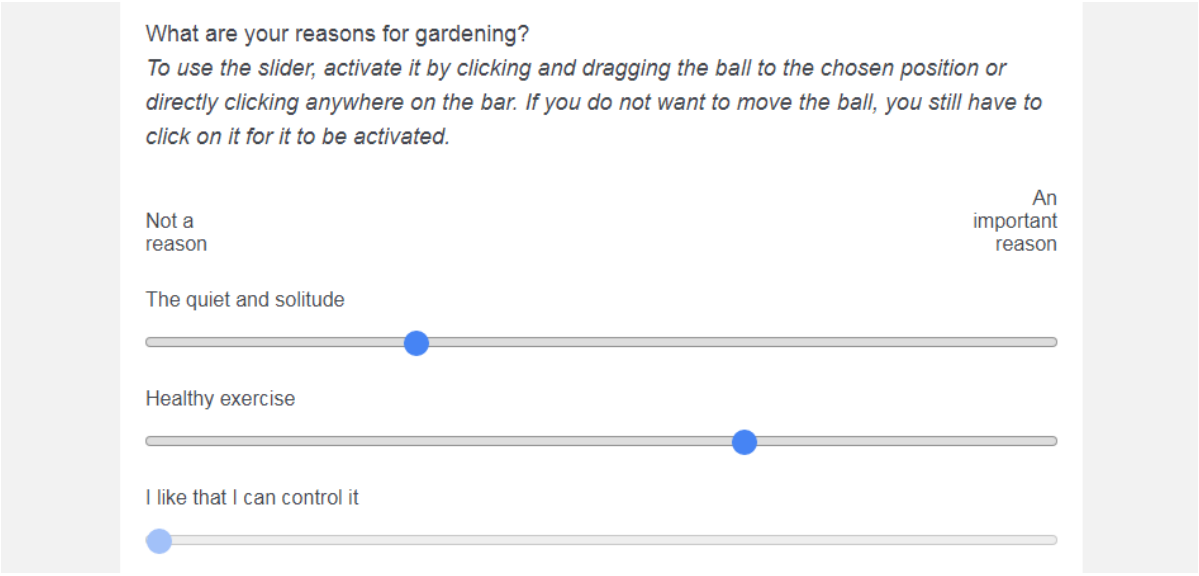


Figure 4.1: Example of VAS as used in the survey. Scales were greyed out prior to selection to show they had not yet been used and every ball had to be activated to record the response. This avoided erroneous recording of unanswered questions as 'not a reason'. Though no numbers were visible on the scales, all responses to VAS questions were recorded on unidirectional scales of 0-100, with 0 corresponding to items not being applicable and 100 to very applicable.

supporting tasks. For each of these tasks, lists were made of commonly used tools and included in the survey through multiple choice with multiple selection format, with open text field boxes for any additional, less common tool used.

4.2.2 Piloting

The survey was piloted by three older female test participants, found via convenience sampling. The pilot focused on the following:

- Content and completeness of questions,
- Wording, structure and flow of the survey,
- Whether responses were as expected,
- Time required to complete the survey.

Small typographical modifications were made. Other changes included:

- Addition of 'The quiet and solitude' as a reason for participation in horticultural activities,
- Addition of 'I don't know' as an option for outside space estimation, as well as both imperial and standard units,

- Addition of general comments open text field,
- Improved wording to explain the mechanics of using the selection tick boxes and slider scales.

The piloting provided responses as anticipated and took the participants 25-32 minutes to complete.

4.2.3 Recruitment

The target group throughout this project were females over 50 years old with some interest in leisure gardening. However, the survey studied a wider group than the target, to allow for comparison in order to identify the extent to which older women differ from the younger generation and from the men in their age bracket. Inclusion criteria were:

- 18+ years old;
- Living in United Kingdom;
- Access to an outside space to grow plants;
- Do (some) gardening.

Participants were approached through an article in the July 2015 issue of The Garden magazine, the monthly magazine of the Royal Horticultural Society (RHS) that is delivered to all of its 420 000+ members. Furthermore, links to the survey were posted on several UK-based horticultural forums and it was tweeted by the RHS several times whilst the survey was open. The aim was to collect 200+ responses and when the survey was closed 214 responses had been collected.

4.2.4 Data analysis

The data was analysed using the Statistical Package for the Social Sciences (SPSS) 22. Initially, descriptive statistics and plots of the scale variables for the three groups individually were used to examine results. Although the Central Limit Theorem states that parameter estimates of a population will have a normal distribution regardless of the shape of the population and as such the Assumption of Normality is not violated provided samples are big enough (≥30 participants) (Field 2013), the power of parametric tests is reduced for non-normal data (Field 2013). Because most

scale variables showed lack of normality, and this was confirmed with Shapiro-Wilk test for normality, non-parametric tests were applied and median and interquartile ranges reported.

General trends were evaluated based on the median and interquartile data. Kruskal-Wallis tests were used to identify differences between the women over 50 and the two other participant groups (<50 women and >50 men). Pearson's chi-square test was used to compare whether proportionally more or fewer older women do specific gardening tasks than the two other groups. Friedman's ANOVA was applied to determine differences between the gardening tasks in enjoyment and perceived difficulty. Follow-up analysis for significant results of Kruskal-Wallis and Friedman's ANOVA tests was undertaken using the Dunn-Bonferroni test for pairwise comparisons, with Bonferroni correction. Spearman's correlation was applied on the median data to identify correlation between enjoyment and perceived difficulty of the gardening tasks for the older women.

4.3 Results

The results section is structured in three sections, with the first section containing participant characteristics, the second results relating to the reasons for gardening, the third presenting results of motivational influences and the last section containing comparisons of the different gardening tasks.

4.3.1 Participant characteristics

The three participant groups were fairly similar in the gardening related characteristics (Table 4.1). The differences between the groups can be seen in a few of the characteristics. Health conditions impacting on participants' abilities to do gardening were more common for the older groups than for younger women, younger women had smaller gardens and spent less hours per week gardening. Differences between older men and older women were smaller, but more older men spent more than 20 hours per week gardening than older women, more older men considered their gardens as large or medium and more stated having health conditions influencing their gardening abilities.

Table 4.1: Garden and gardening related characteristics of the participant groups.

	Women <50	**Women >50**	**Men >50**
Number of participants	48	83	50
Health conditions impacting on ability to garden (% of group)			
Yes	13%	30%	36%
No	85%	69%	60%
I'd rather not say	2%	1%	4%
Garden size (% of group)			
Small (<100 m2)	40%	23%	16%
Medium (100-300 m2)	44%	39%	44%
Large (>300 m2)	15%	33%	40%
I don't know	4%	6%	-
Time spent gardening (% of group)			
1-10 hours per week	77%	58%	58%
11-20 hours per week	15%	33%	26%
>20 hours per week	8%	10%	16%
Type of garden (% of group)			
Garden	100%	99%	94%
Patio/terrace	13%	16%	20%
Allotment	17%	10%	18%
Balcony/window box	4%	1%	4%
Communal garden	4%	1%	2%
Other	4%	-	2%
Other gardeners (% of group)			
Spouse	31%	45%	48%
Other family/friend	4%	11%	6%
Paid gardener	6%	6%	4%
Other	6%	1%	-
Garden features (% of group)			
Perennials	94%	100%	100%
Shrubs	90%	98%	92%
Potted plants	85%	95%	88%
Lawn	83%	92%	80%
Flowers	73%	92%	82%
Trees	77%	87%	80%
Annuals	81%	78%	96%
Vegetable patch	71%	65%	56%
Hedges	56%	59%	56%
Greenhouse	48%	55%	60%
Hanging baskets	44%	46%	66%

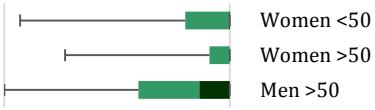
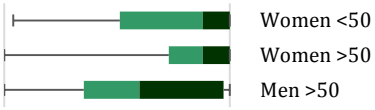
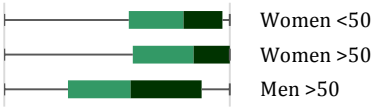
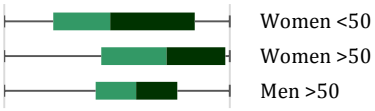
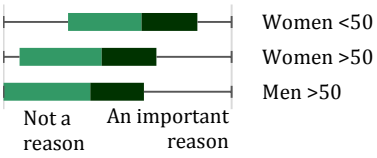
4.3.2 What motivates older women to do gardening?

Participant were asked about their reason to participate in gardening activities and were given opportunity to provide their agreement to a list of twenty statements presented in random order on VAS. The resulting data is included in Appendix E.

Figure 4.2: Medians and quartiles for the various reasons for gardening for the older women sample (N=83). Participants provided answers on 0-100 VAS scale, ranging from 'not a reason' to 'an important reason'.

The main reason for gardening for older women was 'it makes me happy', with reasons relating to other people receiving the lowest overall scores (Figure 4.2). 'Other reason' manual entries related mainly to growing fruit and vegetables and providing a place for wildlife, but overall did not receive high scores. Comparison to the older men and younger women showed significant differences for only some of the reasons for gardening, with most of the differences occurring between older men and older women (Table 4.2).

Table 4.2: Kruskal-Wallis results for the reasons for gardening comparing the three participant groups, with pairwise comparisons with adjusted p and effect sizes. Only test results significant at α ≤ .05 were included in the table.

Kruskal Wallis H(2)			**p**	**Adjusted p**	**r**
It makes me happy	12.689		.002**		
	Men >50	vs.	Women >50	.001**	.264
					
I feel in touch with nature	19.018		.000**		
	Men >50	vs.	Women >50	.000**	.319
					
Relaxing	11.340		.003**		
	Men >50	vs.	Women >50	.003**	.245
					
The quiet and solitude	21.026		.000**		
	Men >50	vs.	Women >50	.000**	.339
					
Getting some fresh air	12.363		.002**		
	Men >50	vs.	Women <50	.048*	.179
	Men >50	vs.	Women >50	.002**	.258
					
Healthy exercise	8.523		.014*		
	Women <50	vs.	Women >50	.020*	-.202
					
Create nice environment to have friends round	6.668		.036*		
	Men >50	vs.	Women <50	.035*	.187
					

*Significant at $\alpha \leq .05$ **Significant at $\alpha \leq .01$

4.3.3 Which factors influence whether older women are motivated to undertake gardening tasks?

Participants were given a list of 43 items, divided into 8 separate questions, to which they could provide their agreement as an influence on a VAS. The resulting data is included in Appendix F.

The influences on gardening motivation were considered of varying importance (Figure 4.3). For this group of women over 50, the effect on the garden was the highest rated factor, followed by several of the tool related aspects, i.e. suitability, ease of use and weight of the tool as well as tool handle comfort and quality of the tool. Results also show the older women perceive weather conditions as having significant impact on whether they are motivated to undertake gardening activities. What other people think or whether they see the older women work did not impact them significantly; these factors received the lowest scores.

Differences between the older women and younger women as well as between older women and older men were found for some of the influences (Table 4.3). Several differences related to the timing of gardening activities and the amount of time needed, which younger women indicated to have greater influence than the older men and women. Furthermore, older men valued weight and ease of use of the tool of less influence than the older women. Some ergonomic factors influenced younger women less than the older men and/or women. Finally, younger women were more influenced by gardening advice of other people than the older men.

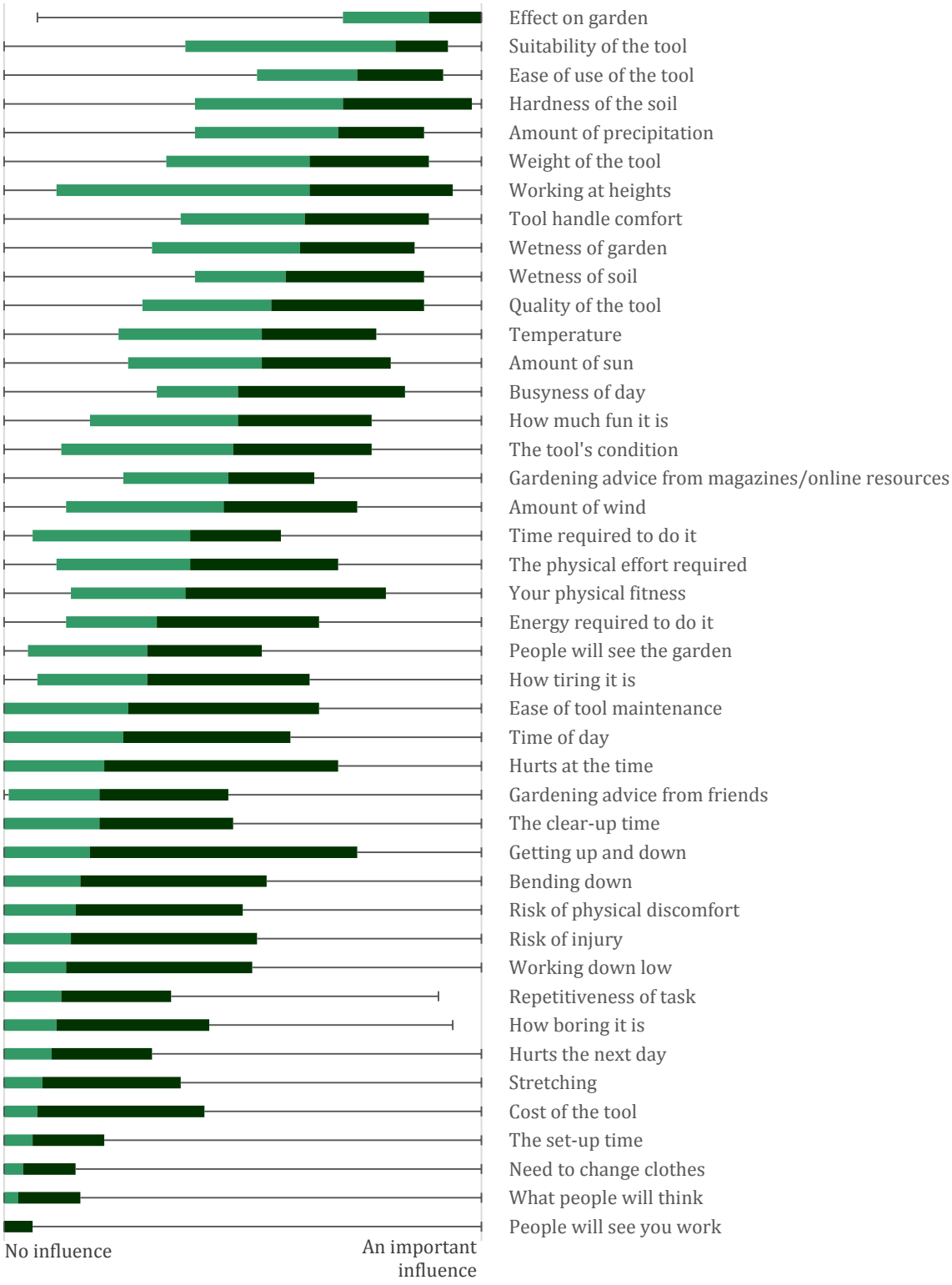


Figure 4.3: Graphical representation of quartiles and medians of the older women sample (N=83) for influences on gardening motivation. On VAS scales of 'No influence' to 'An important influence'. Ordered in descending order by medians.

Table 4.3: Kruskall-Wallis test with follow-up pairwise comparisons for significant differences at α ≤ .05 between the three groups of participants (>50 women, >50 men, <50 women).

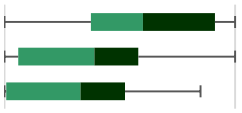
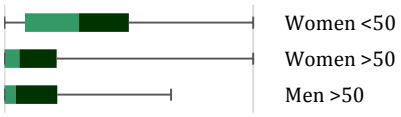
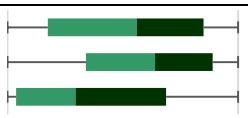
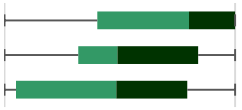
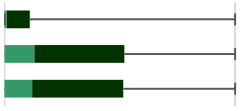
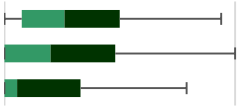
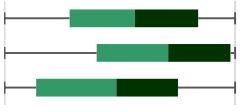
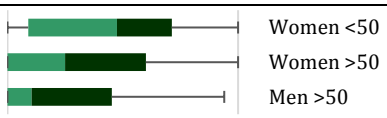
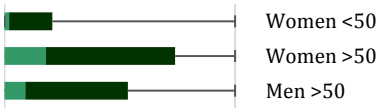
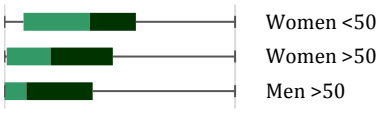
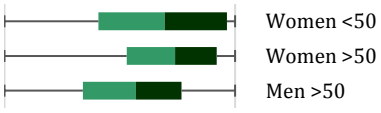
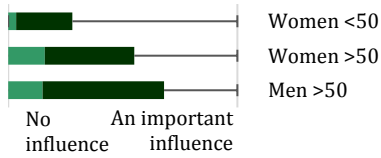
Kruskal Wallis H(2)			**p**	**Adjusted p**	**r**
Time required to do it	19.593		.000**		
	Men >50	vs.	Women <50	.000**	.299
	Women >50	vs.	Women <50	.000**	.282
					
The set-up time	15.346		.000**		
	Men >50	vs.	Women <50	.001**	.271
	Women >50	vs.	Women <50	.003**	.242
					
Weight of the tool	13.529		.001**		
	Men >50	vs.	Women >50	.001**	.272
					
Busyness of day	12.370		.002**		
	Men >50	vs.	Women <50	.002**	.253
	Women >50	vs.	Women <50	.022*	.199
					
Working down low	12.205		.002**		
	Women <50	vs.	Women >50	.004**	-.240
	Women <50	vs.	Men >50	.010*	-.218
					
The clear-up time	9.582		.008**		
	Men >50	vs.	Women <50	.007**	.227
					
Hardness of the soil	9.266		.010*		
	Men >50	vs.	Women >50	.008**	.224
					

Table 4.3 (continued)

Kruskal-Wallis H(2)			p	Adjusted *p*	r
Time of day	8.705		.013*		
	Men >50	vs.	Women <50	.011*	.217
					
Getting up and down	8.407		.015*		
	Women <50	vs.	Women >50	.011*	-.215
					
Gardening advice from friends	8.354		.015*		
	Men >50	vs.	Women <50	.014*	.210
					
Ease of use of the tool	6.086		.048*		
	Men >50	vs.	Women >50	.046*	.180
					
Bending down	6.015		.049*		
					

**Significant at α ≤ .05* ***Significant at α ≤ .01*

4.3.4 Which gardening tasks are perceived as the most difficult and least enjoyed and have the lowest participation by older women?

Gardening tasks were compared based on whether they were undertaken, enjoyed and considered difficult by older women. These results were compared to younger women and older men, to identify any unique characteristics of the target group on their perception of gardening tasks. Correlations were tested between gardening tasks on perceived difficulty and enjoyment.

Gardening task participation

Participants were asked to select the gardening tasks they participated in from a list of twelve with multi-selection boxes. Participation in planting, weeding, watering and pruning plants was very high (>90% of older women), whilst participation was low (<70%) for mowing the lawn, trimming hedges and moving heavy objects in the garden (Table 4.4). The older women participated significantly less in lawn mowing than the older men (Pearson's $\chi^2(2) = 11.820$ at $p = .003$) and both groups of women participated significantly less in moving heavy objects than the older men (Pearson's $\chi^2(2) = 16.283$ at $p < .001$).

Table 4.4: Percentages of participant groups that indicated doing the specific gardening task. Marker area correlates to the percentage of participants that do a task, within the three different groups. Note: total N for the different tasks is not the same for all tasks, as some participants had indicated previously not to have a specific garden feature (i.e. lawn, trees or hedges) present in their garden. Tasks are presented in descending order of participation for the women >50 group.

	Women <50	Women >50	Men >50	Women <50 total N	Women >50 total N	Men >50 total N
Weeding	100%	100%	96%	48	83	50
Planting	98%	99%	94%	48	83	50
Pruning plants	96%	99%	94%	48	83	50
Watering	100%	98%	98%	48	83	50
Pruning trees	77%	97%	75%	39	65	48
Gathering leaves and cuttings	81%	89%	88%	48	83	50
Loosening the soil	71%	88%	82%	48	83	50
Sowing seeds	85%	87%	82%	48	83	50
Lawn edging	77%	76%	83%	35	76	41
Trimming hedges	100%	61%	83%	23	46	30
Mowing the lawn	91%	50%	90%	35	76	41
Moving heavy things in the garden	54%	47%	82%	48	83	50

Table 4.5: Reasons for older women not to participate in the gardening tasks of mowing the lawn, trimming hedges and moving heavy objects in the garden.

	Mowing the lawn		**Trimming hedges**		**Moving heavy objects in the garden**	
	Count (N=38)	% of participants*	Count (N=21)	% of participants*	Count (N=44)	% of participants*
Someone else does it	36	95%	18	86%	32	73%
Too hard	3	8%	4	19%	15	34%
Don't enjoy it	2	5%	1	5%	0	0%
No need to do it	0	0%	1	5%	3	7%

*% of women >50 that indicated they did not do a task but that did have lawns or hedges (where applicable). Percentages add up to >100% because of multiple selection, the reasons were not mutually exclusive.

The reasons for low participation in the three aforementioned gardening tasks were identified for the older women. Many of the older women did not have hedges in their gardens (45%) and some of the women did not have lawns (8%), and as such did not participate in trimming hedges or lawns respectively. Of the remaining older women that did not do the task, someone else did the task for the majority of women (Table 4.5). Moving heavy objects was considered too hard by 34% of the older women that did not do the task.

Gardening task enjoyment

Participants were asked to rate the extent to which they enjoyed gardening tasks on VAS for those tasks they had previously indicated participating in. The 12 gardening tasks were not all enjoyed to the same extent by the older women, with Friedman's ANOVA $\chi^2(11) = 61.747$, $p < .001$ (Table 4.6 for mean ranks). Pairwise comparisons with adjusted *p*-values showed significant differences between some of the tasks (

Table 4.7). Planting was enjoyed significantly more than the tasks of moving heavy objects, mowing the lawn, gathering leaves and cuttings and trimming hedges, and sowing seeds and pruning plants were more enjoyed than moving heavy objects and mowing the lawn.

Generally older men and younger women enjoyed the gardening tasks to a similar extent, with the exceptions of pruning plants and weeding (Table 4.8). Pairwise comparisons with adjusted *p*-values indicated older women enjoyed pruning more than older men (p = .041, r = .19) and older women enjoyed weeding more than both the younger women (p = .037, r = -.19) and the older men (p = .026, r = .20).

Table 4.6: Enjoyment of gardening tasks by the older women with most enjoyed tasks at the top. Median, interquartile range and minimum and maximum values for each task are shown on the scale of 'Don't enjoy it' (0) to 'Enjoy it very much' (100). Moving heavy objects was the least enjoyed task (task with lowest mean rank), followed by mowing the lawn and gathering leaves and cuttings.

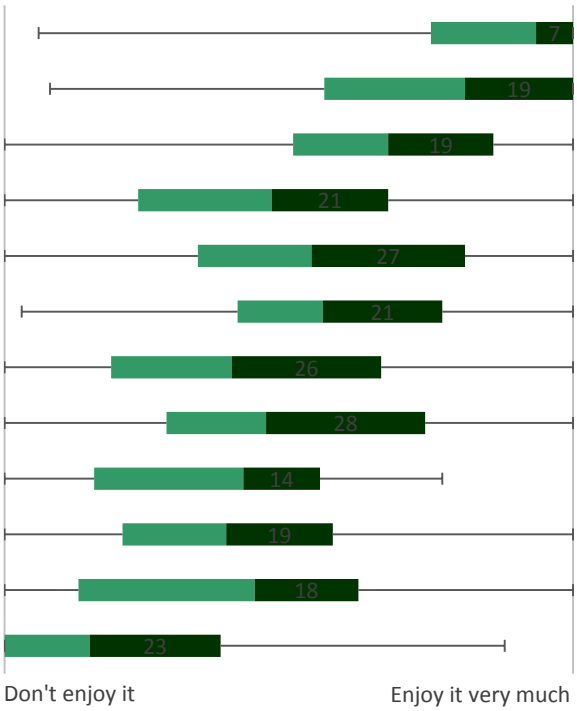
Boxplot of median and quartiles	Task	Mean rank
	Planting	2.0
	Sowing seeds	3.9
	Pruning plants	4.7
	Loosening the soil	6.0
	Weeding	6.0
	Pruning trees	6.4
	Lawn edging	6.6
	Watering	6.7
	Trimming hedges	7.1
	Gathering leaves and cuttings	8.3
	Mowing the lawn	9.5
	Moving heavy things in the garden	10.7

Table 4.7: Pairwise comparisons of enjoyment of gardening tasks with significant differences at α ≤ .05 with Bonferroni adjusted p-values.

	vs.	Adjusted *p*	r
Moving heavy objects in the garden	Pruning plants	.002**	0.83
Moving heavy objects in the garden	Sowing seeds	.000**	0.94
Moving heavy objects in the garden	Planting	.000**	1.21
Mowing the lawn	Pruning plants	.045*	-0.67
Mowing the lawn	Sowing seeds	.005**	-0.78
Mowing the lawn	Planting	.000**	-1.05
Gathering leaves and cuttings	Planting	.001**	-0.87
Trimming hedges	Planting	.020*	-0.71

*Significant at $\alpha \leq .05$ **Significant at $\alpha \leq .01$

Table 4.8: Kruskal-Wallis significant results comparing older women to the other groups for enjoyment of gardening tasks. Only significant results shown here at α ≤ .05.

Enjoyment	Kruskal-Wallis *H*(2)	p	N	Median	Min	25%	75%	Max
Pruning plants	7.379	0.025*						
	Women <50		46	72	0	51	88	100
	Women >50		82	68	0	51	86	100
	Men >50		47	57	3	35	75	95
Weeding	9.601	0.008**						
	Women <50		48	38	0	9	73	100
	Women >50		83	54	0	34	81	100
	Men >50		48	47	0	13	61	100

*Significant at $\alpha \leq .05$ **Significant at $\alpha \leq .01$

Gardening task perceived difficulty

In the same method as the enjoyment of gardening tasks, participants were asked to provide their rating of difficulty on VAS of the gardening tasks they indicated participating in. Older women did not consider the twelve gardening tasks equally difficult, with Friedman's ANOVA $\chi^2(11) = 68.792$, $p<.001$ (Table 4.9 for mean ranks). Pairwise comparisons with adjusted *p*-values showed significant differences between most of the tasks and moving heavy objects (

Table 4.10), where moving heavy objects was found to be considered significantly more difficult than the other tasks except for trimming hedges and pruning trees.

Generally older men and younger women considered the gardening tasks difficult to a similar extent, with the exceptions of pruning trees and watering (

Table 4.11). Pairwise comparisons with adjusted *p*-values indicated older women considered pruning trees more difficult than older men (p = .022, r = .24) and older men considered watering more difficult than younger women (p = .022, r = -.20).

Table 4.9: Perceived difficulty of gardening tasks. Shown in the boxplot are median, interquartile range and minimum and maximum values for each task on the scale of 'Not hard' (0) to 'Very hard' (100). Moving heavy objects was seen as the hardest task to do (task with highest mean rank), followed by pruning trees and trimming hedges.

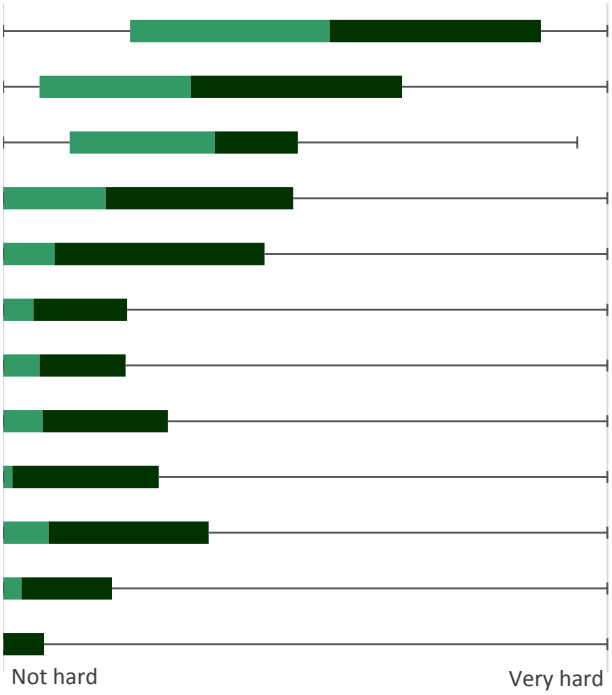
Median and quartiles	**Task**	**Mean rank**
	Moving heavy things in the garden	1.3
	Pruning trees	4.3
	Trimming hedges	4.5
	Loosening the soil	6.5
	Gathering leaves and cuttings	6.8
	Watering	6.9
	Pruning plants	7.3
	Mowing the lawn	7.6
	Planting	7.8
	Lawn edging	8.1
	Weeding	8.5
	Sowing seeds	8.5

Table 4.10: Pairwise comparisons of perceived difficulty of gardening tasks with significant differences at α ≤ .05 with Bonferroni adjusted p-values.

vs.		Adjusted *p*	r
Weeding	Moving heavy objects in the garden	.000**	-0.99
Sowing seeds	Moving heavy objects in the garden	.000**	-0.99
Lawn edging	Moving heavy objects in the garden	.000**	-0.94
Planting	Moving heavy objects in the garden	.000**	-0.90
Mowing the lawn	Moving heavy objects in the garden	.001**	-0.87
Pruning plants	Moving heavy objects in the garden	.001**	-0.84
Watering	Moving heavy objects in the garden	.005**	-0.78
Gathering leaves and cuttings	Moving heavy objects in the garden	.007**	-0.76
Loosening the soil	Moving heavy objects in the garden	.016*	-0.72

*Significant at $\alpha \leq .05$ **Significant at $\alpha \leq .01$

Table 4.11: Kruskal-Wallis significant results comparing older women to the other groups for perceived difficulty of gardening tasks. Only significant results at are shown.

Difficulty	Kruskal-Wallis H(2)	p	N	Median	Min	25%	75%	Max
Pruning trees	7.800	0.020*						
	Women <50		30	15	0	0	53	87
	Women >50		63	31	0	6	66	100
	Men >50		36	12	0	0	27	74
Watering	7.730	0.021*						
	Women <50		48	0	0	0	8	100
	Women >50		81	5	0	0	21	100
	Men >50		49	6	0	0	28	100

*Significant at $\alpha \leq .05$

Correlation between enjoyment and difficulty

Correlation was found between the medians of enjoyment of a gardening task and its perceived difficulty for the older women, with r_s = -.685, 95% BCa CI [-.995, -.144], p = .014 (Figure 4.4).

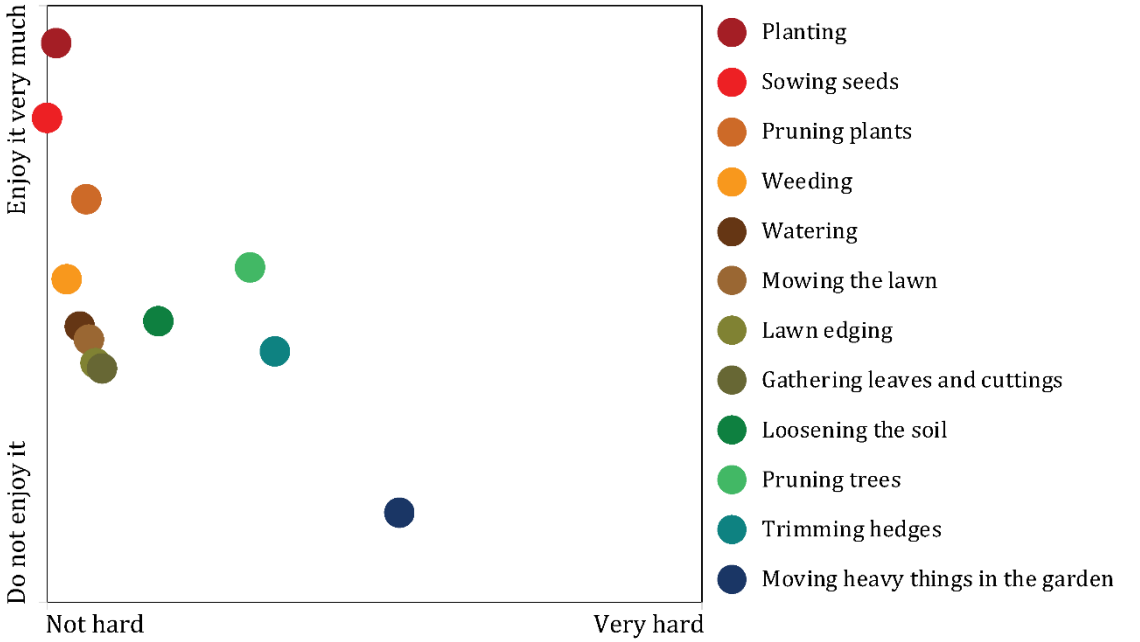


Figure 4.4: Medians of the perception of the different gardening tasks by the women >50 group. The medians of tasks are shown on a horizontal scale of 'Not hard' (0) to 'Very hard' (100) and vertical scale of 'Do not enjoy it' (0) to 'Enjoy it very much' (100). A negative correlation was found. Causation was not established within the study.

4.4 Discussion

This survey-based study sought to identify the reasons older women in the UK participate in horticultural activities and the external influences on motivation to do gardening, establishing the extent to which this group is unique from younger generations and men of the same age. This knowledge was needed if older women are to be encouraged to partake in horticultural activities and thus reap the physical and mental benefits of the outdoor pastime. Furthermore, comparison of gardening tasks on enjoyment and perceived difficulty was needed to prioritise those tasks that could be improved. The results indicated strong intrinsic motivation for gardening and a clear ranking of tasks could be made. These results are discussed in context below.

4.4.1 What motivates older women to do gardening and which factors influence whether older women are motivated to undertake gardening tasks?

The older women rated various reasons for gardening, with the most important reason being one of intrinsic enjoyment; 'it makes me happy'. Furthermore, it was found that the most important

reasons related to the connection with and the aesthetics of the garden, similar to results amongst older adults in Australia (Scott et al. 2015). However, in other research it was found that physical fitness and creativity were the most important motivational domains for older leisure gardeners in the United States (Ashton-Shaeffer and Constant 2006). Whilst health benefits of horticultural activities were seen as more important for the older women than the younger group, health benefits were not the highest rated reason for gardening. The results of the survey suggest that for older female leisure gardeners encouragement for gardening should emphasize several attributes of gardening that make it a leisure activity distinct from other leisure activities and from exercise classes, i.e. the connection to nature, relaxing, providing fresh air, the quiet and solitude and growing something out of nothing.

The older men generally felt less strongly about the reasons for participating in horticultural activities. These results reflect the passion of older women for this leisure activity. They align with market research that found women have more interest in gardening and enjoy it more than men (The Horticultural Trades Association 2011). The inner directed drivers found in previous research to be the most relevant motivators for gardening were also found to be the most important for the older women in this study. Older women do not seem to require external push to engage in gardening activities: it was found they do not see gardening as something that needs to be done, that they simply do to pass the time or because of other external drivers. Instead, the positive attributes of the horticultural activities were more important, i.e. the connection to nature, relaxing, providing fresh air, the quiet and solitude, growing something out of nothing and even the healthy exercise.

Furthermore, the feeling of accomplishment and the influence on how the garden looks were found to play an important role. The highest scoring influence on motivation was found to be the effect on the garden, which reconfirms the significance of not just the experience of horticultural activities, but also its effects. If effort yield insufficient results in the eyes of the older woman, it may cause her to lose interest in gardening, and as such, positive outcomes to efforts are paramount. Participation in gardening reduces with age (Verbrugge et al. 1996, Bijnen, F. C. H. et al. 1998) and many older adults have to modify or limit their gardening participation due to age related issues (Scott et al.

2015). If results of gardening activities are not satisfactory, participation is likely to be discontinued and as such ensuring their gardening activities have the desired effect is paramount. It is recommended that interventions in the form of help, improved tool design or horticultural programmes be implemented prior to a negative feedback spiral occurring, and avoid the garden becoming a reminder of inability (Bhatti 2006).

Both tool aspects and weather conditions were found to be major influences on whether the older women were motivated to undertake gardening tasks. Whilst weather and climate conditions are difficult to improve, tools can be redesigned. The tool aspects that were found to be an important influence to participants' motivation to do gardening activities were the suitability, ease of use and weight of the tool as well as comfort of the tool handle and quality of the tool. If these tool aspects are not optimal in the perception of the older women, these results imply that this might negatively impact their motivation to do the activities. In turn, improving these tool aspects could help to improve the overall gardening experience of older women.

Younger women were more influenced by timing related aspects like time of day, busyness of day, the set-up and clear up time and overall time required than the older men and women. The limit on time available can play an important part in motivation for younger generations to engage in horticultural activities, but this limitation is less likely felt by those of retirement age and over.

The only potentially dangerous or high risk situation identified by the older women as a major influence on their motivation was working at height. This may be a general situation for people to dislike; the younger women and older men felt similar. Other than working at height, physical condition and ergonomic aspects of the tasks were found to be of some, but less consequence, with many older women not seeing risk of injury or discomfort as a reason not to undertake the activities. Furthermore, they did not see their own conditions or the requirements of the specific task (e.g. bending, getting up and down and the physical effort required) as main influences. This is unexpected, as for a leisure activity it could be expected that it would easily be skipped if people were not physically fit or the activity might cause discomfort.

Adherence to exercise is a known issue for older adults in general (e.g. Phillips et al. 2004, Brawley et al. 2003, Stiggelbout et al. 2006), and barriers to exercise or (perceived) risk situations to

exercise participation as well as lapses in participation all influence the intention to behaviour threshold (Stiggelbout et al. 2006). Bending relating activities are often problematic for older adults and older women in particular (Stamm et al. 2016). Working down low and getting up and down were seen by older women as bigger influences on their motivation than younger women, but did not receive high overall scores; they were not seen by many in this study as deterrents to motivation for undertaking gardening activities. Combined with the low medians for risk of physical discomfort, risk of injury and whether it hurts the next day, this is an interesting result, as it shows that older women are not easily deterred by these postural demands of the activity and generally do not fear injury nor discomfort. This can be seen as a positive argument for the potential of gardening in providing a solution to general exercise adherence; the barriers they perceive in other situations are not seen as significant for gardening.

In other research, physical ailments and safety (especially related to falling) were found to be main barriers to exercise for older adults (Lees et al. 2005). The results of this study do not reflect the same significance for these barriers. The results thus support the arguments for gardening as a sustainable means of remaining physically active.

4.4.2 Which gardening tasks are perceived as the most difficult and least enjoyed by older women and in which tasks do few older women participate?

Some gardening tasks were not undertaken by many older women. These were moving heavy objects, trimming hedges and mowing the lawn. For both lawn mowing and moving heavy objects the difference between older men and women was significant. Traditional gender roles may underlie division of these tasks, as participation by the older men was higher for all three tasks and in similar participation percentages to the other gardening tasks, whilst fewer older women participated. The most common reason for older women not to move heavy objects, mow the lawn or trim hedges was that ‘someone else does it’ and it was found that this other person was usually their spouse/partner. However, the reality is that access to this or other outside help can become more limited with age; getting older is associated with increased risk of exclusion from social

relationships (Barnes et al. 2006). To encourage women to continue to do gardening, they should therefore be able to work independently and do all tasks required.

The tasks most enjoyed by the older women were planting and sowing seeds. These tasks both relate to both growing something out of nothing, greatly influence how the garden looks and thus may provide a feeling of accomplishment. As such, these activities align well to older women's reasons for gardening as established before and are likely to provide greater satisfaction than those activities without such clear or permanent results. The tasks that provided the older women with less enjoyment were tasks that required regular repetition, i.e. weeding, lawn edging, watering, gathering leaves and cuttings and mowing the lawn. Though they influence how the garden looks, their effects do not last.

Healthy exercise was given as a reason for older women to do horticultural activities, however this is not reflected in the ranking of enjoyment of the different tasks. The tasks at the top of the enjoyment ranking (planting, sowing and pruning) were tasks of low or medium intensity (see section 2.4) whilst tasks considered not enjoyable generally were the tasks of higher intensity as found by other research. As such, though healthy exercise is a consideration for older women, higher intensity gardening tasks do not seem to be enjoyed much and as such older women may avoid these tasks, thus reducing the potential health benefits of more rigorous gardening activities. More research is required in which both perception and actual intensity of various gardening activities is combined to further clarify the link between enjoyment, intensity and the effect on participation.

The task that was the least enjoyed by older women as well as the older men and younger women was moving heavy objects in the garden. This may be due to its lack of fulfilling the key motivators for gardening for older women as found in the survey. This task does not provide the direct connection to nature or the chance to grow something out of nothing, and though it influences how the garden looks indirectly, it likely would not be called 'relaxing'. Furthermore, moving heavy objects, trimming hedges and mowing the lawn were tasks many older women left to other people to do. This contrasts to the quiet and solitude aspects given as a reason of enjoyment for many of the older women; these tasks are not or cannot be undertaken by the older women themselves,

whilst the quiet and solitude was found to be one of the most desirable attributes to gardening. These tasks were all among the lowest rated in enjoyment.

Moving heavy objects was considered the most difficult task, by all participant groups and a relatively high percentage of those that did not do the task stated it was too hard (34%). A correlation between enjoyment and perceived difficulty of gardening tasks was established; harder tasks were less enjoyed. Though causation could not be established from the enjoyment and difficulty results alone, more difficult tasks are likely to be less relaxing, and as relaxing was found to be one of the main reasons for gardening, these tasks are likely to be less enjoyed. Furthermore, it is speculated that the older women may not always succeed in harder tasks or may not see themselves fit to try. Through this their feelings of accomplishment obtained from the activities are reduced, thus reducing their enjoyment of the activities. Self-efficacy, the concept that someone believes they are able to successfully perform a behaviour, is a known influence on exercise adherence (Schutzer 2004).

Some relation between participation and perceived difficulty seems present, as for most gardening tasks perceived difficulty was low and participation was high and the most difficult task had the lowest participation. However, the relationship does not seem straightforward; tree pruning and lawn mowing did not follow this pattern. Tree pruning was undertaken by nearly all older women, whilst it was perceived as one of the most difficult tasks. Furthermore, though proportionally more women over 50 were found to do tree pruning than men over 50, these men considered the task less difficult than the women over 50 did. No explanation was found for this. Lawn mowing was not considered difficult, but participation rates among older women were relatively low and it was found to be one of the least enjoyed tasks for older women. It is expected that traditional role patterns may play a part in the low participation in lawn mowing by the older women, with this pattern no longer visible among the women under 50; participation among younger women was high even though enjoyment and perceived difficulty were not significantly different to the older women.

Enjoyment and participation in gardening tasks seemed to be related; the most enjoyed tasks had high participation rates and some tasks that were enjoyed less were undertaken by proportionally

fewer older women (moving heavy objects, trimming hedges, mowing). The participation rates are however influenced by external factors as well: even though some older women may prefer not to do certain tasks, they may have to if no-one else is around and inversely, if others are around they may not have the chance to do tasks that they would actually like to do. The role of others, e.g. spouses, family or paid help, in the extent to which gardening tasks are undertaken could be an interesting topic for future studies.

Moving heavy things in the garden was found to be the task with lowest participation rates and highest perceived difficulty, whilst also being the least enjoyed. It is clear this task warrants further investigation. This is a task that has a supporting role to many of the horticultural activities, but it needs clear definition of what constitutes a 'heavy thing' in the garden for older women and an inventory is needed of the scenarios in which moving these objects occur, if this task is to be made easier for older women and thus increase their independence in the garden.

4.4.3 Limitations

The survey used the VAS scale as developed by Aitken (1969). Using VASs has the benefit over Likert scales (1932) that the data approximates continuous data and therefore parametric tests can be applied. In this study it was seen that many participants used the scales to give bimodal answers at either extreme of the sliders. As this was not found to be a common occurrence with these scales, it could indicate strongly polarised views, e.g. people considering the different reasons for gardening either completely applicable or entirely not applicable. However, to an extent this may have also been caused by the interface of the survey software used, which on the computer screen may have been difficult to position accurately, thus causing participants to drag the pointer towards the extremes. Pilot participants unfortunately had not displayed this behaviour. The resulting data was skewed, but in varying degrees and directions for the different attributes measured and therefore transforming was not possible and non-parametric tests were applied.

The sample of self-selected leisure gardeners may not have been entirely representative of the general public of leisure gardeners, as those older adults with access to the internet tend to be of somewhat higher socio-economic status than those without (Gracia and Herrero 2009), the study

results may not reflect the motivations of those of lower socio-economic status. As the survey was distributed in outlets that were most likely to be read by amateur gardening enthusiasts; those with enough of an interest in horticultural activities to read gardening magazines or research about gardening on forums or twitter. Those leisure gardeners that are not as invested in gardening thus may not have seen the survey. The generalisability of the results of this survey, specifically relating to the reasons for gardening and influences on gardening motivation to the whole gardening population is limited and results should be considered applicable only to those with an actual interest in gardening.

4.5 Conclusions

The aims of this study were twofold; to increase understanding motivations of older women for participation in horticultural leisure activities and to identify differences in perception of various gardening tasks in order to identify tasks and attributes of gardening that may act as inhibitors to the continued participation of older women in gardening. This knowledge can benefit those developing gardening interventions, programmes or tools. The following findings resulted:

- The older women were intrinsically motivated to participate in gardening activities. Inner directed, experience and results driven motivations relating to intrinsic happiness, the connection to the nature in the garden and the effect on the garden were the most important. For older women, the experience driven motivations like connection to nature were more important than for older men, suggesting that for older women more than for older men, gardening has potential to serve as a means of keeping up physical activity. In comparison to exercise programs with low adherence, older women undertake gardening not just for its results, but also for the activity itself. Further, if results are disappointing, older women may be less deterred by this than older men. Because the health and wellbeing benefits of gardening are established (Section 2.2), successful continuation of gardening activities by overcoming any challenges that may arise could increase the amount of years lived in good health.
- Older women considered healthy exercise more important than the younger women, indicating an awareness for the older women for the role of gardening on their health and

wellbeing, whilst for younger women, exercise may be found through other means. Though not a key reason for gardening, this finding reflects the importance of the role of gardening for the older person, for many of whom this may be one of the few forms of exercise experienced. Participation may however be better encouraged through the emphasis on connection to nature, relaxing, providing fresh air, the quiet and solitude and growing something out of nothing.

- The effect on the garden was the main influence on whether older women were motivated to undertake gardening tasks, but surprisingly, tool characteristics were also seen as highly important and on par with weather conditions, whose impact on this outdoor activity is obvious. This indicates the significance of tools and suggests suitability of these tools for the older woman should be investigated.
- This study was the first UK-based survey to compare gardening tasks on enjoyment and perceived difficulty. Trimming hedges, gathering leaves and cuttings, mowing and moving heavy objects in the garden were least enjoyed and trimming hedges, pruning trees and moving heavy objects were most difficult. Participation in trimming hedges, lawn mowing and moving heavy objects was low. For lawn mowing, traditional gender roles may influence participation, as older men were found to participate significantly more in this activity. To overcome these gender roles, older women may be encouraged by the provision of tools more suited to, and aimed at, the older woman. The activity of trimming hedges may be explored more to determine the causes of low participation, lack of enjoyment and perceived difficulty.
- Moving heavy objects was considered both the most difficult and least enjoyable task, and a task many older women considered too hard and left to other people to do. It therefore warrants further investigation to identify the challenges with this task and ensure older women can independently continue gardening.
- Correlation was found between enjoyment and perceived difficulty of a gardening task, whereby less difficult tasks were enjoyed more and more enjoyable tasks perceived as less difficult. Causation was not established, but this finding is worth further exploration as more knowledge of this relation could target development of new products or

interventions towards those tasks where a reduction in difficulty may increase enjoyment. Correlations between participation and enjoyment or participation and perceived difficulty were not established and future studies should consider this bridge between motivation and actual participation.

The overall recommendation arising from the above is to ensure older women are able to do the tasks they enjoy and do not consider difficult. This can be done through the provision of appropriate spaces and tools and to further investigate those tasks with low participation: mowing the lawn, trimming hedges, but most notably moving heavy objects in the garden. By ensuring older women are willing and able to undertake every gardening task, independence is assured and continued participation can be achieved. This requires both understanding of the motivations to do individual gardening tasks and the physical challenges experienced in the execution of these tasks. Taking into account the findings that tool characteristics have a significant influence on the older woman's motivation to garden this warrants consideration of the tools used in the tasks.

In the next chapter a focus group study is discussed, in which explanations are sought on why tasks are considered enjoyable or difficult, to established whether enjoyment and difficulty can be connected to the overall gardening motivations. Furthermore, the problem scenarios behind the task of moving heavy objects in the garden are clarified and more insight into the factors influencing the execution of this task is provided.

Chapter 5 Focus groups on enjoyment and difficulty of gardening tasks and exploring issues with moving heavy objects in the garden

5.1 Introduction

The survey described in Chapter 4 identified that moving heavy objects posed a horticultural challenge for older women interested in gardening. This chapter seeks to explore the issue in more depth in order to clarify the scenarios that caused problems and identify underlying key issues so that recommendations to overcoming these problems can be made, allowing older women to successfully complete this supporting gardening task.

The task of moving heavy objects was found to be the least frequently undertaken, least enjoyed and most difficult gardening task for older women compared to the other gardening tasks. It was concluded that more insight into why tasks are perceived as difficult or less enjoyable was needed; this would benefit the development of products and services for older women and their needs. Furthermore, a more developed understanding was needed of the process of moving heavy objects and the scenarios in which these heavy objects are moved which includes the tools or assistive products currently used.

Other research relating to moving heavy objects was found to be aimed at manual materials handling within the context of the workplace with little research looking into manual materials moving by older women (see section 2.6). Furthermore, although the environmental influences have been established as contributors to overall usability of manual moving aids (Mack, 1995, Jung, 2005), the context of the garden and its particular obstacles had not been studied in depth. The objects requiring moving and the definition of 'heavy' to the older women needed to be clarified, as well as the scenarios in which moving occurred and the tools used within this context identified.

Though the survey identified differences in enjoyment and perceived difficulty of various gardening tasks, the contributors to enjoyment and perceived difficulty were unknown. Although research has previously been undertaken regarding reasons to participate in horticultural activities in general, the link to specific gardening tasks had not been made and no explanations were found regarding perceived difficulty of gardening tasks (see section 2.4). These research gaps were addressed through the focus group study presented in this chapter.

5.1.1 Research questions

The aim was to identify the problems associated with moving heavy objects in the garden for older women and explore in greater depth the reasons for enjoyment and perceived difficulty of various gardening tasks that emerged from the online survey. The research questions were:

1. Which factors contribute to enjoyment of gardening tasks?
2. Which factors contribute to perceived difficulty of gardening tasks?
3. Which problem scenarios and usability issues do older women identify in their experiences with moving heavy objects in the garden?

5.2 Method

Focus groups are often used to investigate findings from survey studies in more detail and provide depth to those findings.

The project was approved by Coventry University's ethics process, project number P42240 (Appendix B for project documentation, including participant information and consent forms).

Risks of participation were identified as low, but included upsetting participants due to discussion of difficult or unachievable tasks. Participants were given £20 to thank them and cover expenses but were allowed to cease participation in the study at any time.

5.2.1 Study design

The focus group sessions were set up following the basic structure of opening, introduction to get participants talking, transitions and key questions and closing (Krueger 1998). The following items were included:

Opening

- **Introductory question**: favourite flower/plant, description of their garden.
- **Transition**: agreement to the order of enjoyment tasks as resulted from the survey.
- **Key Question 1**: factors contributing to enjoyment of gardening tasks.
    - **Sub question**: factors contributing to moving heavy objects being least enjoyed.
- **Transition**: agreement to the order of perceived difficulty of tasks as resulted from the survey.
- **Key Question 2**: factors contributing to perceived difficulty of gardening tasks.
    - **Sub question**: factors contributing to moving heavy objects being most difficult.

Break

- **Key Question 3**: instances of moving heavy objects, personal anecdotes.
    - **Sub question**: how to improve the instances mentioned.
    - **Sub question**: advice to give to someone wanting to improve instances.
- **Transition**: final remarks.

End of session

The full questioning guide can be found in Appendix G. After three groups were executed, it was decided to plan one final group in which the focus would lie on the factors that make gardening tasks difficult, to identify coping mechanisms and potential directions for improvement. This group started the same way, but the enjoyment section was left out to allow more time discussing the

difficulty of tasks instead. This time a more structured approach was taken to determine the characteristics relevant to perception of difficulty to put the findings of the previous sessions into context and allow the women to identify the overarching issues themselves.

The development of the questioning route went through various stages, keeping in mind the target group in the development. Simplicity in sentence structure and word use benefit understanding for older participants (Barrett and Kirk 2000). Following Barrett and Kirk's advice changes in topic were announced before the questions were asked. The sessions were undertaken with a few days in between them to evaluate any start-up problems and if needed modify the questioning route. The first group would be considered a pilot session if major modifications proved needed, however this was not the case. Due to the relatively focused nature of the questions asked within the focus groups, the third group did not provide many new leads anymore, but a final group was held to get more depth into the comparison of tasks and what the overarching physical issues were according to the women.

5.2.2 Recruitment

For each of the 4 focus groups, 7 to 8 participants were recruited per group as groups of 5 to 8 participants were targeted. These numbers were chosen as they were deemed sufficiently large for getting a broad range of ideas but small enough to discuss as one group and reach consensus amongst each other (Krueger and Casey 2015). Although over recruiting is recommended, especially with an older target group (Barrett and Kirk 2000), this was not done as a smaller group was preferred over risking groups that would be too large to manage.

Several contacts were used to recruit potential participants (Table 5.1), some of which were directly related to gardening whilst others did not have this particular aim. These organisations in turn either forwarded, presented or mentioned the focus group sessions to their members. Members were then able to contact the researcher if they wanted to participate. Active recruitment of participants was also done at the Women's Horticultural Society. Through participants that were initially called several additional participants were found (snowball recruiting). Each group contained a mix of women recruited through different organisations.

Table 5.1: Participant recruitment through different channels.

Organisations linked to gardening	Other organisations/occasions
Thrive	Coventry Older Voices
Garden Organic	Age UK friend groups
Women's Horticultural Society	Participants at mobility workshop
	Coventry & Warwickshire Accessible Transport Committee
	Coventry University and Warwick University Ideas Cafe

Inclusion criteria for the sessions were:

- Female;
- 50+ years old;
- Leisure gardener with at least two years of experience

Participants were contacted and the nature of the focus group session explained verbally and suitability to participate was established. Specific health conditions were not excluded, but note was taken of these issues prior to the session. Potential participants that reported being professionals in some form of horticulture at the time of study (two potential participants), or reported only having taken up gardening less than two years ago were excluded (one person). Participants were given opportunity to ask questions and after agreeing received participant information leaflets via post or mail in advance of the session. Four focus groups were held with a total of 29 participants.

5.2.3 Participant characteristics

All participants (N=29, female) were UK citizens living in the West Midlands. Participant characteristics can be found in Table 5.2. No participants did any allotment gardening, though several (14%) mentioned having one in the past. Three participants suffered from pre-existing conditions that impacted on their ability to do gardening, unrelated to ageing.

Table 5.2: Garden and gardening related characteristics of the focus group participants.

Participant characteristics	
Number of participants	29
Age (years)	
Mean	70.2
Range	51 – 86
N	29
Gardening experience (years)	
Mean	52.4
Range	22 - 70+
N	27*
Time spent gardening (% of participants)	
1-10 hours per week	75%
11-20 hours per week	14%
>20 hours per week	11%
N	28**
Type of outside space (% of participants)	
Garden	96%
Balcony	4%
N	28**
Location of gardening (% of participants)	
Own outside space	100%
Communal/public/private garden	36%
Acquaintance garden	11%
N	28**
Ability to do gardening changed over (recent) years (% of participants)	
Yes	86%
No	14%
N	28**
Health conditions (% of participants)	
Arthritis	29%
Joint replacement	11%
Other – non-specific conditions	25%
Other – specific conditions	21%
	Eye condition
	Ménière's disease
	Fibromyalgia
	Sciatica
	Heart problems
	Osteoporosis
N	28**

* One participant could not be more specific than stating her gardening experience had been a 'long time'. She was excluded from the calculation of mean. Missing data from another participant.

** Missing data from one participant.

Figure 5.1: Typical focus group session. Two moderators were present for each session.

5.2.4 Procedure

On the day the participants received the explanation of the session, signed consent forms and received their incentive. The sessions lasted about 1.5 hours with a break in the middle and were audio and video recorded. The questioning route timings were adhered to strictly to ensure all relevant topics were discussed, but follow-up questions were asked where appropriate during discussion. A typical focus group can be seen in Figure 5.1. Critical findings of the survey were presented to the focus groups for Question 1 and 2. These were printed out in large type and presented on A3 boards (Figure 5.2). The sessions were held between August and November 2016.

Figure 5.2: Boards were used to convey the results of the survey.

5.2.5 Data analysis

The audio data captured was transcribed verbatim and checked for errors in transcription and in attributing against the video recording. Data from the four focus groups was analysed together. Each comment was attributed to an individual anonymised participant. The coding of data was done by combining paper-based and digital categorising using Microsoft Excel 2013, similar to the approach detailed in Krueger and Casey (2015).

Weighting the importance of concepts (reasons to enjoy tasks, reasons to find tasks difficult, problem scenario components and usability factors) was done based on several criteria (Krueger and Casey 2015):

- Frequency: considering both frequent mentioning (by a single participant or group) and hidden gems;
- Specificity: description of specific actual situations over hypothetical ones;
- Emotion: where passion and intensity came across;
- Extensiveness: whether comments were made by several participants and across focus groups and whether these comments were volunteered or prompted.

5.3 Results

Enjoyment of gardening tasks was explored and their perceived difficulty discussed. Furthermore, the scenarios in which heavy objects are moved in the garden are presented and the usability factors underlying the problems scenarios are presented. The groups were largely in agreement on the major themes, though individual differences took some discussions in different directions. Where quotes are used, individual participants have been represented by a code containing group number and participant number within the group, e.g. P2.4 for participant four of the second group.

5.3.1 Gardening task enjoyment

Participants in three of the groups were asked to identify what contributes to making gardening tasks enjoyable. The participants discussed the grounds for their enjoyment of gardening tasks and lack of enjoyment of moving heavy objects. After familiarisation it became clear enjoyment of

specific tasks linked closely to reasons for gardening as found in the survey and all comments were subsequently mapped onto the reasons for gardening from the survey chapter. Many participants in all groups emphasized the quiet and solitude aspects, the contact with nature as well as relaxing qualities of gardening tasks:

"I think it's anything that's quiet. I find gardening a great way of being quiet and being surrounded by nature, I don't actually have any neighbours we live in the middle of fields so for me I don't have power tools and strimmers and things like that because to me going out to garden is a way of being out and being in nature and hearing the birds song, you know, the robin, the blackbird and the pigeons, sheep and hens and, you know, it's anything that's quiet, so planting, sowing seeds, pruning, weeding, watering…they're all quiet things and that's why I love the garden." (P1.8)

For participants in two of the groups, the results of the efforts of horticultural activities contributed to their enjoyment of the gardening task and provides satisfaction directly or through being able to show it to others. Several discussed wanting to create a 'neat and tidy' result for themselves or for those passing by, even if the task itself was not particularly enjoyable. This made tasks like weeding and gathering leaves and cuttings more enjoyable for them, whilst others aimed to create beauty through growing vegetation in different colours:

"I'm just sitting in my chair mesmerised by a little patch of land and I'm taking pictures of it and I want to recreate it, you know, I want some painter to come along and do it, a watercolour, cos it's so beautiful and that's what I love seeing the end result." (P3.5)

Furthermore, several participants discussed the satisfaction with their own accomplishment, growing something out of nothing as a reason to enjoy sowing and planting and some mentioned the physical benefits of horticultural activities:

"[…] once you've done it you sit there and you think I've done that good [participants laugh] I know my back aches and my leg hurts and my arm aches." (P2.4)

Lack of enjoyment was explicitly linked to difficulty of the tasks by one participant and in all three of the focus groups that discussed enjoyment conversations turned to discuss the negatives of those tasks at the bottom. Lack of enjoyment according to the participants was linked to the task being considered tedious (weeding), boring (weeding, mowing, hedge trimming), not being able to cope and frustration arising from this (moving heavy objects), the activity itself making a participant feel unwell (lawn edging), heavy and cumbersome (watering) and generally a chore (all tasks).

5.3.2 Perceived difficulty of gardening tasks

Participants in all groups were asked about what makes gardening tasks difficult. After grouping responses per task for most tasks there were some clear reasons given to explain why they were considered difficult. Moving heavy objects received additional attention in the focus groups because of the results of the survey (Chapter 4) and as such was discussed in individual questions in every group. The results of these discussions are presented in the problem scenarios and usability factors in section 5.3.3 and 5.3.4 below.

Trimming hedges was considered difficult by participants in all of the groups, with some participants indicating they left this task to a professional or their spouses. The weight of the tool and wielding it around were mentioned as a main concern:

"And, you know, I'm seventy-five, I can't lift all these things. And, you know, your balance isn't as good when you're older is it, so if you, you're trying to hold something up here and control that, and you're moving around, you're not steady on your feet always. So that can be quite difficult." (P4.5)

Getting up on ladders was considered dangerous by some participants and was mentioned in connection with trimming hedges and pruning trees in two of the focus groups. The height at which work needed to occur was not the only problem with pruning trees, as it was also considered difficult by participants because the branches needed to be cut would often be thicker than the tools or participants could handle.

The older women considered some of the tasks difficult because they required bending, i.e. gathering leaves and cuttings and weeding. Other causes for perceived difficulty identified by the older women were weight of the tools for leaf collecting and watering with a watering can, the action of digging required for loosening soil, planting and turning compost as well as the regular recurrence or long interval required for some tasks, i.e. weeding, gathering leaves and cuttings and watering. Finally, pruning was considered difficult by those with arthritis in the wrist or hands.

Several participants indicated they saw a difference between physically hard tasks and those tasks requiring expertise to complete successfully. Tasks mentioned belonging to the second type of task were sowing seeds and pruning, which were not considered physically hard, but limited success contributed to frustration and some participants therefore called pruning 'frightening'.

5.3.3 Problem scenarios relating to moving heavy objects in the garden

Participants were asked to describe situations in which they had to move something heavy in their gardens. Participants discussed a large number of scenarios, for a diagram of all scenarios and accompanying problems, please see Appendix H. Scenarios related to three most extensively discussed types of heavy items: compost bags (Table 5.3), potted plants (Table 5.4) and heavy tools (Table 5.5).

The majority of strategies mentioned in all the groups for moving heavy objects related to using a wheeled vehicle to move the load. Participants talked about sack trolleys of different varieties and they were discussed the most in all groups. Wheelbarrows were also mentioned in all groups. The only type a participant expressed enthusiasm about was the ascender barrow, because of its functionality of lowering the tub. Stability of a regular single-wheeled barrow was questioned, and wheelbarrows with two or four wheels were seen as appropriate solutions. Wheeled bases to use under pots were used by several participants in three of the groups to move pots, but not discussed in one of the groups and limited participants contributed to the discussions. Wheeled garden trugs were mentioned in one of the groups as a product several participants could see potential for, however none of them used the tool. They imagined adding a seat to that product would make it

even better. Several participants used old shopping or travel trolleys to move items, and though one participant considered them too small, the other two participants used theirs happily.

Table 5.3: Problem scenario relating to moving compost bags.

Compost bags		
"You often get people who will be very kind at the garden centre and supermarket and whatever and will load up your car for you but when you get home if you haven't got a strong man the other end who can lug it through for you or you want to get on with it straight away how do you get it out of your car to where you want it in your garden, that's one issue." (P2.8)		
Relevance	Moving compost bags resonated strongly with the participants; it was discussed in every group, with all but two participants contributing to the conversations and a very similar scenario was volunteered by a participant in every group.	
Coping strategies	**Lightening the load** • Dividing the load up into buckets. • Purchase of smaller bags. • Use of lighter or dehydrated compost.	**Wheeling it around** • (Foldable) Sack truck. • Suitcase trolley. • (Step climber) Shopping trolley. • Tub barrow. • Ascender barrow. • Wheelbarrow. • Step climber sack truck.
	Dragging Dragging bags from back of car.	**Avoidance** Getting compost delivered.

Table 5.4: Problem scenario relating to moving potted plants.

Plant and flower pots		
"With a small garden you tend to use more pots cos you can swap things around to keep your colour, so it can be difficult because the bigger your plant gets the bigger your pot gets, you're potting them on and potting them on and you end up with enormous pots you can't move." (P1.4)		
Relevance	Moving pots around was mentioned by participants as a difficult task in two of the groups and discussed extensively, and all participants contributed to the discussions around moving pots. However, one group hardly spoke of it and another discussed moving pots only after prompting by the researcher late in the session.	
Coping strategies	**Lightening the load** • Use of lightweight plastic pots, bins or trugs. • Use polystyrene foam as drainage material.	**Wheeling it around** • Wheeled bases. • (Foldable) Sack truck. • Step climber sack truck.
	Dragging • Just the pot. • On bits of carpet. • On empty sacks. • On tray underneath pot.	**Avoidance** Keep pots in one place.

Table 5.5: Problem scenario relating to moving heavy tools.

Heavy tools		
	"[…] gardeners are traditionally big beefy men who can handle these things." (P4.6)	
Relevance	Heavy tools were volunteered as a topic of discussion in all of the groups, though the tools discussed differed. In one of the groups, several participants felt strongly about the weight of a watering can and this was volunteered first, whilst in the other groups loppers and hedge trimmers were mentioned first and watering received little attention. Participants in all groups discussed and agreed that gardening tools in general had been designed with men in mind.	
Coping strategies	**Lightening the load** • Border or ladies forks and spades.* • Children's watering can, smaller watering cans. • Smaller hedge trimmers, lawn mowers, leaf blowers. • Battery operated tools versus diesel powered. • Lightweight sheers.	**Change tool type** • Rake instead of leaf blower. • Terex spade instead of regular spade. • Watering hose instead of watering can. • Two or four wheeled wheelbarrow instead of regular wheelbarrow.

* Some noted that quality lightweight modern tools were expensive, and that as such they preferred older tools, which they considered more robust even though some might be heavier.

5.3.4 Issues associated with the problem scenarios

Participants were asked to describe situations in which they had to move heavy objects. In section 5.3.3 the scenarios in which heavy objects are moved were discussed and the problems were related to these scenarios. During the discussions, several factors contributing to a lack of usability in moving heavy items in the garden were mentioned. In this section the most relevant contributions based on criteria of Krueger and Casey (2015) are presented (Table 5.6), with all factors discussed included in Appendix I.

Lack of availability for assistance was often mentioned, with participants expressing frustration at help not being around when required, especially after having purchased items that need to be taken from car to garden. Insufficient strength specifically due to the ageing body or in general was identified by many older women as a main reason for lack of success in moving heavy items.

Table 5.6: Most relevant underlying issues to moving heavy objects in the garden based on the focus group discussions. Topics were categorised based on Mack et al. (1995) and relevance was established based on the criteria by Krueger and Casey (2015) mentioned in section 5.2.5. Full lists of issues discussed in each group can be found in Appendix I.

Topic	Category	Relevance
Availability of assistance	Task	All groups discussed lack of help available when needed, in particular after purchasing items at a garden centre and getting them where needed. Neighbours would be asked by some, but some were adamantly against asking help.
Strength	Personal	All groups discussed having reduced strength to lift heavy items compared to their younger selves, though one participant considered compost bags were too heavy for anybody regardless of age.
Age	Personal	The ageing body was identified as having reduced strength in all groups. Furthermore, one group also mentioned reduced balance, increased back pain, knee pain and stiffness. A participant in another group mentioned reduced height and yet another considered herself getting 'frailer and frailer'.
Steps, stairs and obstacles	Environment	Three groups discussed the challenges of moving compost or gravel bags across steps and in two height differences at doorways were mentioned as a difficulty. The fourth group discussed these obstacles only in relation to moving around, not in conjunction with heavy objects.
Load	Task	Weight of compost in bags was discussed in three of the groups, but with varying focus. One group discussed shape, size and weight of compost bags: 'odd' and 'they flop'. All three groups discussed sizes available for purchase and one of those also discussed the difference in weight of different compost types. Weight of potted plants was also discussed in two of the groups.
Load securing system	Tool	Participants in three groups mentioned the wheeled bases for potted plants were easily overturned and in one group participants stated struggling getting the pot onto the base to begin with. Participants in one group thought that regular wheelbarrows tip easily.
Terrain	Environment	Two groups discussed the difficulty for them to move wheeled objects across gravel and other surfaces (grass, specks, muddy areas, paving with pockets of alpines).
Space available	Environment	Limited space for storage was mentioned in all groups, though only in relation to heavy objects in two of the groups. Sack trucks that fold for storage provided convenience for three participants. Limited space to manoeuver in the garden was mentioned by two participants, one directly in conjunction with moving heavy objects in wheelbarrows along narrow paths.
Interface	Tool	Lack of a handle on wheeled bases was identified as a problem in two of the groups. Compost bags were hard to hold onto according to one participant.

The organic environment of the garden presented some difficulty, with steps, stairs or smaller height differences presenting challenges to many of the participants both with and without tools for

moving items and the terrain presenting difficulties for wheeled tools. Limitations on space available to move around in and limited storage facilities for tools were also mentioned as having an impact. Aside from the weight of the items requiring moving, which participants mentioned as being too heavy to lift, the shape of compost bags complicated lifting and carrying these heavy bags. In relation to tools, the main topics of discussion related to wheeled bases. Pots on wheeled bases were found to easily overturn when being moved and with the wheeled bases lacking handles, participants considered potted plants hard to move.

5.4 Discussion

This focus group study aimed to understand the factors influencing enjoyment and perceived difficulty of various gardening tasks and to identify the problems associated with moving heavy objects in the garden for older women.

5.4.1 Gardening task enjoyment

The participants discussed enjoyment of gardening tasks and identified the reasons for them to enjoy specific gardening activities. The online survey had previously shown that older women did not enjoy gardening tasks to the same extent, with planting, sowing seeds and pruning plants being enjoyed most and gathering leaves and cuttings, mowing the lawn and moving heavy objects being enjoyed least.

The main reasons for older women to engage in gardening activity as found in the online survey could be mapped onto the reasons for enjoying specific gardening activities; when asked to identify why specific tasks were enjoyed, participants often provided characteristics of the gardening tasks similar to the reasons for participating in horticultural activities in general, e.g. relaxing, quiet and solitude and to grow something out of nothing. However, some tasks like gathering leaves and cuttings and weeding were not enjoyed for any characteristics of the tasks, yet were undertaken for the tidy end result. These results suggest that for adherence to gardening, activities that align to the overall reasons for gardening should be emphasized and considered most, whilst those that contrast to these reasons are likely to be sources of discontent and thus possibly negatively affect adherence to gardening overall. Conversely, tasks that provide (too many) opposites of these

characteristics are likely to be decrease adherence, e.g. tasks that require loud equipment, do not provide clear end results or cannot be considered 'relaxing'. This knowledge can provide insights to those interested in the field of adherence to exercise or leisure activities and can be used in the development of gardening programmes and tools aimed at this target group.

Furthermore, when enjoyable characteristics were lacking, the repetitive nature of tasks was mentioned as a negative, though arguably many of the more enjoyable tasks are also repetitive; pruning plants, sowing and planting likely require repeated actions during one session. It is therefore expected the enjoyable characteristics of an activity can negate other potentially negative qualities to an extent. Consequently, older women may be more willing to participate in tasks they might consider difficult or tedious if these tasks do provide sources for enjoyment as well. However, if enjoyment diminishes, participation in horticultural activities could reduce as well. The results of this study indicate participation in horticultural activities that are enjoyed could cause older women to ignore perceived negative qualities of the activities or take the good with the bad. This could mean that older women may be nudged into doing more exercise through gardening activities they enjoy. Though this should be tested in an interventional study, if this holds true, it would be strong support for the potential role of gardening in the physical and mental health of older women and would benefit those developing exercise interventions and policymakers.

5.4.2 Perceived difficulty of gardening tasks

Participants in the focus groups were asked to compare gardening tasks on their difficulty and to describe the underlying reasons for considering tasks difficult. The results were largely in agreement with research previously published that aimed to quantify intensity of the activities. Trimming hedges was found to be a difficult task because of the tool weight and height at which it had to be handled. Trimming hedges is categorised as a moderate intensity activity (Ainsworth et al. 2011b). Other research among professional horticulturalists found this activity generated self-reported pain in lower back, arms and lower legs and the strongest pain was found in the neck (Savitri et al. 2012). The combination of the weight of the tool and the height at which the shrubs or hedges that require trimming are often located were pinpointed by the older women as main contributors to making the activity difficult. Though older women arguably do less of the activity

than professional gardeners, their ageing bodies are likely to have reduced strength and thus the activity impacts them significantly. Participants in the fourth focus group discussed needing something to support their arms as they were holding tools like hedge trimmers. To make this task easier, weight of the tool should be reduced or taken from the hands of the participants to carrying close to the torso or even be taken off the body completely. Savitri et al. (2012) saw a decrease in pain when they provided workers with a trimmer consisting of a power source worn as a backpack with an long-handled trimmer head, though it was not reported whether this tool worked as efficiently as the other tool and some pain was instead experienced in the shoulders.

Both hedge trimming and tree pruning were previously found in the online survey to be two of the least enjoyed and most difficult tasks and tasks older women often left to others. As such provision of lighter weight, more easily manageable tools with sufficient reach would benefit the older women and allow them to partake in hedge, shrub and tree trimming more.

The regular occurring task of weeding was not considered a difficult task by many older women (Chapter 4), however in the focus groups the bending associated with weeding, planting and gathering leaves and cuttings came up as a significant theme. This difference between the studies may be explained by the link between enjoyment and perceived difficulty found in the survey study. Perhaps this has caused older women to consider tasks they enjoy as less difficult, even though when prompted to explore difficulties with gardening, aspects of these tasks do come up as difficult. As participation in these tasks is high, it seems the bending and reaching required does not deter older women from participation and as such, when developing interventions these tasks should be included.

That said, potential may exist for the development of weeding and planting tools that negate bending and low reaching. Although older women are more flexible than older men (Milanovic et al. 2013), flexibility decreases with age (Araújo 2008). Furthermore, bending can cause dizziness, which older women are more prone to (Fernández et al. 2015). In some of the groups methods to avoid bending were discussed, among which participants indicated long-handled tools provided some help, but they could also become unwieldy. Furthermore, participants indicated kneeling pads and stools had some problems; the first were uncomfortable on the knees and impossible for some

to use and get up from and the latter was too high, not wide enough and damaged the lawn. A solution that worked well for one participant was using a yoga ball, which allowed her to sit comfortably and she could bounce herself off when needing to move. Although this method may not work for all, improvement of the tools available to aid in bending may aid older women in more successfully completing several gardening tasks.

5.4.3 Problem scenarios and usability factors

Three scenarios relating to moving heavy objects were found to be the most relevant: purchase of compost bags or similar items and getting them from the front of the house (and the car) to the garden, shed or garage, moving plant and flower pots around within the garden and moving and holding various heavy tools. Although purchase of items like compost bags is likely to be limited to a few instances per year, this scenario generated strong reactions with the participants, indicating that despite low frequency, this activity is one older women have a great awareness of. The lack of available help and the feeling of the items and consequently themselves being stuck, expressed by several of the participants may have caused the strong reactions. Other moving tasks within the garden could be postponed, but arguably there is a sense of increased urgency when new items have just been retrieved and are already in the boot of the car; the activity is already half-way and needs finishing.

Moving potted plants, potted flowers and sink gardens was another scenario receiving considerable attention. Though one participant, not understanding the need to move pots, exclaimed participants should just leave them in place, many indicated a desire to switch around their pots, both aesthetically to change the way the garden looks and functionally; tender plants require sheltered places in the colder seasons. Rather than planting tender plants in beds, the pot is a vessel meant to ease moving and protect these more vulnerable flora from frosty soil. Ironically, these vessels themselves are often heavy and therefore difficult to move. Unfortunately, plants carry much of their weight above soil level and the potted plant can tip unless the pot is of sufficient weight to counter wind forces against the plant. Thus the scenario creates a juxtaposition in which the pot should be heavy to provide stability and lightweight to provide easy moving. Furthermore, even lighter weight pots do not sufficiently lighten the load, with participants indicating attempts to

reduce weight of drainage materials to reduce overall load weight. However, no satisfying solution has yet been found, as it was still experienced by the participants as a scenario that poses significant difficulty.

When asking participants to consider the moving of heavy items in the garden, the tools used in other gardening tasks were often mentioned and subject of complaints. Power tools such as hedge trimmers and leaf blowers received attention. Through lighter weight hedge trimmers are increasingly available on the market (the lowest weight found in the local shops was 2,25 kg), the repetitive and prolonged nature of hedge trimming combined with the postural demands on the body (lifting arms and exerting forces sideways) will likely cause arms to tire and backs to get sore. It is recommended to tool manufacturers that trimmers are developed to suit the older women, as these results suggest that the low participation found in the survey chapter is largely attributable to the tools used.

5.4.4 Usability factors associated with the problem scenarios

Lack of availability of assistance was the most salient issue to contribute to the problem scenarios of moving heavy objects in the garden. In other research, the most used compensatory strategy when it came to garden work was to seek paid or voluntary help (Scott et al. 2015). The reality for many of the older women in the study was that this help was not available, or at least not when required. Some of the older women indicated preferring not to ask and valued their independence strongly, whilst for others there was simply no-one available to ask. Whilst community gardening initiatives exist, in which communal gardens are kept by groups of volunteers or members, assistance in the private garden tends to come from family members, acquaintances or paid help (Chapter 4). Older women however often become bereaved with nearly half living alone and 2.9 million older people (65+) feel they have no-one to turn to for help and support (Age UK 2015). Provision of an infrastructure for local community networks may provide a solution to both social isolation and tending to the more difficult gardening tasks; working on some of the gardening tasks as a team may aid the older women in continuing gardening more successfully and strengthen their social networks.

Reduced strength or fitness due to the ageing body or insufficient strength in general were seen by the older women to be other main contributors to the problem scenarios. Although exercise can reduce the decrease in muscular strength to a degree (Galloway and Jokl 2000), the ageing body naturally becomes more fragile and prone to injury and pain (Section 2.1). It has been found that older adults can recover their mobility after their independence in activities of daily living has been lost, but prevention of loss of mobility is preferred and both an early start to and prolonged effort in physical activities are paramount (Manini 2013). As such, ensuring the requirements put on the older women's physique by the activities of moving heavy objects in the garden are appropriate should be a focus.

One way to reduce the requirements of the older woman's body during the moving activities is through the use of appropriate tools. Where assistance to lighten the load from others may be hard to come by, assistance may instead be provided by utilising products. This was the most common strategy for moving potted plants and compost bags; use of sack trucks, wheeled bases or wheelbarrows to carry the bulk of the load. Although seemingly developed for the garden or at least patio, wheeled bases were found to easily overturn by the participants in this study and their wheels were thought to be incompatible with the garden terrains of many participants. Furthermore, a suitable interface was lacking; participants did not appreciate having to bend and pull at the same time and suggested addition of a handle. These results point towards a need for more appropriate movers for potted plants. For compost bags, some used wheelbarrows and these received some criticism, but more used sack trucks, which they had little negative feedback about. However, the problem scenario for many participants did not seem solved by the use of either tool and more research is required as to the appropriateness of these tools.

The garden's natural environment provided further issues; steps, stairs and other height obstacles were frequently volunteered by the participants as source of difficulty when moving heavy objects. Steps and stairs are a known source of falls in older adults and become more difficult to negotiate with age (Jacobs 2016). Research regarding stair ascent or descent whilst carrying items has been limited and only one publication was found regarding stair ascent using various hand trucks, but this study only looked at force required for varying configurations and did not consider the impact

of these tools on the individual and as such overall usability (Young et al. 1997). More knowledge is required in this field, as tools could have significant influence in successful negotiation of garden related obstacles and thus independence in participation in garden activities.

There were also other usability influences resulting from the garden environment that were mentioned in the groups; participants discussed the different types of terrain and the limited space available to move around, with the terrain receiving the most attention. One participant recalled an instance of tripping over seemingly nothing, and this is consistent with other research, which has found greater variability in the minimum foot clearance of older people compared to younger people during normal gait (Barrett et al. 2010). Although uneven surfaces were seen by some as tripping hazards on their own, the gravel or paving also were seen as problematic in conjunction with wheeled movers, especially wheeled bases. Larger wheels would ease this, however research has found that the ease of pushing wheelbarrows with much wider and larger wheels than wheeled bases was still impacted by surface material, with grass requiring the highest muscle load, followed by gravel, whilst asphalt required the lowest muscle load (Lin 2014).

When discussing moving heavy objects in the garden, the objects themselves were logical topics of discussion and their size, shape and weight especially were extensively discussed. It was previously found that for irregularly occurring lifting tasks (once per five minutes) the average maximum acceptable weight of lift for older women (55-74) was 8.5 kg (Wright and Mital 1999a). Compost bags typically range from 13 litre / 3kg to 35 litre / 24kg. Hence many of the bags on offer are close to or in excess of what older women have indicated as being their maximum lifting weight. Many women in the groups mentioned how smaller bags are more expensive compared to the amount received and they are thus tempted to buy bigger bags, that are then more difficult to handle. The potential for dehydrated compost seems significant, as it can be carried more easily and only be bulked up when needed, though it may not be suitable for every type of compost or soil required.

Whilst watering using a 6 kg watering can was found to be 2.8 METs for older men (65+) (Park et al. 2011), classifying it a low intensity activity, for some of the women in the focus groups lifting and carrying watering cans was a problem scenario as the weight was considered to be too much. For carrying items, the average maximum weight of one-handed carrying was found to be 5.5 kg for

women between 55-74 (Wright and Mital 1999b). Carrying watering cans of around or even above this weight can thus be expected to cause problems. Though decreasing the load by adding less water seems straightforward, in practice the increased frequency was mentioned by participants as making the trip 'not worth it'. Though garden hoses may provide an alternative solution, many still indicated using a watering can and some considered garden hoses 'unwieldy', thus presenting problems of their own.

5.4.5 Limitations

The scope of the study was to investigate the factors influencing enjoyment and perceived difficulty of gardening tasks and identify the problems related to moving heavy objects in the garden, and to build on the general findings of the survey with a more in depth exploration. Inherent to focus group studies, the factors and problems surfacing included only those perceived by the participants and mentioned within discussions. The results therefore are limited to those issues participants themselves are able to distinguish, omitting tacit knowledge. However, though participants may lack the ability to deduce, identify or express every factor or issue, the results are indicative of major points.

Several variables influenced the outcome of the study. Firstly and most significantly, though recruitment took place through various channels, the group of women may not have been representative of all older women that have an interest in gardening in the UK. The participants did not represent all cultural or geological diversity of the UK. The participants however did come from various socio-economic backgrounds, had varying health conditions and varied in ages and as such, it is expected these results are representative of older female leisure gardeners in the UK.

Boards were included on which the gardening tasks were ordered on their enjoyment and difficulty as resulted from the online survey (Chapter 4). It could be stated that providing such a board would make it more challenging for participants to disagree to the views presented or to introduce tasks not included on the boards. However, the boards were used to open discussions and participants were encouraged to consider whether they agreed to the order presented. As the results of the survey study had pointed to moving heavy objects as most in need of improvement, the boards

presented the researcher with the opportunity to take the participants along in discussions surrounding this task, even if they did not consider it a problematic task themselves. Though the boards influenced the direction of the discussion into the tasks included on the boards, the actual content of discussions of factors influencing enjoyment and difficulty of the tasks is not expected to have been significantly influenced.

Focus groups are criticised for suffering from dominant voices; those participants that dominate conversations and do not allow others to voice their potentially dissenting voices. This effect was experienced strongly in 1 of the groups, where 2 participants (who were related to each other) felt strongly about the difficulties with watering and did not consider moving heavy objects a topic worth discussing due to its lack of frequency. Although several other participants did voice their disagreement to this point of view, the further discussions were often redirected towards watering and the researcher struggled to allow other participants to speak. This group therefore spent less time discussing other scenarios of moving heavy objects. The influence of the dominant speakers was minimised by taking care in analysis to check which participants brought up topics and thus establish whether issues were brought up by a single participant or agreed to by several.

5.5 Conclusions

This study aimed to further investigate enjoyment and difficulty of gardening tasks and to identify specific problems with the task of moving heavy objects in the garden. More knowledge of enjoyment and perceived difficulty of gardening tasks was needed in order to understand potential barriers in continued participation occurring in these tasks. Four focus groups were held with older women. Comparison of gardening tasks on enjoyment and perceived difficulty had not been undertaken before and the findings of this study help to understand older female leisure gardeners in the UK better and thus provides focus for further study, development of interventions and improved product design. Though the intensity of some gardening tasks has been investigated and compared, older women had not previously been provided a platform to indicate their issues with gardening activities.

The following findings resulted from this study:

- Enjoyment of specific tasks was found to be closely related to the overall motivations for gardening found in the online survey (Chapter 4) and quiet tasks as well as those with clear results were more enjoyed. The fact that these findings hold true on a task level is significant, as they allow for tasks to be categorised on a more detailed level (e.g. tasks enjoyed for connection to nature, because of the quiet, the neat result etc.), which benefits the development of gardening interventions that are sure to be enjoyed by older women and for which continued participation can be more easily achieved.
- The task or environment inherent challenges of working at height, bending, and frequency of the task made some gardening tasks more difficult than others, notably weeding, watering, planting and tree pruning. Weeding and planting, mentioned in conjunction with bending and low reaching were not found to be considered difficult tasks in the online survey and participation was high. These results suggest overall enjoyment of the activity may cause older women to ignore or forget the difficulties associated with aspects of these tasks. Though more research in the form of an interventional study would be beneficial, it is recommended based on these findings that gardening interventions incorporate these tasks, despite bending and reaching being considered challenging.
- Moving compost bags presented a clear and concrete problem for older women, moving potted plants was also a problem for many and heavy tools were also seen as problematic (leaf blowers, hedge trimmers).
- Environmental factors specific to the garden environment were mentioned frequently as providing challenges to move heavy objects across them and warrant further investigation into their impact on the execution of the task:
    - Steps,
    - Terrain: grass, gravel, slate,
    - Obstacles: lips on garages and sheds, car boots.
- Wheeled bases as often used by the older women were not found to be an appropriate solution; they were said to easily tip and the wheels did not work sufficiently on the

terrains found in the garden. It is recommended they be redesigned to be better fit for purpose.

- Foldable sack trucks were considered good products according to the few participants that used them. Builder's style wheelbarrows on the other hand received mainly criticism for tipping easily and being heavy. Ascender barrows and two or four wheeled wheelbarrows were considered better solutions and one group saw potential in a wheeled garden trolley, though no participant used one. More research into the usability of these assistive devices is required, as little objective information on their performance is available.

In the next chapter moving objects as a key challenge in the garden is further explored. As well as potentially providing physical exercise and exertion, it is a task currently often avoided and one that is required by many, thus inhibiting the continuation of other gardening tasks. Observations were conducted to further investigate the natural obstacles and tools in context to obtain tacit input and in order to make recommendations that will increase the autonomy for older women to do the task of moving heavy objects in the garden.

Chapter 6 Observation of moving heavy objects in gardens

6.1 Introduction

In the previous chapter the focus was increasingly on moving heavy objects in the garden. When moving items in any setting using an assistive device, the ease of moving the object is influenced by factors relating to the tool or device used, the person moving the items, the characteristics of these items and the setting or environment in which the moving task takes place (Mack et al. 1995). In focus group sessions (Chapter 5), some of the main issues when moving heavy objects in the garden were found to be with the tools used to move items, the obstacles posed by the natural garden environment and the characteristics of the loads needing to be moved were found to be important in the focus group sessions. Modification of these factors could improve the particular scenario of moving heavy objects in the garden directly. Within the garden environment, navigating across obstacles, steps and stairs, across varying terrains and within sometimes limited space available to move was considered to be problematic by the focus group participants. Furthermore, the hand-tool interface and load securing system of the tools used and the load weight and hand-load interface were topics of frequent discussion in the focus groups. The focus groups provided indication for further investigation of the environmental, tool and load factors.

The Literature review in Chapter 2 demonstrated that there has not been significant focus on the role of natural obstacles or challenges inherent to the horticultural environment on the usability of moving heavy objects in the garden and more understanding of the nature of the obstacles and the interaction with the tools and loads was needed in order to identify the root causes impacting on the ability of older women to successfully complete the task of moving heavy objects in the garden. With this knowledge, those involved in the manufacture of tools, products to be moved and the construction of the garden environment may be able to develop more appropriate solutions, enabling older women to complete the task of moving heavy objects in the garden successfully and independently.

To consider the physical setting in which older women move heavy objects and the influence of tool, load and environmental characteristics, observations were needed. Observations of workers in farming, public garden maintenance or horticultural settings have been made (e.g. Khidiya and Bhardwaj 2010, Savitri et al. 2012, Nwe et al. 2012, Ng et al. 2013, Gangopadhyay et al. 2005, Jain et al. 2018, Fulmer et al. 2002), though few focused explicitly on moving of objects through carrying or pushing and pulling. Among agricultural children workers in India it was found that carrying of seeds and crops overhead posed no risk and low risk respectively to the young workers (Gangopadhyay et al. 2005), though the method used did not account for the low age of the workers. Though carrying formed part of crop cutting and weeding activities evaluated by Jain et al. (2018), the impact of the carrying part of these activities was not evaluated separately. Lifting fertiliser sacks and moving garbage bags within garden maintenance were found to have medium postural risks (Savitri et al. 2012). In harvesting oil palm fruit weighing between 5-50 kg, lifting and moving the produce in wheelbarrows was qualitatively evaluated and extensive stooping was observed during collection of loose fruit (Ng et al. 2013). Furthermore, the authors identified moving full wheelbarrows as high musculoskeletal risk especially in combination with the uneven landscape and overgrowth. The results of these investigations are difficult to translate to the older woman in her garden in the UK, where the activities are voluntary leisure activities and moving heavy objects is not as repetitively done. No existing observational studies in private gardens or

allotments were found, considering professional nor leisure gardeners. Therefore, observations of older women in their own settings were seen to be required.

The most appropriate method for the evaluation of postural and consequently musculoskeletal risk is Rapid Entire Body Assessment (REBA) (Hignett and McAtamney 2000). REBA is a method to evaluate the physical setting and translate the visual data into a measure for impact on the body of a user (Figure 6.1). This widely used systematic method (Al Madani and Dababneh 2016) was developed for the swift and accurate assessment of whole body postures, external loads and repetition and identify the risk to the musculoskeletal system associated with these postures (Middlesworth 2015). REBA was developed specifically to cope with the unpredictable working postures found in healthcare and other service industries (Hignett and McAtamney 2000), which made it appropriate for use in the garden environment, where the non-standardised settings and loads were expected to generate unpredictable working postures too. The REBA analysis sought to classify the postures occurring during instances of moving heavy objects by the older female participants for their musculoskeletal risk. Subsequently, the instances of highest risk could then be further analysed to identify the influence of tool, load and environmental characteristics contributing to the high risk scores.

Figure 6.1: REBA Employee Assessment Worksheet (Hignett 2000)*. The method provides a single score for the postural risk during work.*

6.1.1 Research question

The study sought to identify specific challenges that may act as barriers to moving heavy objects in the garden. The research questions were:

1. Which components of the task of moving heavy objects in the garden pose significant musculoskeletal risk?
2. Which factors contribute to the significant musculoskeletal risk?

6.2 Method

The focus groups in the previous chapter had researched the thought process and subjective evaluations of the activities, whereas this chapter observed the physical setting and the impact of this on the older women's bodies. This observational study was undertaken to explore the specific problem scenarios, within the gardens of the participants in order to examine the potential impact of the task of moving heavy objects in the garden and identify aspects of the task that require modification through improved tool design, instruction or garden design.

Ethical approval was gained from Coventry University (P46159) (Appendix C for project documentation, including participant information and consent forms).

6.2.1 Study design

This study aimed to obtain observational data in order to identify the impact of the environmental, load and tool related issues found to be of consequence in the focus group sessions. Therefore, the environmental factors considered were steps, stairs and other height differences, the terrains on which moving occurred and the space available in the garden and storage (e.g. shed, garage). The tool factors considered were the hand-tool interface provided, the load securing system available and the overall influence of the use of an assistive tool. Furthermore, the weight of the load and the interface between the hand and the load were considered.

The observations were carried out in participants' own gardens, with their own tools and with the items they considered to be heavy objects in order to capture the breadth of experiences and identify those that required change.

REBA was used to evaluate postures observed, providing an indication of potential risk and thus prioritisation of more problematic situations and identify those most in need of change.

To ensure relevant scenarios were seen, each participant's focus group input was reviewed prior to the session and notes were brought along. Though ideally the study should include the activities in the most natural way during normal gardening routines, the infrequent occurrence and timing of the sessions did not allow this; the sessions were therefore set up to include a tour of the garden to relax participants and a demonstration (talk-through or physical) of the situations mentioned in the focus groups.

The situations with high priority based on the REBA evaluation were subsequently analysed to identify the underlying causes and provide recommendation for improvement.

6.2.2 Recruitment

A small sample was targeted to allow a short but focused study based on specific scenarios. Participants were recruited from the focus group participants (in Chapter 5). Participants with (from descriptions in the focus groups) various garden environments, physical capabilities, tools and situations were selected and asked to participate. Because a physical demand was being asked of the women it was decided not to give an incentive for participation in this study to avoid participants feeling obligated to take part.

6.2.3 Participant characteristics

All participants (N=8, female, age 64-86) were UK citizens living in the West Midlands. Participant characteristics can be found in Table 6.1. All had taken part in the previous focus groups.

Table 6.1: Garden and gardening related characteristics of the observation participants.

Participant characteristics	
Number of participants	8
Age (years)	
Mean	74.5
Range	64 – 86
Gardening experience (years)	
Mean	53.9
Range	22 - 75
Time spent gardening (% of participants)	
1-10 hours per week	38%
11-20 hours per week	13%
>20 hours per week	50%
Type of outside space (% of participants)	
Garden	100%
Location of gardening (% of participants)	
Own outside space	100%
Communal/public/private garden	25%
Acquaintance garden	38%
Ability to do gardening changed over (recent) years (% of participants)	
Yes	100%
Health conditions (% of participants)	
Arthritis	25%
Joint replacement	13%
Other – non-specific conditions	25%
Other – specific conditions	50% Eye condition Ménière's disease Sciatica Heart problems
Estimated garden size (m^2)*	
Small garden (<200 $m^{2)}$	63%
Medium garden (200-400 m^2)	13%
Large garden (400-1000 m^2)	13%
Very large garden (>1000 m^2)	13%
Garden features present	
Steps, thresholds, humps or otherwise uneven surfaces	100%
Railings	38%
Pots	100%
Lawn	88%
Slabs	88%
Stone/wooden paths	50%
Slopes or ramps	50%
Gravel	50%
Narrow paths	25%

*Estimated garden size classified according to the Horticultural Trades Association descriptions (The Horticultural Trades Association 2011). Garden sizes exclude outhouses, sheds, garages and drives but include green houses or conservatories used for plant growing and incorporates both front and back gardens.

6.2.4 Procedure

The sessions took place in late October and start of November 2016. Prior to each session the participants were re-introduced to the study and given the opportunity to ask questions. Informed consent was obtained. The sessions lasted between 1 and 2 hours.

The observations were guided by a protocol to ensure some structure and consistency, but allowing for adaption to the participant, their garden and issues of concern to them. The sessions encompassed a detailed tour of participants' garden led by the participant to get an overview of the garden and allow the participants to get used to the cameras. After that, the researcher asked to see the specific problem scenario that had come up in the focus group, if that scenario had not already been shown. Some participants provided a verbal walkthrough rather than a physical demonstration as either materials were not available or participants were not needing to move the items. The participants were questioned on the situations encountered and given opportunity to comment throughout.

Video and audio data was gathered on five different scenarios of moving heavy objects in the garden:

1. moving compost bags,
2. moving pots,
3. moving leaves and cuttings,
4. moving water for watering,
5. moving concrete slabs.

Full descriptions of the tasks observed or described can be found in Appendix J and include timings for the different subtasks where applicable. As the activities took place in participants' own gardens and with materials available to them, weights and sizes of items differed for each setting.

6.2.5 Data collection and analysis

Using the video footage an observation transcript was made for all the sessions, containing time coding of events, i.e. topics of conversation and tasks being shown. The instances of discussing or

demonstrating moving heavy objects were selected. The routes taken or described were analysed and visual representations were made to represent these routes. The task was more closely examined and a breakdown of tasks and subtasks was made.

REBA was used to compare the physical impact of the different tasks and subtasks with each other. Using the REBA assessment worksheet, for each posture scores were given to sections of the body based on the REBA scoring system. The body sections included were: neck, trunk, legs, upper arms and wrist. Furthermore, the REBA method considered hand-tool interface suitability, the external forces present and how often a posture was repeated, how long it was sustained and whether it was rapidly changing or caused an unstable base. The obtained scores per section were used to look up total scores in provided conversion tables. The postures observed were categorised according to the REBA classification (negligible, low, medium, high and very high risk). REBA defines medium tasks as requiring further investigation and change soon, high risk as needing further investigation and change implemented and very high risk as tasks for which change needs to be implemented.

The resulting medium and higher risk postures were subsequently analysed to determine contributions of environmental, tool and load factors.

The various postures observed were scored according to the REBA method by two researchers separately. Inter-rater agreement was 88% and consensus was sought. To give the REBA scores, the most extreme posture within a subtask was selected and used and the more extreme limb was used in case of asymmetrical movement.

6.3 Results

Observations of moving heavy objects were undertaken in older women's gardens. The results are presented to identify the root causes of difficulty for older women to complete the tasks requiring moving of heavy objects and by doing so provide recommendations on how best to overcome these issues for older women, tool manufacturers and those otherwise involved. To this end, REBA-evaluated postures occurring during the execution of these tasks are presented and prioritised to identify the situations in which significant risk occurred to the older women. Subsequently, further

analysis of these situations is presented per influencing factor category (environmental, tool and load). A summary of the observations relating to moving heavy objects can be found in Appendix J.

6.3.1 REBA analysis

The participants moved various heavy objects and the video data of these instances was used to select relevant subtasks and key participant postures of these subtasks. The postures were subsequently analysed using REBA scores to determine the subtasks of interest. Of the subtasks, 41% received medium risk scores, 24% were found to be high risk and no tasks were classified as very high risk (Table 6.2). The REBA method indicates medium and high risk tasks be investigated further and changed to avoid injury.

Table 6.2: REBA scores for the moving heavy items subtasks with medium and high scores.

	Subtask description	REBA Score	Participant
High REBA score	Lifting compost bag from ground	10	1
	Opening door whilst holding compost bag	10	1
	Lowering compost bag onto sack truck	10	3
	Carrying compost bag up steps	9	1
	Lowering sack truck whilst descending down steps	9	2
	Lifting potted plant	9	3
	Pulling potted plant off sack truck	9	3
	Pulling potted plant onto sack truck	9	5
	Setting down compost bag on shed floor	8	1
	Lifting watering can	8	2
	Dragging compost bag from boot of car	8	4
	Lowering compost bag onto sack truck	8	4
	Open foldable sack truck	8	3
Medium REBA score	Carrying compost bag on level ground	7	1
	Turning tap on watering butt	7	2
	Picking up trug with cuttings from step	7	2
	Setting down trug with cuttings on step	7	2
	Lifting compost bag from ground	7	7
	Setting down potted plant	7	3
	Carrying potted plant	7	3
	Setting down watering can	6	2
	Folding up sack truck after use	6	3
	Lifting potted plant	6	7
	Setting down potted plant	6	7
	Lifting potted plant	6	3
	Emptying trug with cuttings in recycling bin	5	2
	Getting sack truck ready to move when loaded with compost bag	5	3
	Getting sack truck ready to move when loaded with potted plant	5	3
	Stepping up step	4	2
	Altering empty sack truck direction on level ground, in limited space to manoeuver	4	2
	Lifting trug with cuttings	4	2
	One-sided carrying of trug with cuttings	4	2
	Setting down trug with cuttings	4	2
	Dragging compost bag from boot of car	4	3
	Pulling potted plant onto sack truck	4	3

6.3.2 Environmental

Rather than from ideal working height, loads in many cases had to be lifted from and set down (close to) ground level. The lifting or lowering stage of the tasks therefore generated many of the high and medium risk scores. A bending posture was seen in 62% of the high risk score subtasks and in 60% of medium risk subtasks.

Figure 6.2: Subtasks influenced by environmental obstacles. Top row: high REBA risk score. Middle and lower rows: medium REBA risk score.

Other subtasks with high REBA scores that were influenced by the environmental circumstances involved steps, pulling a compost bag from a car boot or a participant having to open a sliding door whilst holding on to a compost bag singlehandedly (Figure 6.2, top). Furthermore, several of the medium scoring subtasks were interactions taking place on a step, one relating to the boot of a car and one influenced by the limited space to manoeuver (Figure 6.2, lower).

6.3.3 Load

For 62% of high scoring tasks, the load weight was over 10 kg, and for 38% load weight was estimated between 5-10 kg. For the medium risk scoring tasks, 14% involved a load weight of over 10 kg and 64% involved a weight between 5-10 kg. The varying weights of the loads observed proved to be an issue for several participants; two participants worked together to unload 70 L compost bags from the car as they stated not being able to do this alone, the weight of a terracotta pot was found to be too high for one participant, one participant remarked part-filled (estimated <5 kg weight) watering cans were too heavy to hold for any length of time and another participant stated only moving some of her pots, as some of her bigger pots and a small sink garden she was unable to move (Figure 6.3).

The participants picked up the compost bags by the edges, which required them to use pinch grips (Figure 6.4, left). Similarly, the pots were picked up or lifted by an edge to put them on the sack trucks. These edges offered better grip than the compost bags, albeit not ideal, as they made participants bend or twist their wrists (Figure 6.4, right).

Figure 6.3: The influence of weight of the load. Weight was too high for some, with participants avoiding moving heavy pots (left), working together (middle) or giving up when unable to lift the load (right).

Figure 6.4: Influence of different grips. Left: participants held the compost bags by the edges, making for an awkward pinch grip. Right: example of bent wrist and acceptable but not ideal hand hold on edge of potted plant.

6.3.4 Tool

Two participants did not use a tool at all to move compost, whilst the others used sack trucks during the moving. None of the participants used wheelbarrows during the observations, and only one participant mentioned a wheelbarrow at other times. None of the participants had any wheeled bases to move potted plants that were still in working condition and as such this tool was also not seen in use.

Influence of using a sack truck

Using sack trucks appeared to alleviate many of the risks whilst participants were moving objects on level ground, with pushing full bags on sack trucks receiving low or negligible risk scores in REBA compared to a medium score for carrying a partially filled bag of compost. However, both before and after the objects were on the sack truck, the participants were required to bend and to get the bags onto the sack trucks, which were the subtasks with some of the highest impacts.

In addition to the impact of initial loading and removing of the load, the use of the sack truck scored poorly going down steps; it made one participant adopt a posture that was scored high risk as it required slight bending, twisting in the back, balancing on a single leg and a backwards extended arm on the railing (Figure 6.5, middle). Finally, after loading, the sack trucks required a hinging motion to get them from upright to pushing position. To do this, the participants pushed the sack truck forward with a single foot whilst simultaneously pushing down or pulling on the sack truck

Figure 6.5: Influence of using a sack truck. Left: one participant showed her tactic for getting compost out of the boot of her car. She set down the handles of the sack truck on the edge of the car boot and slid the bag down across the handles. She stated this technique worked very well for her. Middle: posture observed whilst participant was letting a sack truck down the steps. The participant would lower the sack truck a step at the same time as she was taking a step down. Right: the sack truck had to be pushed out with a single foot to get its centre of mass moved on top of the wheel base, and this created an unstable posture for the participants.

handle (Figure 6.5, right). This action caused instability and asymmetry in participants' postures, and received medium risk scores because of this.

Hand-tool interface

A range of tools were used to provide grips, with plastic trug, watering can and washing rack (used to store smaller potted plants) providing power grips for the participants, and sack trucks also provided appropriate handles (Figure 6.6).

6.1 Discussion

This observational study set within the garden of older women was intended to identify the environmental, load and tool related factors impacting on the usability of moving heavy objects in the garden by older women. This knowledge was needed to identify the barriers for older women to successfully and continually partake in horticultural activities. The individual and combined influence of environmental, load and tool factors are discussed in corresponding sections below.

6.1.1 Environmental

The garden environment was found to impact on the tasks of moving heavy objects by the older women in several ways. The most significant finding related to the bending induced by the required

Figure 6.6: Appropriate handles on various tools. The foldable sack truck (top left) provided a narrow hold, suitable for singlehanded operation, however both participants that used the product opted to use both hands instead. Lower right: although providing a good grip, the participant had to lift the wash rack she used to store pots beyond comfortable height to keep it off the ground when carrying the pots.

start and end locations of the heavy loads; most were kept at ground level. Bending is a known source of lower back pain (Hoogendoorn et al. 1999) and bending postures have been observed in various other gardening tasks, e.g. weeding, harvesting and pruning (Park and Shoemaker 2009).

Increasing the starting height of lifting from floor level to hip level reduces low back loading (Faber et al. 2009). There are various ways to increase start and end height. Raised beds can provide a solution for parts of the garden, but pots tend to be kept on patios or paved areas. Raising pots onto stands might provide a solution for some, but there are potential downsides in both aesthetics and stability, as big plants need a heavy base to stay upright, and a raised platform might not provide the required stability in all weather conditions. Furthermore, compost tends to be kept in sheds or garages until use, and keeping it at a higher level in these locations may not be possible and could impede storage space and manoeuvring to get to other garden equipment. Where the environmental conditions cannot be modified, potential seems to exist for a manual moving tool that would negate bending and aid the user during loading and unloading.

Steps were also found to impact on the older women's ability to successfully move heavy items. REBA scores for moving objects on full sized steps were high compared to moving these objects on level ground, confirming their impact on moving tasks. Stairway falls result in a high risk of death or severe injury (Jacobs 2016). Standard step height and tread should be lower and longer (Hsue and Su 2014) and an appropriate handrail should be provided (Jacobs 2016). Where environmental obstacles cannot be modified, use of an appropriate tool may aid the older women in crossing steps. Though manual moving devices such as sack trucks have been developed specifically for moving loads, the sack truck arguably is not suitable for use on a step; the sack truck was seen to contribute negatively to navigating steps, generating one of the highest REBA scores. Rather than providing stability, the sack truck is another element the older women have to control. An assistive device that would provide the older women with more stability whilst carrying the load for them on the steps would likely benefit them. Tri-wheeled sack trucks exist, specifically designed to cope with ascends and descends on stairs and may be appropriate solutions, however their usability for the older woman and on the varying step heights and sizes as seen in the garden is unknown. Similar to the mechanisms often seen on trolleys at airports, an assistive tool that would block unless a lever is pulled may provide a means of support on steps. However, incidental comments in the focus group sessions regarding the handles on lawn mowers suggest a lever that needs to be squeezed continuously may provide difficulty on the hands. Another alternative could take the form of an autonomous device, which would eliminate the need for the older woman to descend or ascend steps and control a tool simultaneously. In today's world, this would however seem over-engineered and would make the assistive device considerably more expensive. A simple mechanical system with a retractable pulley may be a suitable solution, allowing older women to either lower loads down or pull them up without having to be on the steps whilst doing it.

6.1.2 Load

The tasks observed required the participants to lift and move loads of varying weight and dimensions. Objects that the average person perhaps would not consider heavy (e.g. a part-filled watering can or compost bag) had a great impact on some participants, who had to employ alternative strategies to move these objects. In one case, participants were seen to work together to

retrieve a compost bag from the car boot, however these participants had purchased larger, 70L compost bags and this resulted in similarly high REBA risk scores as those participants lifting smaller compost bags alone. Though this is an incidental report, it is suggestive of an attitude that came across in the focus groups as well; one of finding limits in lifting and carrying and perhaps even crossing these limits, neglecting risks attached. It would be interesting to further investigate this attitude amongst older women, as it could mean that any assistive devices developed to ease carrying may also increase the amount of weight carried. This would be a similar scenario to the transition from lifting and carrying to pushing and pulling using carts in industry, which had not led to the expected reduction in musculoskeletal overexertion injuries (Mital and Ramakrishnan 1999, Todd 2005).

To reduce weight, various strategies were found to be used by older women (e.g. dehydrated compost, splitting up bags of compost, Styrofoam as drainage material in pots rather than gravel) (Chapter 5). However, where weight remains an issue, solutions to reduce the manual moving of these weights could benefit the older women not just in the specific scenarios seen within the garden, but also in other tasks of daily living, e.g. grocery shopping. Within the journeys made as seen in the observations, the most crucial stages in which older women would require assistance are the lifting and lowering of items, as existing tools do little to help in these stages. In the focus groups some women suggested a 'draw-bridge' system, in which a wheeled mover could first be placed around the pot and through its closing mechanism would lift the pot of the ground. Though an interesting idea, the challenge would be stability of the pot on this mechanism and the suitability of the system to any pot size, but the findings are indicative of a need for the older women to have help with the lifting and lowering part of the moving sequence.

Load weight alone does not determine the risk; the manner in which the weight is handled greatly influences the overall musculoskeletal risk of the activities. The hand-product interface was not optimal for some of the observed situations, especially regarding pots. A full cylindrical grasp provided by suitable sized handles would reduce the strain on the hands, especially if oriented to provide limited pronation of the lower arm. Though handles should ideally be located near the body to reduce shoulder flexion, the centre of mass of the pot would then potentially cause imbalance,

resulting in ulnar deviation which would have to be countered. As such the optimal placement of the handles should be so that the pot and plant are balanced when picked up. However, even with better handles, picking up and setting down the loads seen in the observations would cause problems. Rather than optimising only the handles when the larger system needs revising, it is suggested that the hand-held lifting and carrying of heavy loads is removed through the use of an appropriate assistive device instead.

6.1.3 Tool

Tool characteristics were found to impact on the ability of older women to move heavy objects in their gardens. The participants in the study used sack trucks or manual lifting and carrying to move items in the observations. Counterintuitively, it has been found in other research that changing a task from manual lifting to pushing or pulling using an assistive tool does not necessarily decrease musculoskeletal strain, and pushing and pulling in industry accounts for a significant proportion of musculoskeletal injuries and complaints (Todd 2005). In this study however, REBA scores for using the loaded sack truck to move items on level ground were low risk activities, whilst manual carrying received low or medium risk scores, thus suggesting the use of a sack truck on level ground benefitted the participants. This may be explained by the limited loads on the assistive tool compared to industry, where the physical limits for pushing and pulling are more than double compared to lifting and carrying (Todd 2005), and this may cause operators to increase load per trip, resulting in similar risk levels to the musculoskeletal system as when lifting and carrying smaller loads.

The loading and unloading impacted greatly on the overall usability of the sack truck as participants were seen in high risk bending postures. The load is kept higher off the ground for wheelbarrows, which were not used in any observations, however participants would then still have to lift items into and out of the wheelbarrow. Ideally, a tool for moving would be able to adapt to the height required and would help older women during the loading and offloading.

Using a sack truck to transport a load down steps caused a high risk posture in which the participant had to control the sack truck as it was lowered down each step whilst stepping down

herself as well. Pulling a load up onto a step was not seen, but for higher steps would mean the majority of the weight would have to still be lifted by the person. For sack trucks it has been found that on fixed step size, decreased wheel size and increased load increase the average force required to pull a sack truck up a flight of stairs and increased load also increases the average peak force (Young et al. 1997). Review of the performance of sack trucks versus wheelbarrows on the varying obstacles found in the garden however has not been undertaken and further research into the usability of these tools on the kinds of steps and obstacles seen in the observations is needed. As risk of falling from stairs is already significant for older people (Mustafaoɫlu et al. 2015), addition of a device that in itself must be controlled is likely to increase this risk. Potential seems to exist for an assistive tool that would allow older women to move items across height differences without causing instability.

Participants in the study were seen to start the sack truck using one foot to push it out, which received a medium REBA risk qualification, mainly due to the potential instability of this method. In a lab based study of cylinder trolleys, which are operated in similar fashion to a sack truck, feet were not used to start the movement (Okunribido and Haslegrave 2003). The use of the foot reduced the amount of inward and downward oriented pushing of the arms which eased the subtask of starting the sack trolley. The downside however is decreased stability as participants lean down on the tool whilst simultaneously pushing the tool out with their foot. More research would be needed to identify whether this is a significant risk for falls for the older women.

6.1.4 Observations of work adaptions

The observations enabled identification of ways in which the participants adapted tasks to their own capabilities and developed ‘work arounds’. These work arounds can provide useful insights, as they show the situations which older women identified as problematic.

The loading and unloading, which was seen to be a high risk task when undertaken manually, was made easier by some participants. One participant described sliding a compost bag from the boot of her car across the sack truck handlebars to avoid setting it down on the sack truck. Furthermore,

Figure 6.7: One participant used products not intended for garden use to help her in the garden; a wash rack to group small pots and make them easy to move, a shopping trolley to carry cuttings, compost and tools and an end of PVC pipe to increase her range and make a full pot easier to water.

participants were seen to tip the sack truck forward when unloading compost bags, which negated the need to bend down during unloading.

Many of low and negligible REBA risk scores were given to the activities of a single participant, who was very keen on utilising whatever she could find and using it to make activities easier for her. As she stated having problems bending down, she had generally become inventive to work around this. This participant tied her short handled tools to a broom to create long-handled tools, had come up with the use for a wash rack as a pot collector, had used old shopping trolleys to carry tools and cuttings and used a section of PVC pipe to allow her to easily water plants in pots (Figure 6.7).

6.1.5 Limitations

The observations provided new insights and highlighted some areas in which more research is needed. However, in the very varied environment of a garden, it can be stated with some certainty that not all situations of interest were observed. The seasonal nature of for example purchasing compost bags, which tends to be done in spring or summer, reduced the number of situations of interest observed. Furthermore, participant numbers were limited and as it would have been unethical to coerce the participants into showing situations they were not happy to volunteer, some situations that had been described in the focus groups were not demonstrated during the observations or only gestured. However, many observations were still made and the diversity encountered is expected to cover at least some of the variety seen.

The varied environments seen in the gardens made observations from ideal angles difficult; in a few occasions, the researcher ended up behind the participants, thus making accurate observation of the arms and particularly wrists challenging. This was solved by looking at combinations of several frames of the video for the same subtask, but an additional camera operator would have been beneficial, albeit more intrusive to the participants.

REBA was developed for healthcare and other service industries (Hignett and McAtamney 2000) and only a single application considering limited tasks in professional horticulture was found (Savitri et al. 2012). This is the first time it has been applied in the context of moving objects for older women. The frequency and longevity of a task are part of a REBA assessment, but were not applicable to the moving heavy object tasks observed. However, an extreme posture could have an impact even without repetition; loosing balance, overextending joints or overexerting muscles could affect anyone and the ageing person in particular even with a single instance.

The REBA assessment has been developed with people of working age in mind. One participant mentioned lifting and carrying a watering can had become nearly impossible, but REBA analysis of her posture lead to a low risk score, thus not accurately describing her experience. The risk scores therefore may need adjusting to this older participant group, increasing scores overall.

As the REBA method provides ranges of angles, weights and frequencies, its accuracy is limited. In this study for example the difference between walking up a slope and walking straight was not distinguishable, even though the risk to the older person may be quite different. It was not feasible to measure the weights of each heavy item, but estimation of the weights could be done to the level of detail required by REBA.

6.2 Conclusions

It is task inherent that certain items will have to move from one place to another in the garden. This study set out to investigate the impact of environmental, tool and load factors on the ability of older women to move heavy objects in their gardens. The following findings resulted:

- The bending to lift and lower loads to ground level significantly impacted the difficulty of the moving tasks. This lifting and lowering still occurred in those scenarios where an

assistive device in the form of a sack truck was used. Development of a device that would circumvent the bending in the loading and unloading phases would be beneficial.

- Steps and height differences were seen in many gardens, and navigating them whilst carrying loads or manoeuvring a sack truck created situations of high musculoskeletal injury risk. The sack truck was a source of added instability rather than assisting the user. However, only one type of sack truck was seen to be used, and more research is needed on the use of tools on steps to determine their usability in the garden for the older woman.
- The weight of the loads used varied, but there seemed to be a tendency to lift as much as they thought possible. The implications of this would be that the older women will still find the limit of their abilities, meaning that even if the assistive device would help reduce the effort, this would in turn tempt the older women to increase the weight carried and thus not result in a reduction of musculoskeletal injury risk. More research would be required to determine whether this incidental result holds true for the larger population of older female gardeners.
- The frequent lack of appropriate handles to lift and carry items made successful completion of the task of moving heavy objects in the garden harder, and though improved handle design would not negate the larger problems associated with the lifting and lowering of heavy items and the moving across height differences in the garden they would make lifting and carrying of smaller pots and compost bags easier.
- To induce initial movement, a foot was used to push the sack truck forward. This decreased stability, but more research would be needed to identify whether this is a significant risk for falls for the older women.

This chapter has demonstrated one particular tool (REBA) for analysing activity in a real world setting that has highlighted some particular issues and helped explain why certain tasks prove challenging and undesirable. Whilst research on bending and lifting is plentiful, moving loads using an assistive device, and in particular across the height differences often seen in the garden has not been topic of much research. In the next chapter these will be explored further in a controlled environment with the aim of identifying the impact on the older woman's body whilst using various

common garden movers in order to provide recommendations for appropriate tool use and tool design.

Chapter 7 Biomechanical analysis of loads on the body when moving heavy objects over steps

7.1 Introduction

From the studies detailed in Chapter 4 (survey amongst leisure gardeners), Chapter 5 (focus group sessions with older women) and Chapter 6 (observations in the garden) moving heavy objects in the garden became the focus as it was found to be the task least enjoyed and most difficult. As a result the activity was found to often be avoided. Furthermore, it was discovered many older women faced similar problems with the task in which the heavy objects needed to be moved across a garden environment not ideally equipped for this. The observations showed that one associated problem were the height related obstacles often encountered en route when moving heavy objects potentially reducing the benefits of the tools used and adding difficulty to the task of pushing or pulling a load around the garden. To remove this challenge and allow the older woman to safely and successfully move items herself, use of appropriate assistive devices is important.

Tools can be used to transport loads, thus minimising (to an extent) lifting and carrying, but their use on obstacles in the garden has not been a topic of extensive research. From the existing literature (Section 2.6) it was clear that many studies have been conducted on pushing and pulling for a variety of applications and with a variety of tools. However, the consideration of obstacles as

encountered in a garden environment has been limited. Only one study tested the performance of variations of sack trucks on steps, though not considering impact on the body (Young et al. 1997) while no studies were found to relate to a garden setting nor to gardeners themselves.

In this chapter, a biomechanics study was conducted to investigate the influence of some of these obstacles on using a tool to move heavy objects. Biomechanical assessments using motion capture in combination with force plates is often applied to gait patterns and the applications extend to sports and workplace movement (Madeleine et al. 2011) and has proven quality of data and validity of findings (Bouillod et al. 2016, Eichelberger et al. 2016). It has been applied to manual materials moving (Glitsch et al. 2007, Lee et al. 1991) as well as stair ascent and descent by elderly people (Reeves et al. 2009). In the garden, the only discovered applications of the method considered digging (Shippen et al. 2017) and shovelling (Shippen et al. 2015).

7.1.1 Research questions

In the absence of existing quantitative biomechanical information on the loads within the body, this research aimed to determine the impact of navigating environmental obstacles in the garden on the body by providing objective data on the manual forces exerted and the joint contact forces and torques experienced by older female leisure horticulturalists using a range of gardening tools on several obstacle heights. This data was used to identify the influence of tool, environmental obstacle and personal factors and provide recommendations on tool design and use in this type of situation as often encountered in the garden. The research questions for the situation of moving various common assistive gardening devices across obstacles of varying heights were:

1. What is the magnitude of manual forces exerted and resulting impact in the main joints of the body?
2. Which personal, tool and environmental factors influence moving heavy objects across obstacles of varying heights and to what extent?

7.2 Method

In order to gather the force and movement data required, motion capture in combination with force plate data was the chosen method, being a well-established method to calculate forces acting on the body and the loads occurring within the body. This method has been applied extensively at Coventry University and the software package Biomechanics of Bodies (BoB) (Shippen and May 2016) had been developed in-house specifically for this purpose. The study was established to test various existing tools, steps of different sizes and to emulate some of the variety of obstacles found in actual gardens. Manual forces were calculated and the shoulder and lower back joint contact forces and torques were considered as these are commonly associated with chronic and acute injuries in physical activity for older women (Figure 7.1). Furthermore, lower extremity joints of the knees and hips were included in the analysis.

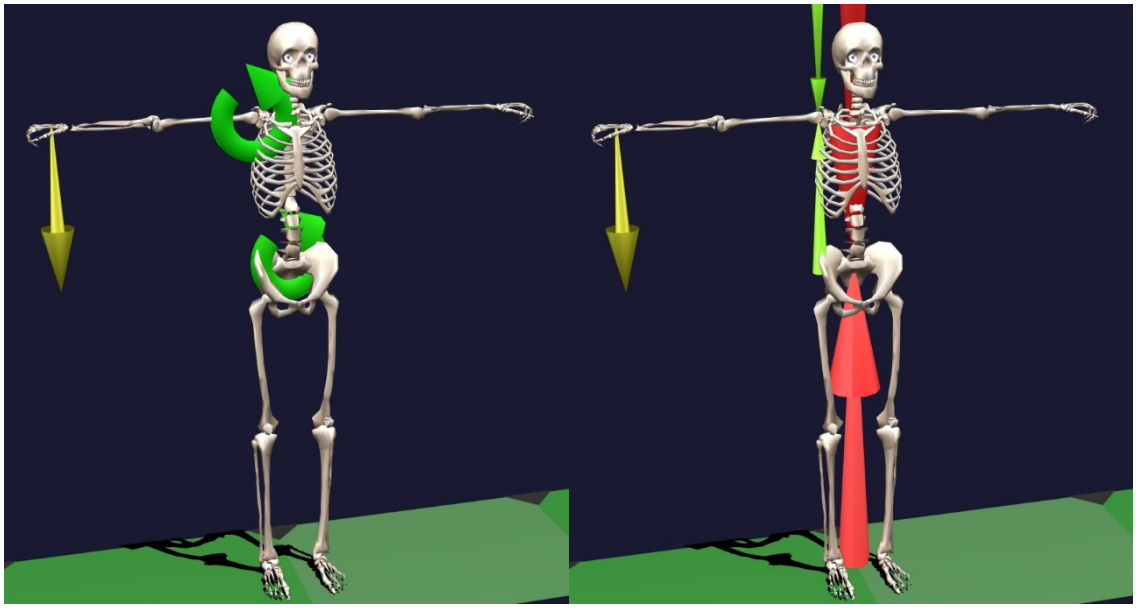


Figure 7.1: Example of the effect of external forces on joints in the body. An external force (in this case, a manual force on the right hand) is exerted on the body, e.g. because the person is holding an object. The external force generates torques and forces in the shoulder and lower back joints. To maintain the posture shown, forces and torques therefore need to be generated by the person to compensate. This is done through the limiting freedom in the joints (i.e. the structures themselves; passive compensation) and through muscle activation (active compensation). Damage to the structures and muscles may occur when external forces become too great to compensate.

Subjective scoring evaluations were added in between trials and a short interview was conducted afterwards. This type of data helps to provide meaning to measurements that might otherwise be

difficult to interpret or explain. The Borg scale for perceived exertion was used (Borg 1998) to capture overall exertion and combined with a body diagram for perceived discomfort to capture any local discomfort due to the use of the tools, similar to Corlett and Bishop (1976). The brief interview afterwards allowed the opportunity to evaluate their experience during the trials and ask about previous experience with the tools.

7.2.1 Ethics

The project was approved by Coventry University's ethics process, project number P52669 (Appendix D). Because of the physical nature of the study and the potential frailty and thus risk involved in having older participants, great care was taken to ensure their safety both during recruiting and on the day of the study (see also section 3.7).

7.2.2 Obstacle development

The obstacle heights used in the trials were 30, 60 and 90 mm. The 30 mm was used as it resembles the height of a door threshold or tree root across a path. A normal UK step size for private dwelling according to building regulations has a minimum rise of 150 mm (HM Government 2013). For this study, the maximum of 90 mm was chosen because although steps of larger height are encountered in the garden, it could be reasonably expected that alternative measures would be taken for steps at or over this height, e.g. creating a ramp out of a piece of wood, adding a brick before the step, finding an alternative route or waiting for help. One observational trial participant used a sack truck on approximately 200 mm high steps, but only to move loads down the step, pulling it back up once empty.

To accommodate for the force plate height, elevated floor panels were used. The tools required different distances between feet of the participant and the obstacles. The obstacles were therefore attached to a floor panel with clamps so they could be moved to the correct location quickly and

easily (Figure 7.2). Pins were added to the bottom plank so additional levels could quickly be added.

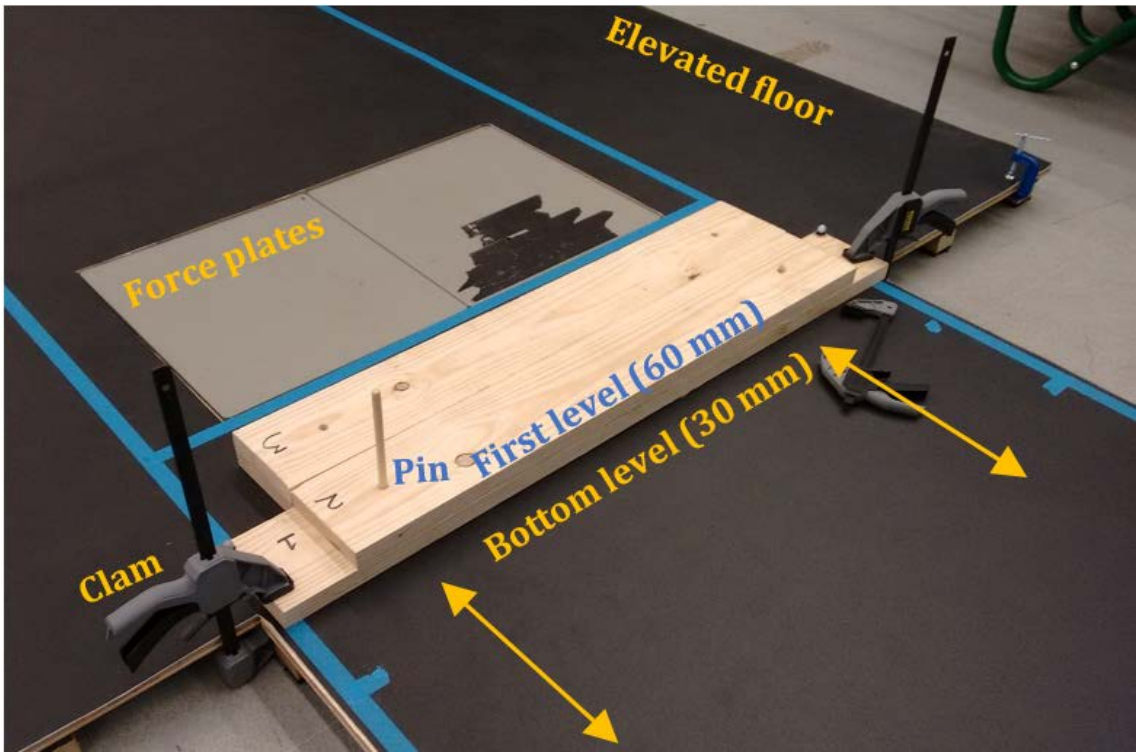


Figure 7.2: Increasing obstacle height was accomplished by stacking wooden planks of 30 mm thick on top of each other. As the force plates were at a fixed location, but the different tools required varying distance from the feet, the distance of the obstacles was modified as required per tool by moving the planks further or closer and clamping them to the floor panels.

7.2.3 Tool selection

Many tools for moving heavy objects were mentioned by participants in the focus group sessions (Chapter 5). The most frequently mentioned were different types of sack trucks and wheelbarrows. A wheeled garden trolley was included as it was discussed at length in one of the groups. In relation to cost, participants suggested a price of around £20 was deemed reasonable for a tool for moving heavy objects. For this study it was therefore decided to include only tools at the lower end of the price spectrum of available tools, costing up to £50.

Figure 7.3: The tools included in the study. From left to right: puncture proof tyre wheelbarrow, inflatable tyre wheelbarrow, garden trolley, foldable sack truck and three wheeled step climber sack truck.

Through a combination of websites, shop / garden centre visits and a discussion with RHS gardening advice expert a variety of appropriate products were identified. These were the Walsall Easiload wheelbarrow with two different wheel types, two very different types of sack truck, varying in weight, handle height, handle type, and wheel type and finally, one wheeled garden trolley (see Figure 7.3).

7.2.4 Tool characteristics

The tool characteristics are detailed in Table 7.1.

Table 7.1: Characteristics of the different tools included in the study.

	Tool mass (kg)	Compost bag mass (kg)	Wheel radius (mm)	Wheel axle to handle (mm)	Between handle distance (mm)	Between wheel distance (mm)	Effective width of wheel(s) (mm)
Puncture proof tyre wheelbarrow	9.9	6.5	168	1180	485	-	15
Inflatable tyre wheelbarrow	9.5	7.2	175	1180	485	-	60
Wheeled garden trolley	1.7	7.1	65	770	-	290	35
Foldable sack truck	4.1	6.9	88	895	-	463	35
Three wheeled step climber	11.5	6.5	75*	900	380	427	35

* The step climber consisted of a tri-star configuration, in which three smaller wheels (of which radius is reported in the table) were fitted in a larger structure rotating around a secondary axis. Distance between axis of superstructure and of individual wheels was 105 mm.

Table 7.2: Participant characteristics.

Participant	Age	Height (cm)	Weight (kg)	Stated injuries or impairments
1	66	162	41.4	-
2	75	158	77.6	Mild arthritis of the hands, knee replacement
3	75	162	82.7	-

7.2.5 Recruitment

The target group for this research utilised our existing database of respondents, the inclusion criteria were:

- Female;
- 50+ years old;
- Leisure gardener with at least two years of experience;
- Good overall health (no chronic or acute illnesses or injuries, apart from mild arthritis).

7.2.6 Participant characteristics

Those who responded positively to the invite to take part where further screened and three female respondents took part in the study (Table 7.2). The participants had different levels of experience with the tools used in the study. Participant 1 stated in the post-trial interview that she owned wheelbarrows, a sack truck and had previously owned a garden trolley of similar design to the one used in the trials. The other two participants both only owned metal framed sack trucks, with frames similar to the step climber sack truck in size, but with two wheels like the foldable sack truck.

7.2.7 Equipment

A 12 camera optical tracking system (MX40: ViconMotion Systems, Oxford, UK) was used to capture the movements of the subjects. The twelve cameras were set up around the area in which the subjects would be moving at a distance of approximately between three and six metres away, ensuring the relevant part of the trial was captured sufficiently from all sides whilst keeping the

quality of the capturing as high as possible through limiting the distance. The heights at which the cameras were placed was between one and three metres, alternating between high, medium and low heights to create an optimal grid to capture the marker reflections. The cameras were aimed and (re)calibrated using the Vicon Nexus software system until all cameras reported limited errors and the area was sufficiently covered. The system capture rate was set to 100 Hz as the low speed of anticipated movement did not warrant a higher capture rate which would have a penalty of requiring higher storage and computational resources.

Participants were given tight-fitting Velcro-covered suits and were markered using the Vicon system markers. Markers were placed at the following locations:

- Head: Right front, left front, right back, left back,
- Upper torso: C7, T10, xiphoid process, clavicle notch, right mid back,
- Arms: shoulder, upper arm, elbow, forearm, wrist bar, top of hand
- Lower torso: right anterior iliac spine, left anterior iliac spine, right posterior iliac spine, left posterior iliac spine,
- Legs: thigh, lateral femoral epicondyle, shin, calcaneous, second metatarsal head, lateral malleolus.

To measure manual force exerted by participants, force plates (e.g. Lee and Aruin 2015) or load cells (e.g. Boyer et al. 2013) are often used in laboratory settings. Load cells are mounted onto the handle of the product being used or the test rig on which force is to be exerted. In this study, it was opted to estimate the manual forces from the ground reaction forces using force plates. The addition of load cells onto each of the tools, connected to a suitable processor, would require considerable instrumentation. Furthermore, it would alter how natural participants would be able to interact with the tools as both weight of the load cells and existence of wired connectors would likely inhibit natural interaction. If the acceleration of the centre of mass of the subject is assumed to be small relative to 1g, the force acting between the subject and the tool can be estimated by the difference between the subject's weight and the force measured by the force plates (Figure 7.4).

The force plates (OR6-7: AMTI, http://www.amti.uk.com/products/or6-7-force-platform.php) have a capture rate of 1000Hz. To reduce some of the environmental vibration noise, a viscoelastic liquid containing siliconepolydimethylsiloxane was inserted between the force plates and the floor. When the tool was pushed or pulled over the obstacle the participant had both feet on the force plates or one foot in the air and one on the force plates.

The full trial was filmed with a single video camera at fixed position to enable reviewing of trials if needed. The participants were audio recorded for the interview after the motion capture had finished.

7.2.8 Procedure

To set up the markers and initiate the motion capture system the participants assumed the standardised 'motorcycle' pose. This enabled the system to establish their personal model and enabled the Nexus software to automatically label the markers in subsequent trials.

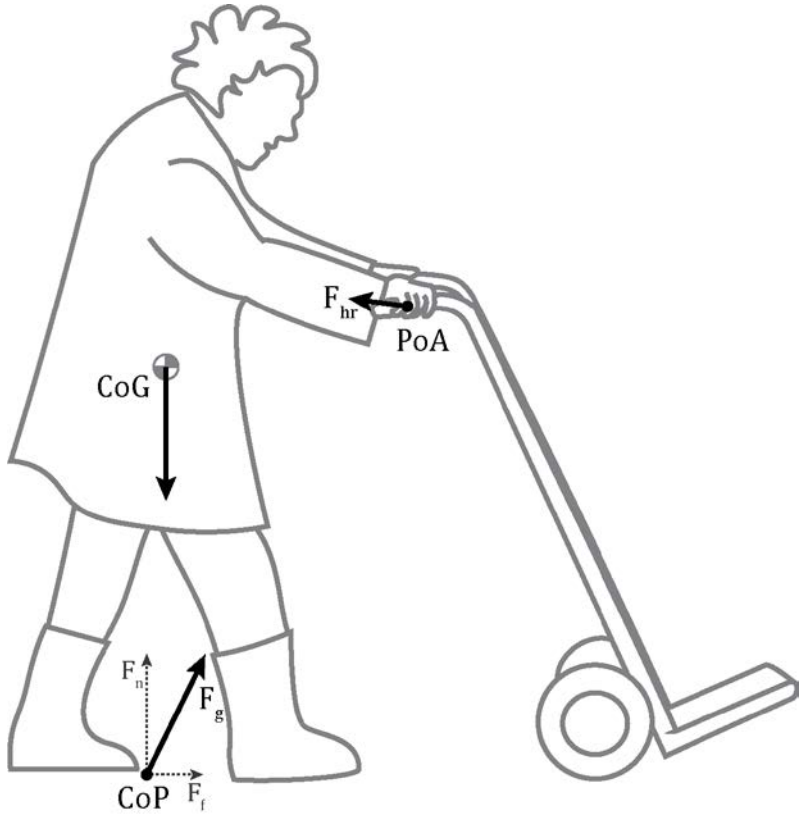


Figure 7.4: Representation of a free body diagram of a pushing subject. CoP= centre of pressure of the ground reaction force (F_g) at the feet, F_n= normal forces, F_f= friction forces, CoG= centre of gravity. PoA= point of application of the handreaction force (F_{hr}).

Participants then were given each of the five tools in turn and with each tool performed the motion of pulling it or pushing it up the obstacle in front of them. An initial test-run was undertaken to check whether the obstacle was at the correct distance for recording the forces on the force plates and the obstacle was moved if needed.

Participants then performed the required motion and were asked to repeat between one and five times to ensure sufficient trial data was captured with valid trials. For each tool, the lowest obstacle was the starting point and the height was then increased two times. The tools were given to each participant in a different order to avoid the ratings skewing due to participant fatigue. Once all heights were recorded for a single tool, the participant was asked to rate perceived exertion using Borg's Rating of Perceived Exertion scale (RPE) (Borg 1998) and to indicate any areas of discomfort on a body diagram similar to the approach detailed by Corlett and Bishop (Corlett and Bishop 1976).

After all trials were completed, the participant was asked some open questions regarding their experience with similar tools, experience on the day and to discuss which of the tools would have their preference. This information was used to compare their subjective evaluations to the objective data and aid in explaining which data may be skewed because of prior experience.

7.2.9 Theoretical modelling

Figure 7.5 shows the initial contact between the wheel and the obstacle with no reaction force between the wheel and the floor as the wheel starts to lift. This diagram was used to calculate the magnitude and direction of the force to lift the wheel over the obstacle. To lift the wheel with the minimum force magnitude, the force is directed normal to a radial line from the wheel centre to the point of contact with the obstacle. The limiting condition is when the obstacle is the height of the wheel radius which would require the force to be applied vertical, i.e. a direct lifting of the tool and its contents.

By taking moments about the contact point between the wheel and the obstacle at the instant the wheel loses contact with the floor it can be seen that for $h \leq r$:

$$F_{pull} = W\frac{\sqrt{2rh - h^2}}{r}$$

Where

F_{pull} = force to rotate the wheel over the obstacle.

W = the proportion of the weight or the tool and its load carried by the wheel (N).

r = the radius of the wheel used (m).

h = the height of the obstacle (m).

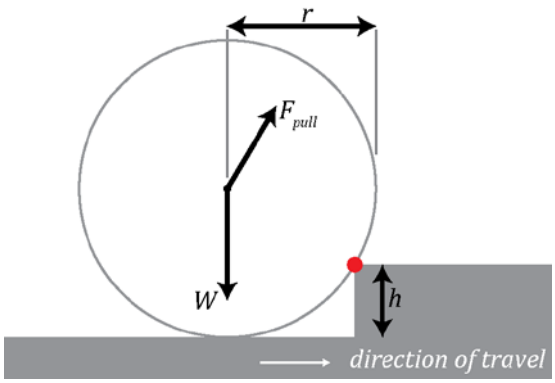


Figure 7.5: Model of forces occurring at time of maximum pulling force required. The amount of force required depends on the weight put on the tool axel and the proportion of the wheel and the height of the obstacle.

For the inflatable tyre on one of the wheelbarrows, the deformation of the wheel will impact on the forces measured as it reduces the effective radius at the pivot point and vertically to the ground. In reality, this deformation will also create a different dynamic force pattern, damping the hard peak occurring with rigid tyres. As an accurate calculation for the deformation of the tyre required input variables that were not easily obtained (e.g. the volume of the inflatable tyre, the pressure of the tyre and the stiffness of the tyre) and the models created by others in literature had their limitations in accuracy (Gao et al. 1992), it was decided to compare the data of the inflatable tyre wheelbarrow to the rigid theoretical model instead.

For the step climber, the situation is also different to the one described above, as for this tool the tri-star wheel configuration provides a secondary axis around which the three wheels can pivot. This creates two distinct scenarios depending on the obstacle height; one in which the tri-star

wheel does not yet pivot (scenario 1, Figure 7.6a) and one in which the tri-star wheel does pivot (scenario 2, Figure 7.6b).

Furthermore, the tri-star configuration means that there is always a second small wheel needing to be pulled across the obstacle. This means there is a second set of equations required to calculate the force required to pull the second wheel onto the step. Again, there are two distinct scenarios, however in this case the first scenario is one where the tri-star wheel pivots around the edge of the obstacle (Figure 7.6c) and the second scenario is where the obstacle height is bigger than the radius of the small wheel, thus negating rotation and requiring the user to pull the load vertically only (Figure 7.6d).

When the step climber is still on the ground, by taking moments about the contact point between the wheel and the obstacle at the instant the tri-star wheel at the front (wheel on the lower right within Figure 7.6a) loses contact with the floor and combining with $\Sigma F = 0$ it can be seen that for $h \leq r_1/2$ (scenario 1):

$$F_{pull} = \frac{(a-b)W}{(a\tan(\alpha)-c)\tan(\alpha)+a-b}$$

With

$$\alpha = \sin^{-1}\frac{r_1 - h}{r_1}$$

$$a = \sqrt{3}r_2 + \sqrt{2r_1h - h^2}$$

$$b = \frac{1}{2}\sqrt{3}r_2 + \sqrt{2r_1h - h^2}$$

$$c = \frac{1}{2}r_2 + r_1 + h$$

And for $h \leq r_1/2$ (scenario 2):

$$F_{pull} = \frac{1}{2}\sqrt{3}W$$

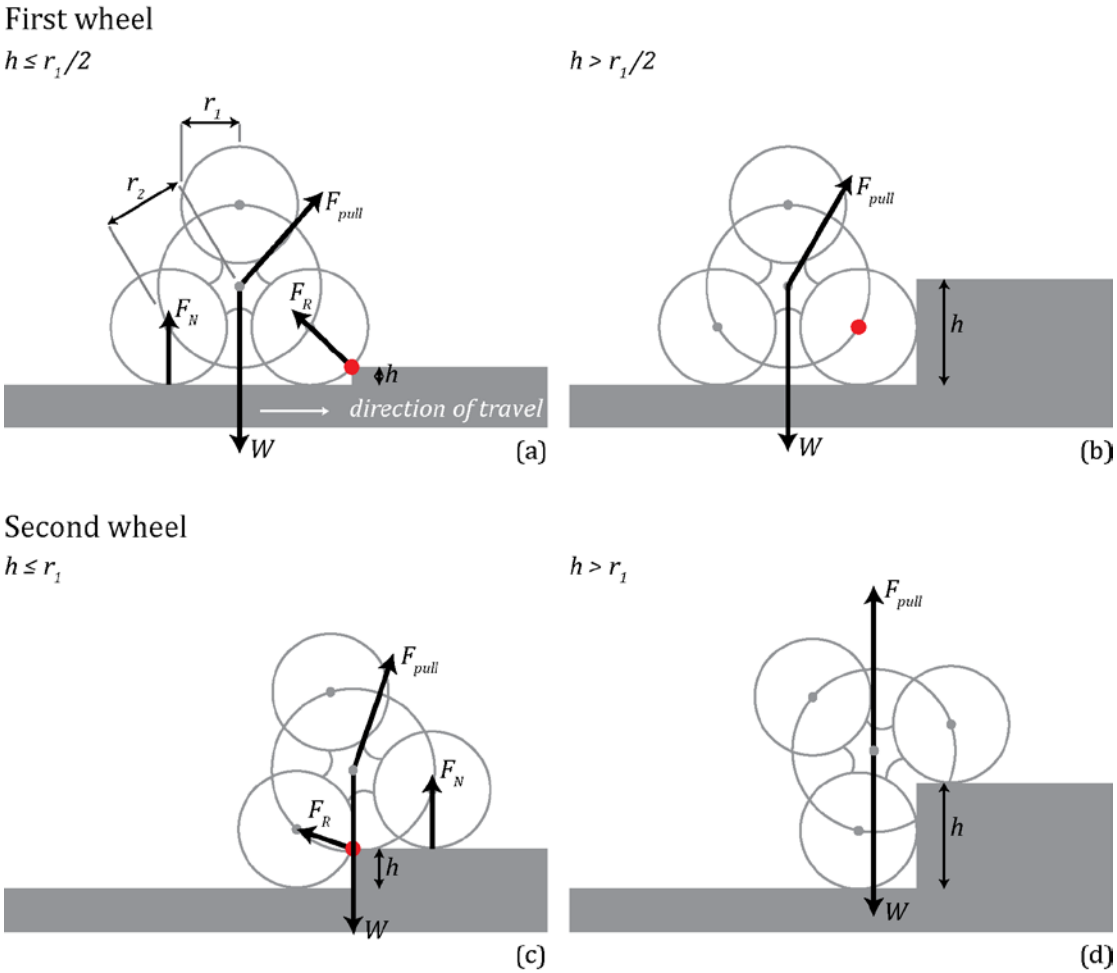


Figure 7.6: The four scenarios encountered when moving a step climber onto an obstacle. The relevant forces are F_N , the force of the ground preventing the step climber from falling through, F_R, the reaction force in the pivot points of (a) and (c) when the step climber leans on this point to rotate about, F_{pull}, the minimum force required to start moving the step climber, and W, the proportion of the weight or the tool and its load carried by the wheel (N).

Once the first wheel of the step climber is on the obstacle, the equations that describe the movement are for $h \leq r_1$:

$$F_{pull} = \frac{(d-e)W}{(d\tan(\alpha)+f)\tan(\alpha)+d-e}$$

With

$$d = \sqrt{3r_2^2 - h^2} - \sqrt{2r_1h - h^2}$$

$$e = d - r_2\cos(30° - \sin^{-1}(\frac{h}{\sqrt{3}r_2}))$$

$$f = r_1 + r_2 \sin(30° - \sin^{-1}(\frac{h}{\sqrt{3}r_2}))$$

And for h > r_1:

$$F_{pull} = W$$

Where for all the above:

F_{pull} = force to rotate the wheel over the obstacle (N)

W = the proportion of the weight or the tool and its load carried by the tri-star wheel (N)

r_1 = the radius of the three smaller wheels (m)

r_2 = the distance between the tri-star wheel centre and the centre of the three wheels (m)

h = the height of the obstacle (m).

The resulting equations can be plotted to show the difference in force required for the step climber as compared to the other assistive moving devices (Figure 7.7).

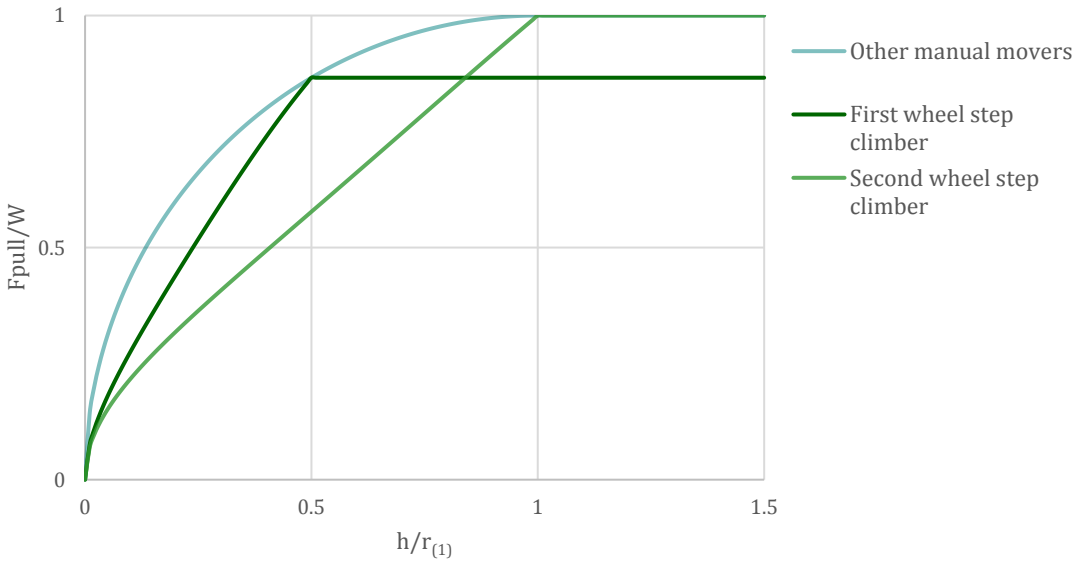


Figure 7.7: Comparison of pulling force required for the different manual movers, with the theoretical manual pulling or pushing force required (F_{pull}) as a ratio of the weight of tool and load. For the step climber, force required to pull the first wheel onto the obstacle is less due to the pivoting of the tri-star system. However force required to pull the second wheel onto the step is equal to the other manual movers for obstacles higher than the radius of the three smaller wheels. For the other manual movers, once

obstacle heights are higher than the radius of the wheel, vertical lifting will occur and the force required to lift is equal to the weight of the tool.

For all the manual movers, the wheels received a proportion of the total weight of the tool and load, with its proportion depending on the location of the centre of mass in relation to the axis and the remaining weight was directed to the participant. The proportion of the weight that was directed to the wheel axis was measured for each of the tools by holding the tools at approximately the angle at which the three participants held the tools during their trials and measuring the remaining vertical force directed to a force plate through the wheel.

These models have several assumptions, for example they do not account for any lack of friction from the tyres at the pivot point, and do not account for the deformation of the inflatable tyre. The first would increase the force required and the latter would decrease the force required, as it would displace the location of the pivot point, which would reduce the effective radius of the wheel at the pivot point and thus reduce the x-directional component of the pulling force.

7.2.10 Data analysis

The analysis of the motion capture and force plate data was undertaken using Vicon Nexus software and BoB (Shippen and May 2010). The latter uses inverse dynamics on a model of the human body and was used to estimate joint contact forces and joint torques.

The captured data consisted of 118 trials, with for each tool, height and participant combination (5 x 3 x 3 = 45) at least two trials. The data was first loaded into Vicon Nexus and the body model was attached. This automatic labelling does not always correctly label the subject, and any partially missing markers were digitally replaced using gap filling, with spline filling used for mid sections of the limbs and pattern fill used for other missing sections. Finally, for a few trials a hip marker was entirely missing, this was replaced by assuming the hip as a rigid system and aligning a marker relative to the movements of the other three markers.

The force plate data was digitally filtered using a 8 Hz low pass 4^{th} order Butterworth filter to reduce the high frequency noise. Because accuracy of foot placement at the crucial times during the trials was difficult to establish during the trials, this was checked in the analysed data and the trials

with no missing or partial feet on the force plates at these times were selected for each tool-height-participant combination. Where trials were equally sufficient in foot placement and execution one was selected prior to force data evaluation to avoid bias. This reduced the total number of trials down to 42, one for each height, tool and participant combination but with three missing data points because of partial or missing feet on the force plates.

The force plate data was then exported to Matlab. Matlab was used to produce plots of (normalised) ground reaction forces (GRFs). The plots were then compared to the Vicon trial data to establish the approximate time at which the participant pushed or pulled the tool up and over the obstacle and thus identify the approximate time at which peaks occurring in the GRFs as a result of the obstacle could be expected. In Matlab, the GRF peaks occurring within these intervals were identified.

The force occurring at the handles of each tool was estimated by taking away the participant's weight from the GRFs and either dividing the remaining resultant GRF between the two hands if both hands were used or applying them to a single hand where appropriate.

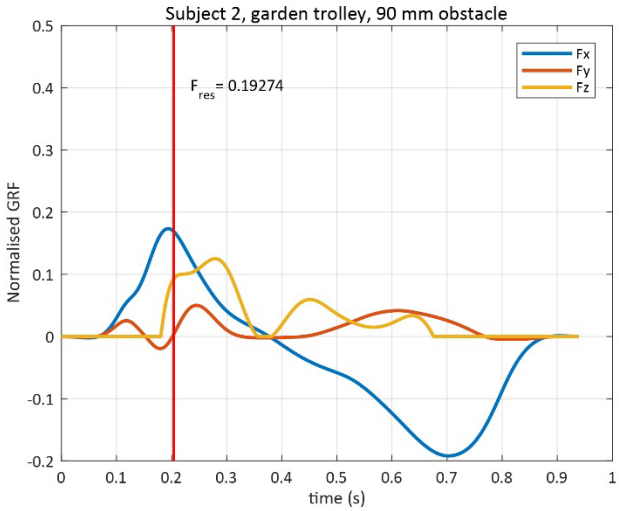


Figure 7.8: Illustrative example of the directional components of the ground reaction forces. With F_x being the component in the horizontal direction of the pulling motion, F_y the force horizontally perpendicular to the direction of the motion and F_z the vertical component of the force. The combination of the three directional components of the ground reaction force created a combined peak at the time of the vertical red line. However, individual contributions of the directional components do not have their peaks at exactly the same time and as such the impact of the motion on individual joints may be highest just before or after the GRF peak rather than occurring at precisely the same time.

The force and motion data was then imported into BoB, from which both joint torques and joint contact forces for potentially relevant joints were generated using the in-built inverse dynamics modelling. The joint data was imported into Matlab to find peaks occurring within 0.5 seconds around the occurrence of the GRF peak. The GRF peak was where the overall magnitude of GRFs was the biggest, however this peak is calculated from the three individual directional forces (Figure 7.8). As these individual components of the GRF can cause peaks to occur in the joints around the time of the GRF peak, but not quite at the same time, an interval of 0.5 seconds was taken within which to locate peaks in the joint forces and torques. The peak values for the joint forces and torques were then used to compare impacts on the joints for the different tools and heights.

In research on walking patterns the ground reaction force data tends to get normalised to the participant's bodyweight to allow for cross-participant comparison (Wannop et al. 2012). However, in these trials the external manual force as derived from the GRF was not normalised by bodyweight as this would create a misrepresentation of the results, as there is an external force present caused by the tool and load. The influence of the tool and load weight was however discussed.

The information provided in the post-trial interview was summarised and used along with the RPE and discomfort scores given to explain some of the trial data and compare preference of the participant to the perceived exertion and discomfort as well as the joint contact forces.

7.3 Results

Three participants pulled five tools across three obstacles whilst their movements were being recorded using motion capture and the forces were measured using force plates. The data regarding the peak ground reaction forces, joint contact forces and joint torques used in this chapter can be found in Appendix K, Appendix L and Appendix M respectively. The analysed data regarding differences between tools is described, split into sections on manual forces, joint contact forces and torques, subjective data, comparison of data to the theoretical model and the special case of double peaks occurring during the step climber trials. The resulting manual forces, joint contact forces and torques and subjective data are discussed in relation to the increasing obstacle height.

7.3.1 Tool differences

The tools used in the study through their different characteristics resulted in differences in manual and joint contact forces, joint torques and subjective evaluations.

Manual forces

The peak forces between tool and participant were generally higher (range: 162-325 N) for the step climber than for the other tools (Figure 7.9). Apart from the step climber, the foldable sack truck required higher manual forces than the other three tools for the medium 60 mm obstacle (range: 146-226 N), and one of the 90 mm trials generated the highest peak force of all the tools (368 N). For the wheelbarrows and garden trolley the peak manual forces ranged between 43-193 N. The wheelbarrows scored similarly, though the puncture proof wheelbarrow generated some higher peak forces for the highest obstacle than the inflatable tyre wheelbarrow. The garden trolley induced peak forces between tool and hand similar to the wheelbarrows.

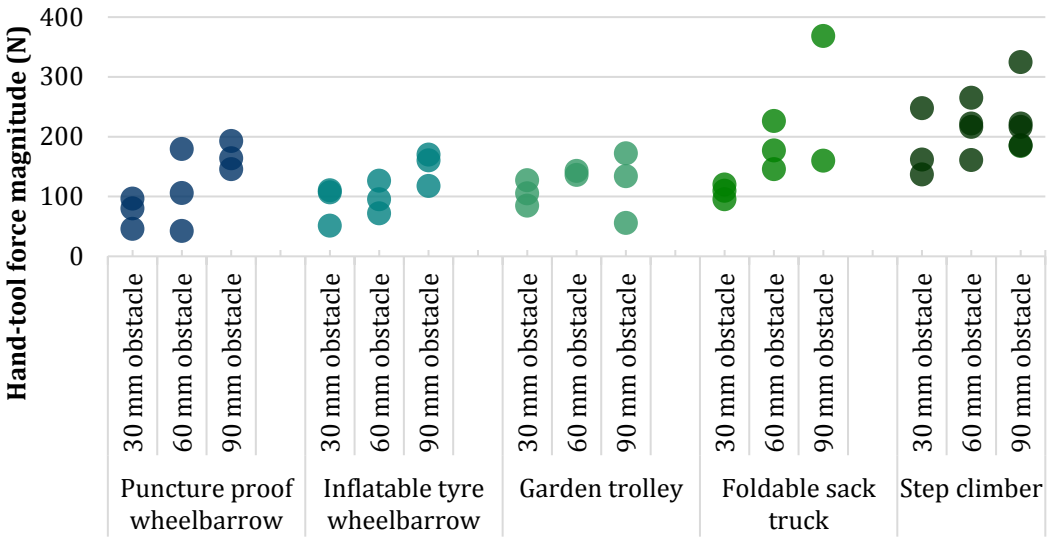


Figure 7.9: The peak magnitudes of the forces between tool and subject. These were higher for the step climber sack truck and somewhat for the foldable sack truck, whilst the two wheelbarrows with different types of wheels as well as the garden trolley generated very similar and generally lower manual forces.

Step climber double peaks

For some of the step climber trials, there were two distinct peaks rather than a single peak (Figure 7.10). This was the case for the medium and high obstacle for one of the participants and all heights for another participant. For these trials, the spoked tri-star configuration wheel first rotated until the first wheel was on top of the obstacle and then the tool was pulled along further to pull up the second wheel, causing these two events to create two peaks in the forces between the tool and person. The third participant did not have two peaks as she pulled the tool up in one motion.

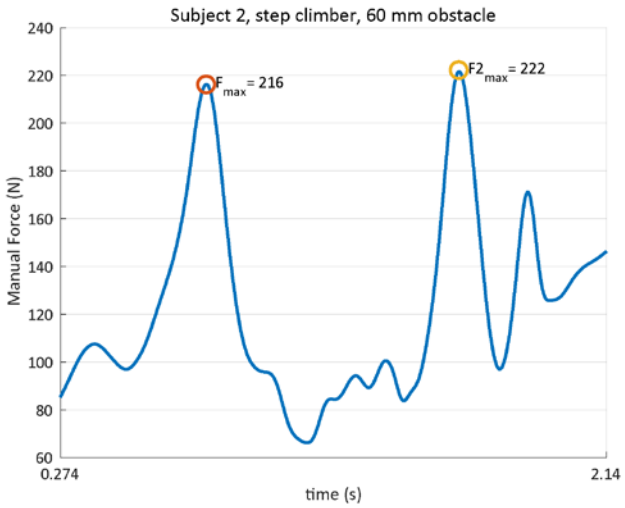


Figure 7.10: Illustrative example of a trial with a double peak caused by the use of the step climber's tri-star wheel. This trial shows the double peaks in the manual force generated on the medium height (60 mm) obstacle.

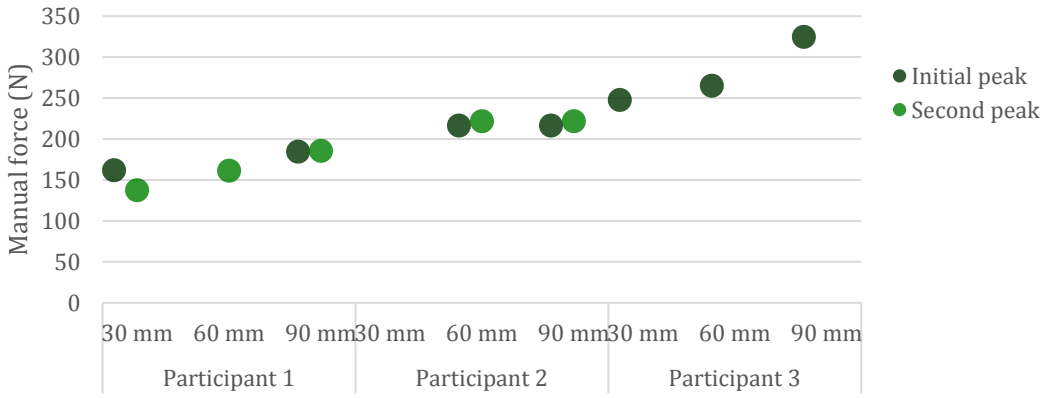


Figure 7.11: The forces exerted by the participants to pull the step climber across the obstacle. These were in similar range for both parts of the movement as can be seen for participant one and two. Due to incomplete or partial foot placement, the first peak of the 60 mm trial of the first participant and the full trial of the 30 mm obstacle for the second participant were not recorded. Participant three pulled in a single motion and thus only one peak was recorded for her trials.

The forces exerted for the double peak trials were in similar range for both peaks whilst the single peak trials were higher (Figure 7.11).

Efficiency of force used

The tool results were compared to the theoretical lowest force required to the pull the tool and load onto the obstacle (Figure 7.12). Generally, participants used more force than required, with one participant in particular generating higher forces than the other two on the garden trolley, foldable sack truck and step climber. For the wheelbarrows, scores were closer together and closer to the theoretical minimum, though a different participant generated somewhat higher manual forces than the other two on these tools. Dips below the theoretical minimum can be observed for one participant, the likely reason behind this is the use of momentum due to prior acceleration.

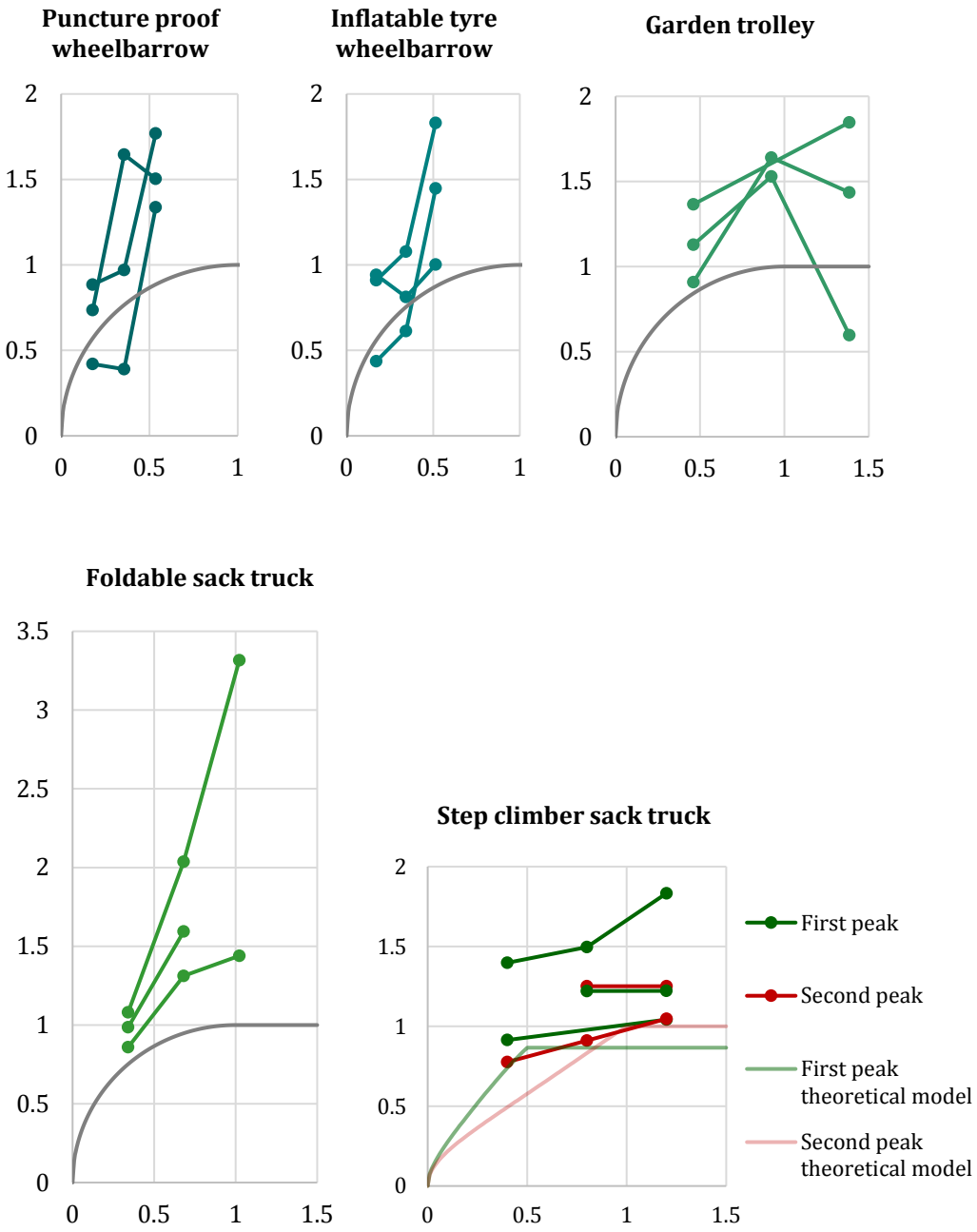


Figure 7.12: The measured manual force for each trial plotted against the hypothetical optimal, i.e. most efficient force exertion (grey line).

Joint contact forces and joint torques

In the joint contact forces (JCFs) and joint torques (JTs), the difference between the step climber and the other tools was not reflected as the peak joint contact forces and joint torques generated

were similar across all tools (Figure 7.13 and Figure 7.14). The JCFs across all joints were of very similar magnitudes, with slightly higher peaks found for the shoulders for the foldable sack truck.

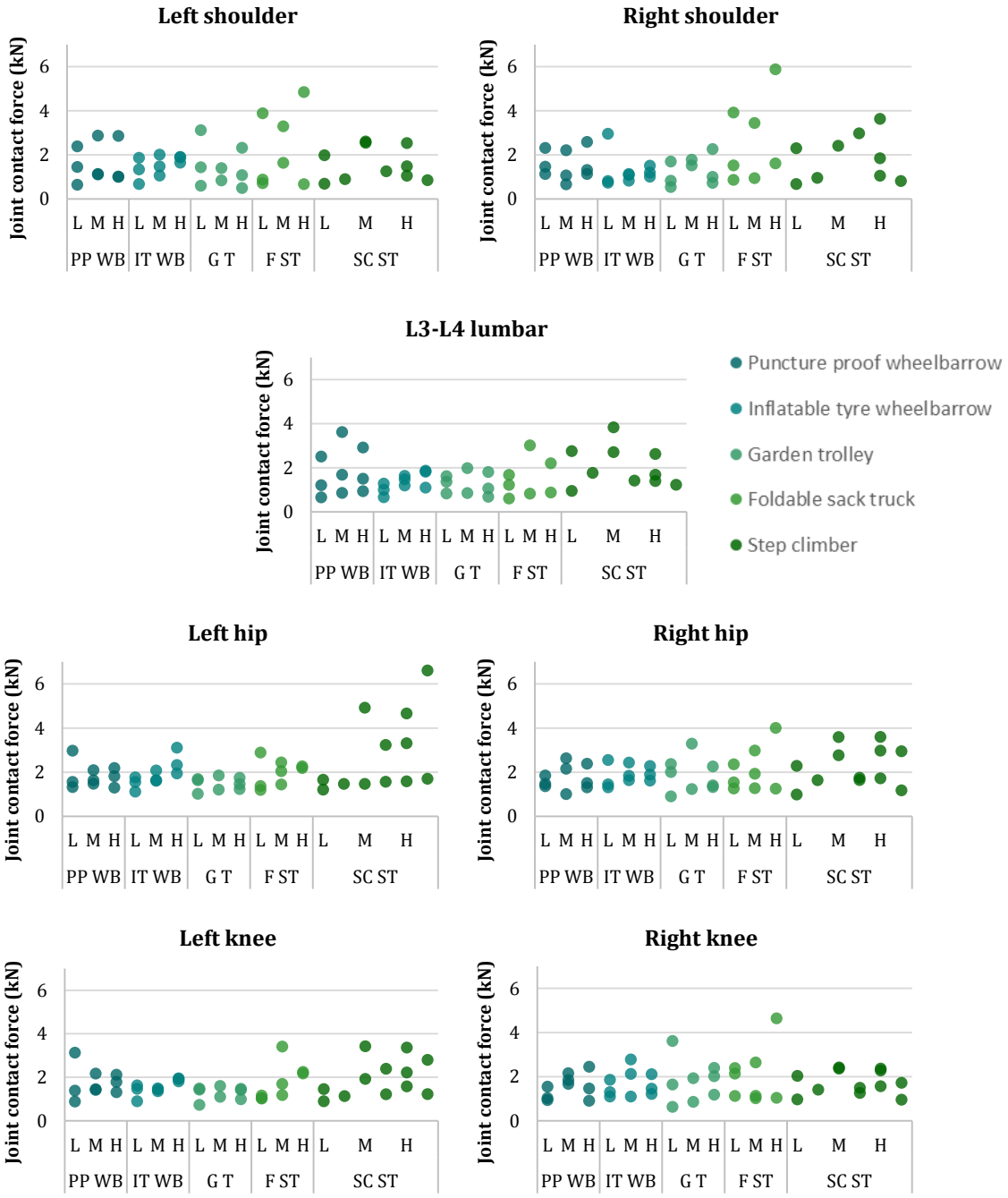


Figure 7.13: The contact forces per joint, per tool, and horizontally grouped per obstacle height (L=30 mm, M=60 mm, H=90mm). Each dot represents the JCF for one joint of one participant using a tool to get across an obstacle.

The lumbar joint torques were the highest of all the joints and among all the tools, and higher for the puncture proof wheelbarrow and the step climber sack truck than for the other tools, with the garden trolley generating the lowest joint torques. Shoulder torques were the lowest for all the tools.

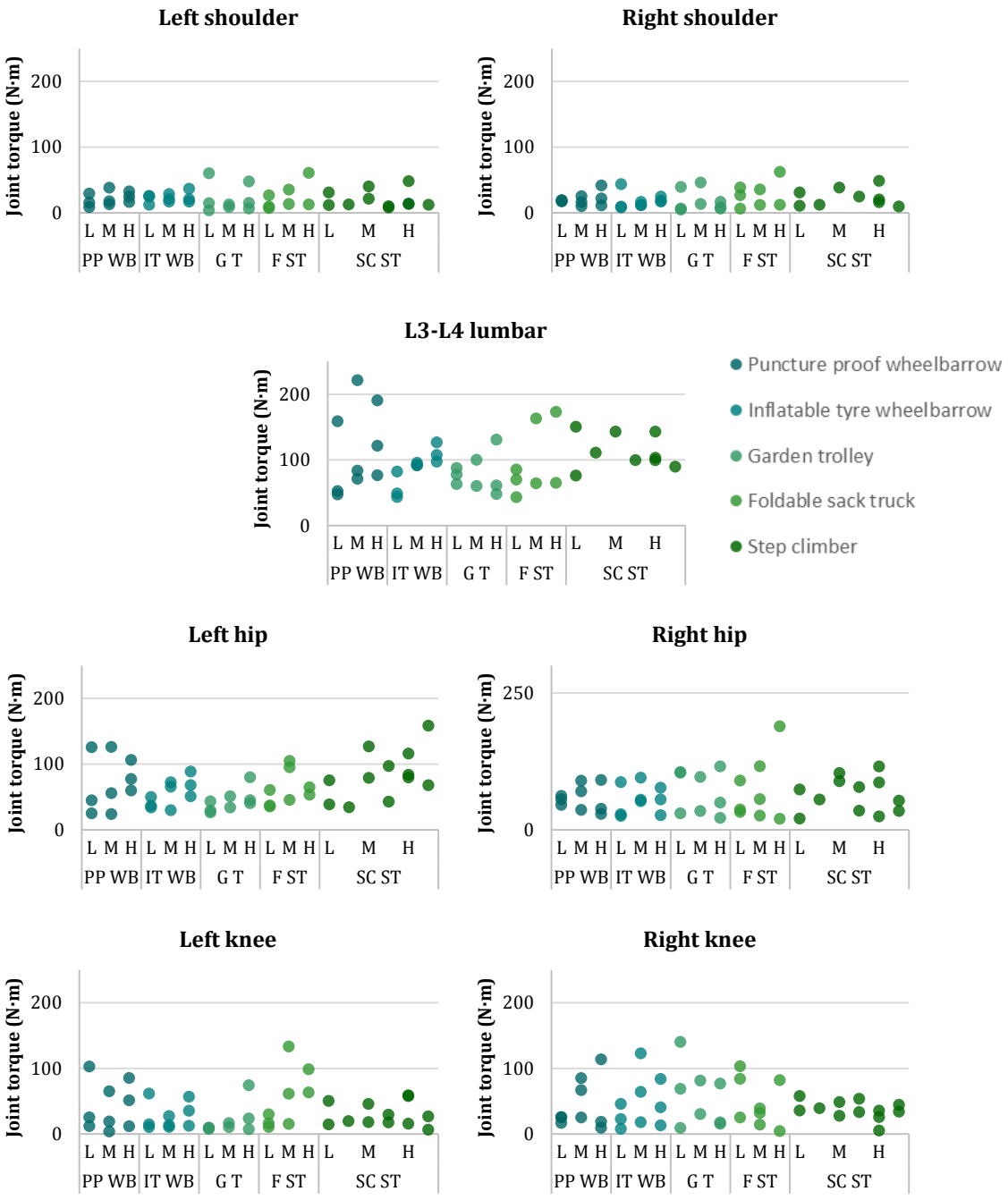


Table 7.3: Ratings of perceived exertion (RPE) given after each trial using Borg's scale. In brackets is the order in which each tool was tested, e.g. participant 1 started with the garden trolley and finished with the puncture proof wheelbarrow. Participant 1 rated her exertion from using each of the tools as 6, the minimum value on the scales relating to textual reference of 'no exertion at all', whilst the other participants distinguished between the different tools in their RPE scores given, ranging from 7.5 or 'extremely light' to 13 or 'somewhat hard'.

Participant	Pre-study rating	Puncture proof wheelbarrow	Inflatable tyre wheelbarrow	Garden trolley	Foldable sack truck	Step climber sack truck
1	6	6 (5)	6 (4)	6 (1)	6 (3)	6 (2)
2	6	9 (1)	9 (2)	13 (4)	9 (3)	13 (5)
3	6	7.5 (2)	7.5 (1)	13 (5)	12 (4)	13 (3)

Figure 7.14: The torques per joint, per tool, and horizontally grouped per obstacle height (L=30 mm, M=60 mm, H=90mm). Each dot represents the JCF for one joint of one participant using a tool to get across an obstacle.

Subjective data

The participants gave ratings of perceived exertion after using each of the tools (Table 7.3). All participants rated their pre-study RPE ratings as 6 and stated in the post-trial interviews they had not been active on the day prior to the trials taking place. The participants also rated their perceived discomfort on body diagrams and they did not provide many discomfort ratings. The first participant gave her mid back a score of 1 on a scale of 0 to 5 for the step climber sack truck, whilst no other tool received a score from her. The third participant scored a 7.5, using the RPE scores, for her left knee for the puncture proof wheelbarrow and the inflatable wheelbarrow. Though the participant used the RPE rating instead of the discomfort scale on the body diagrams, it shows that she experienced some discomfort in her knees during the wheelbarrow trials.

When asked after the trials, the participants had varying preferences regarding which of the tools, if any, they would like to take home if given the opportunity, which they would purchase and the order of preference in general. Participant 1 mentioned the garden trolley first, the foldable sack truck second and either of the wheelbarrows third and the step climber last. When asked which one she would purchase, she stated it depended on what she would be wanting to move, mentioning the wheelbarrows first and the garden trolley second. Participant 2 did not want to take home any if given the chance, as she stated she had no use for them, but if she had to take one it would be the

wheelbarrow with inflatable tyre. This participant also would not purchase any of the tools. Although the third participant initially stated she did not use any 'gadget' to carry things, if she had to, she would take home the step climber sack truck to carry stacks of pots, as she considered the wheelbarrows too big and bulky and thought the wheels of the garden trolley were too close together. Other comments provided by the participants are summarised in Table 7.4.

Table 7.4: Additional comments on each of the tools as provided by the participants.

Tool	Participant 1	Participant 2	Participant 3
Puncture proof wheelbarrow	Well-balanced.	Fine, but movement jarred and jolted.	'Wider' than inflatable tyre wheelbarrow.
Inflatable tyre wheelbarrow	Well-balanced.	Fine, better for rough terrain, by far the easiest, apart from heavy loads, strain on shoulders.	'Neater' than puncture proof wheelbarrow. Preferred 'fatter' wheel over puncture proof wheelbarrow.
Garden trolley	Preferred tool.	'Uncontrollable', 'unstable', wheels vibrate, 'temporary' and 'too short'.	Wheels too close together, tips more easily.
Foldable sack truck	'Useful'.	Single-handed operation was liked, 'manoeuvrable', preferable for heavy loads as could 'just tip it'.	Useful, wide base and space between wheels prevents tipping.
Step climber	'Odd', 'problem is you have to give it momentum, but then it wouldn't stop'. Did not hurt, but 'felt wrong', felt in back rather than core.	'Too big and bulky, 'very heavy', 'cumbersome' and 'awkward', 'very high', 'more of a man's thing' and noted specifically that the wheels do not twist to go around corners. Saw potential use for 'big job' or hard landscaping or on higher steps.	Useful for steps in garden.

7.3.2 The influence of obstacle height

The influence of increasing obstacle height on manual force required, joint contact forces and joint torques was evaluated. An increased obstacle height showed a general upward trend in overall force required to move the tool across the obstacle, though this was trend was not observed for each tool and participant (Figure 7.15). The JCFs for most of the joints reflected the upward trend or generated similar JCFs across all obstacle heights (Figure 7.16), with the notable exception of the L3-L4 lumbar joint, for which a few of the trials generated higher JCFs for the medium height obstacle than the highest obstacle. This was not observed in the JTs for this joint. The joint torques in general did not display an unequivocal upward trend (Figure 7.17).

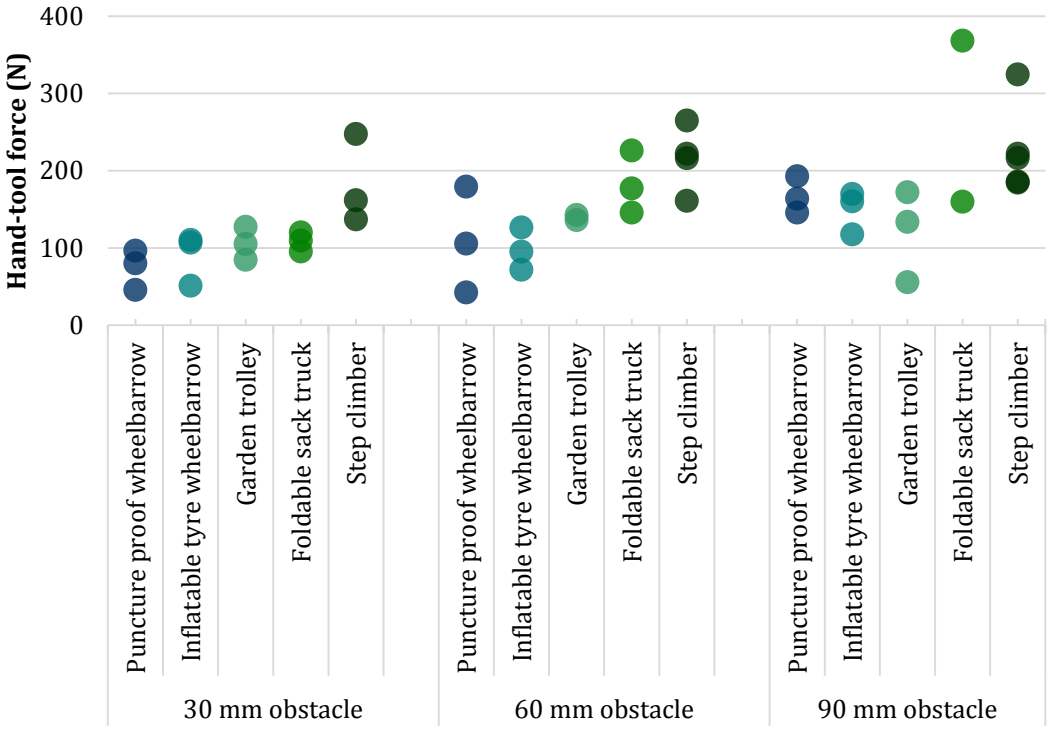


Figure 7.15: The peak magnitudes of forces between the subject and the tool per obstacle height. Each dot represents a trial of one participant using one of the tools.

The highest joint torque peaks for all obstacle heights were the L3-L4 lumbar torques. Lifting and pulling tasks are notoriously associated with back pains and injuries, and the relatively high lumbar torques suggest that this task is another example of this. The hips were the joints with the second highest torques, followed by the knees and ending with the shoulders receiving the lowest torques. The joint contact forces in the shoulders and lumbar region contained larger ranges than the knees and hips, containing both lower and higher JCFs than the knees and hips.

In regards to the difference of increasing height of the obstacles, the first participant said she was pulling more with increasing height, whilst both the second and third participant did not feel like the increased heights made a difference, with the second participant stating that because she could see the obstacle, she used her 'gumption' to pull harder. Similarly, the third participant stated:

> *"If you've got that obstacle to get over, your brain tends to put your body in a different position, so that you are ready to lift more than just drag."* –Participant 3

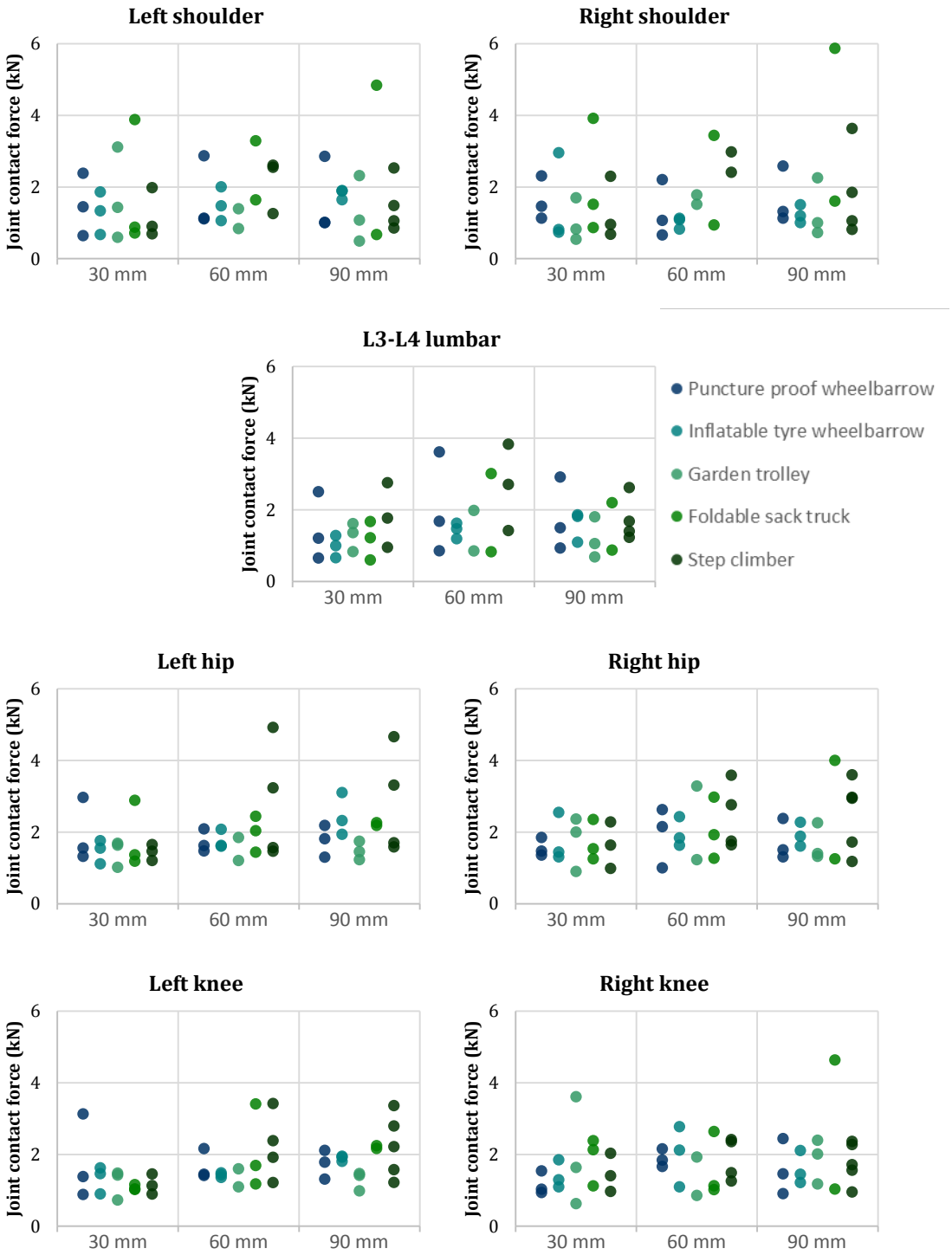


Figure 7.16: The contact forces per joint, per obstacle height (30, 60 and 90 mm), and horizontally grouped per tool. Each dot represents the JCF for one joint of one participant using a tool to get across an obstacle.

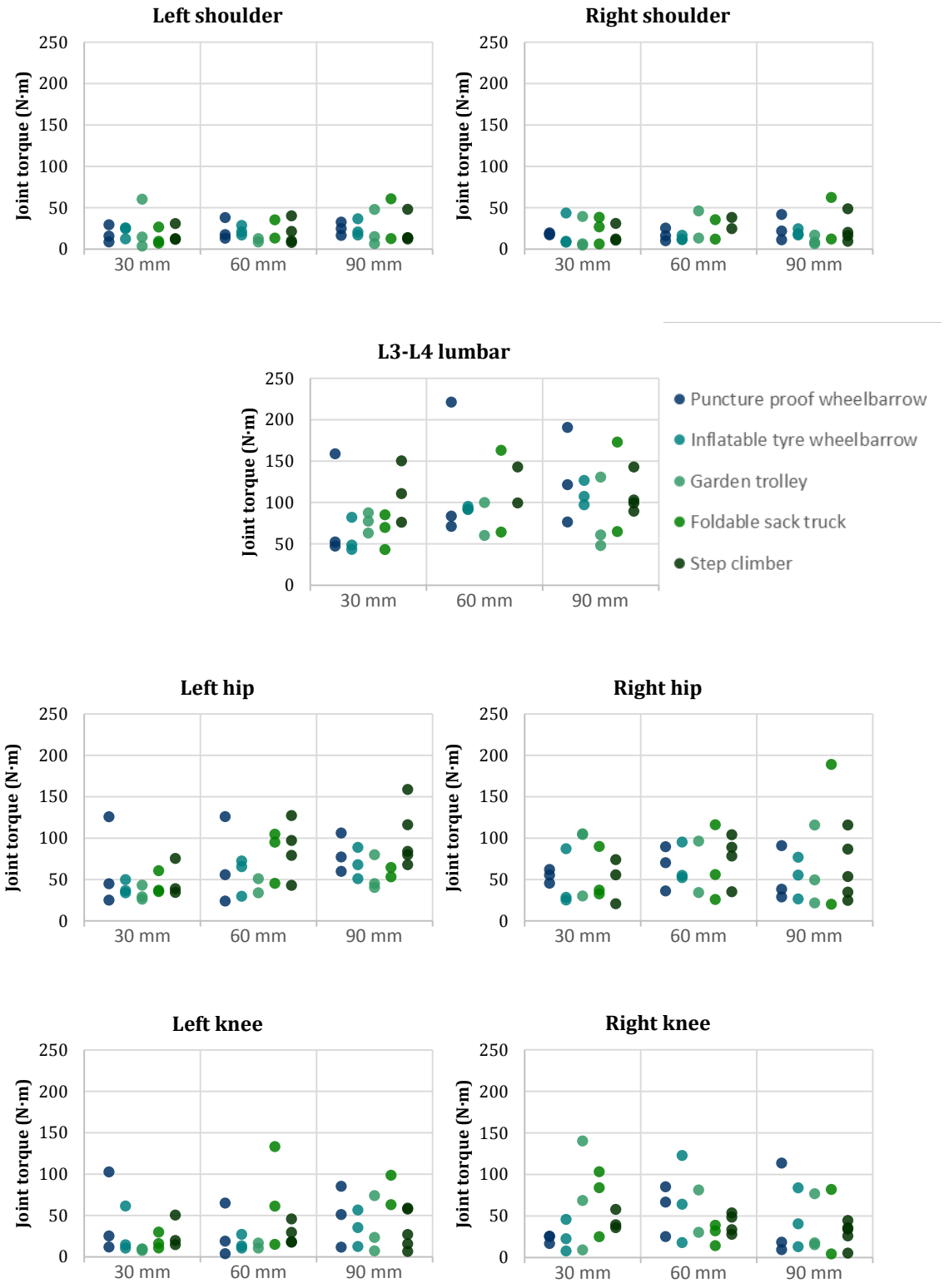


Figure 7.17: The torques per joint, per obstacle height (30, 60 and 90 mm), and horizontally grouped per tool. Each dot represents the JT for one joint of one participant using a tool to get across an obstacle.

7.4 Discussion

In the existing literature there was a lack of research into the use of tools on steps and obstacles, with focus given instead to straight movements and manoeuvring on level ground (Argubi-Wollesen et al. 2017). However, natural curvature and height differences in gardens can create obstacles as discovered in the focus groups (Chapter 5) and observations (Chapter 6). This study aimed to identify the characteristics of five different tools that impacted the loads on the body. Because data on the biomechanical or physiological limits of older females did not exist, comparison of the findings had to be done against limited available data of working populations in horizontal pushing/pulling tasks.

7.4.1 Tool differences

Generally the participants used more manual force than theoretically needed to pull the tools across the obstacles (Figure 7.12); they were inefficient in their exertion of forces. Furthermore, the inefficiency of force used (relative increase over the theoretical minimum) increased with increased obstacle height. The amount of effort required might be reduced by training to achieve more efficient use of the equipment. Redesign of the tools to better align the direction of push or pull to the natural direction in which forces can be exerted would also likely reduce excess use of force and generate forces closer to the theoretical optimum.

Puncture proof wheelbarrow & inflatable tyre wheelbarrow

The wheelbarrows generated similar forces between the tool and person, as well as similar joint contact forces and joint torques. Both received the shared lowest (best) RPE scores. However, for participant 3 the JTs and JCFs were higher for the L3-L4 lumbar joint using the puncture proof wheelbarrow (range: 2.50-3.61 kN and 159-221 Nm) than the inflatable tyre (range: 1.28-1.81 kN and 82.0-127 Nm). This difference was not seen for the other participants.

Figure 7.18: Puncture proof wheelbarrow pushed (grey) and pulled (green, purple).

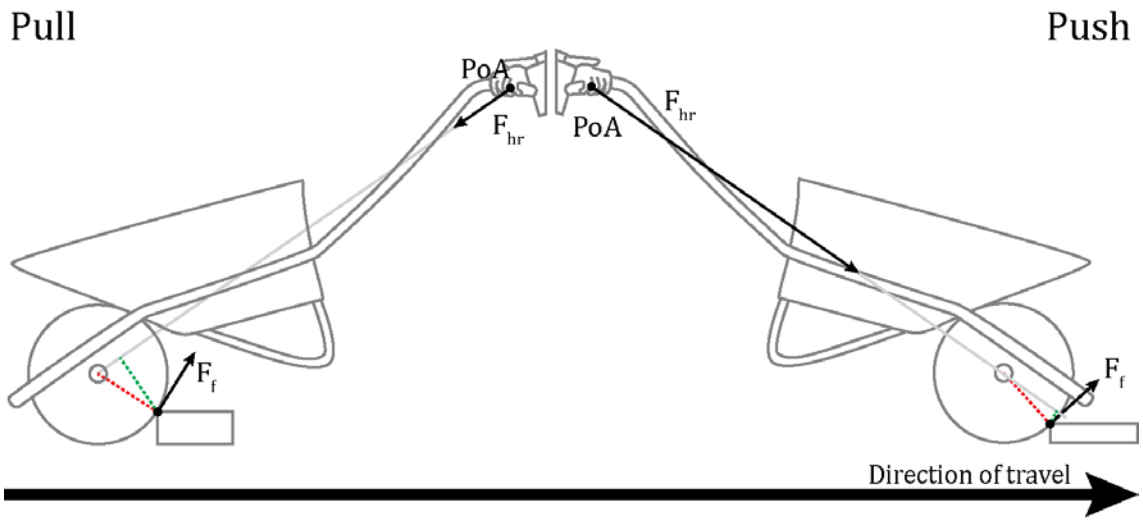


Figure 7.19: The exertion when pulling a wheelbarrow across an obstacle. Exertion is lower as the force directed along the wheelbarrow axis has sufficient arm to create torque. When pushing, the force is directed along the same axis, but has a much smaller arm. The only way to compensate is by lowering the wheelbarrow handle to increase the arm.

The participants had very different strategies using this tool, with participant 2 pushing the wheelbarrow across the lower two obstacles and the other two participants opting to pull the tool across (Figure 7.18). Participant 1 leaned backwards to provide leverage whilst participant 3 did not use her bodyweight. This participant experienced the aforementioned spikes. In this study no clear difference in manual forces, JCFs and JTs was found. In other research on hand trucks rather than wheelbarrows, contradictory results were presented as to whether pushing or pulling hand carts had a higher impact on the body (Argubi-Wollesen et al. 2017). Theoretically, pulling the wheelbarrow would allow participants to use force more effectively (Figure 7.19).

For the trials in which the wheelbarrows were pushed, the participant thus had to accelerate considerably to get the tool across, which may have been the cause of a lower peak; the average force due to acceleration may have been higher but this was not measured in this study. The range of obstacle heights that can be overcome by pulling a wheelbarrow is greater than the range for pushing: once the height of the obstacle is higher than the angle formed by the handles, the forces at the handle provide a neutral or negative torque, at which point the wheelbarrow will not ascent the obstacle.

The manual forces generated for the wheelbarrows were in similar magnitude for all participants (range: 42.5-193 N). The postural differences of one participant compared to the others were

therefore seen as the main factor for the higher JCFs and JTs and as such, the difference in wheels were not clearly reflected in the JCFs and JTs. Although the user experience of one participant with the wheelbarrow with puncture proof tyre was that of it being 'jarred' and 'jolted', this was not reflected in the resulting impact on the body. The cushioning effect of an inflatable tyre should reduce peak forces and torques, but no difference was observed. This might have been because of the limited load added to the wheelbarrows, thus not causing the inflatable tyre to significantly deform. The unused state of the rubber tyre might have also made it less malleable than a more used one. Heavier loads would likely exacerbate the differences between the two wheelbarrows, as the dampening of the inflatable tyre would likely be more noticeable.

Though no clear difference between the wheelbarrows was seen, overall the wheelbarrows received favourable scores over the other tools, both in participant perception where they received the lowest perceived exertion scores and in JCFs, JTs and manual forces. Even though both wheelbarrows weighed over 7.5 kg more than the garden trolley and a proportion of that weight was carried by the participants by lifting the handlebars, the manual forces generated were similar (range garden trolley: 55.7-172 N, wheelbarrows: 42.5-193 N). Furthermore, the JCFs and JTs were in similar range too (range garden trolley JCFs: 0.54-3.61 kN, JTs: 3.59-140 Nm, wheelbarrows JCFs: 0.64-3.61 kN, JTs: 14.6-221 Nm).

A disadvantage for most wheelbarrows is that the wheel is not visible for the user and thus it is harder to correctly estimate when to expect the obstacle. This might have impacted on the efficiency of their efforts as this might have made them use excessive force or directed the force in an imperfect angle. In real life situations more environmental cues might provide them with better judgment of the timing, direction and magnitude of force required, however not being able to see the wheel is likely to still be a disadvantage in optimising the amount and direction of force.

With age, reduced balance is a known risk factor for falls (American Geriatrics Society et al. 2001). The wheelbarrow is a tool that needs to be stabilised by the user whilst for older adults a tool that provides them stability would be more appropriate. Especially when moving backwards to overcome obstacles this may become a problem in real life settings.

Garden trolley

The garden trolley was found to generate relatively low peak forces between the hand and tool, comparable to the wheelbarrows and most of the foldable sack truck manual forces. This tool weighed the least and therefore the tool was expected to generate the lowest manual forces, JCFs and JTs. The forces and torques were low compared to the other tools, but did not reflect the limited weight as the much heavier wheelbarrows required similar manual forces, JCFs and JTs, as discussed above.

The garden trolley had the smallest wheels of the tools tested and because of the design of its rounded tub, for some of the trials the tub hit the obstacles before the wheels, causing the participants to slide the tool up and over the obstacle without the wheels initially playing any role. Although this tool has been produced specifically for the garden, where ridges, steps and other small obstacles are commonplace, for this study it did not produce sufficient clearance to overcome these kinds of obstacles. Bigger wheels reduce the force required to pull loads up step (Young et al. 1997) and would avoid sliding the tool tub against the obstacle.

One participant considered the wheels on the garden trolley to be too close together and another participant called it unstable. Both these participants used single-handed pulling and faced in the direction of travel. Due to this pulling strategy, they did not hit the obstacle with the tool completely symmetrical, instead in some trials having one side hit the obstacle before the other. As the handle was made for singlehanded operation, this was an expected strategy. However, coupled with the narrow wheel base this can cause instability. A wider wheel base would reduce this instability.

One participant mentioned she felt vibrations from rolling the garden trolley even on the smooth vinyl flooring used. The wheels on the garden trolley were a hollow plastic, which did not provide much dampening for the relatively low loads used in this study. Without a load in the truck, the wheels would not rotate properly on the same floor, instead skidding across the floor, indicating resistance in the bearing between wheel and axle or reduced frictional properties of the wheel surface compared to the other tools. Proper maintenance and the right combination of surface and wheel material greatly influence overall wheel friction (Argubi-Wollesen et al. 2017).

In regards to the handle height, in terms of spinal compression forces, handles are recommended to be at waist height for pulling (Lett and McGill 2006), regardless of the handling posture (Argubi-Wollesen et al. 2017). The participants were all of similar height (158-162 cm), just below the national average female height. As such it would be expected the tools would be of suitable height or (too) tall for them, however one participant considered the garden trolley to be too short. The handle was considerably lower than the step climber and foldable sack truck.

One participant opted to pick the tool up by the sides rather than the handle, as she stated she preferred dual-handed operation which was not possible on the handle. Although studies have found inconclusive results on which handle position could be considered ideal, joint loads are generally minimised if resulting forces pass directly through or near the joint axis (Argubi-Wollesen et al. 2017). Argubi-Wollesen et al. therefore recommend handle design that allows for switching between grips. For the garden trolley, modification of the handle to accommodate the differences in strategy and preference could be beneficial.

Foldable sack truck

The tool that caused the highest JCF peaks in the shoulders and some of the JCF and JT peaks in the lower extremities was the foldable sack truck. For one of the participants, the single-handed use of the tool explained spikes occurring in the shoulder of the arm used to pull the tool. Although she employed a single-handed strategy for both the foldable sack truck and the garden trolley, which are of similar weight, she used her left foot to step out for the garden trolley and her right for the foldable sack truck, the latter creating a twist in the body that caused spikes in one shoulder and the opposite lower extremity (Figure 7.20).

Figure 7.20: Foldable sack truck (grey) and garden trolley (blue).

Other research has shown an additive increase in vertical torque in the body as a result of combined asymmetric pushing, though they did not discuss the impact on individual joint contact forces or joint torques (Lee and Aruin 2015). Both the foldable sack truck and the garden trolley were pulled singlehandedly by one and two

participants respectively. The joint torques and joint contact forces were reduced in the shoulder joint on the opposite side of the pulling arm (range JCFs: 0.49-1.43 kN, JTs: 6.40-14.5 Nm) compared to the pulling arm (range JCFs: 0.72-3.91 kN, JTs: 8.41-60.1 Nm). The shoulder JCFs and JTs in the pulling arm were not significantly higher than those in bimanual pulling when looking at one participant who did both singlehanded pulling with the garden trolley (range JCFs: 2.32-3.11 kN, JTs: 47.8-60.1 Nm) and bimanual pulling with the foldable sack truck (range JCFs: 1.52-5.87 kN, JTs: 26.6-62.2 Nm). However, the manual force between tool and person was lower for the garden trolley (range: 127-172 kN) than for the foldable sack truck (range: 120-368). When considering the data proportionally, shoulder JTs were higher for the single-handed pulling as compared to the bimanual pulling. This difference could not be established for the JCFs. More research would be needed to establish the impact of single-handed pulling, but perhaps surprisingly, the results of this study do not point to a large increase in the forces and torques of the shoulder.

The foldable sack truck caused some higher manual forces than the wheelbarrows and garden trolley, but the overall trend was fairly similar to those tools. This tool was approximately 2 kg heavier than the garden trolley, had a higher handle and wider wheel base. It was the tool most discussed in the focus groups and seen in observations, but it was not the preferred tool for any of the participants, with one participant having to see the tool to even remember it. There were however no flaws or negatives mentioned in its use, as participants deemed it useful and manoeuvrable and stated its wide wheel base would prevent tipping.

Step climber

The step climber sack truck for all participants generated the highest peak manual forces. It received negative feedback from two participants, though one participant actually saw some use for it for the steps in her garden. The step climber generated higher peak JCFs and JTs in the lower back and hips than the other tools, but for the other joints did not score higher than the other joints.

The step climber was the heaviest of all the tools tested, weighing over 11 kg, whilst the other tools with similar upright operation, the garden trolley and foldable sack truck, weighed less than 4.5 kg. This big difference compared to the relatively small load added in this case meant that although the tool should reduce force required to move the tool and load up an obstacle, it actually increased the

manual force to be the highest of all the tools. One participant stated she thought it was 'too big and bulky', 'cumbersome', 'awkward' and 'very heavy' and another stated it 'felt wrong'. Cart mass has been shown to be the biggest determinant in strain on the musculoskeletal system (Argubi-Wollesen et al. 2017) and as such, a tool that is perhaps less heavy duty but has a reduced weight would benefit this target group.

For the relatively low obstacles with a rise of up to 90 mm used in this study compared to full sized UK steps with a rise of 150-220 mm, the step climber is not ideally suited. Obstacle heights of up to ½ times the radius of the wheels (in this case, up to 37.5 mm) cause the tool to not function as a step climber, pivoting around the main axis, but instead upon hitting the step the front wheels are pulled across. In this situation, the handle being attached to the main axis is a disadvantage as it means an additional torque has to be overcome compared to a handle attached to the wheel directly. In this study, the smallest obstacle of 30 mm thus caused this situation to occur and all three participants pulled the tool across without the tool pivoting. For the 60 and 90 mm obstacles the tool did pivot for all participants, however because the height of the obstacles was limited, the tool made an audible impact when the wheels had pivoted round and hit the top of the obstacle. The wheels on this tool were firm solid rubber and as such did not provide much shock absorption. Although the design if used on the steps it was intended for and with a heavier load would provide a reduction in required peak manual force, for lower obstacles and relatively light loads as used in this study the tri-star mechanism provided no benefit over single-wheeled tools in terms of peak manual forces, JCFs and JTs.

One participant opted to use the top handlebar rather than the provided hand grips. This meant she was holding the tool more horizontally than the other participants who were using the provided hand grips, however this did not seem to cause a difference in the JCFs and JTs, as they were in keeping with the overall trend for this participant of JCFs and JTs of similar magnitude to one of the other participants. This provided further support for the recommendation of Argubi-Wollesen et al. (2017) to include different types of grip into the design as people will have their preference.

7.4.2 The influence of obstacle height

With increasing height, the manual forces increased as expected. The JCFs and JTs did not increase considerably with increasing obstacle height, despite the upward trend in manual forces. The JCFs and JTs are functions of the externally applied forces together with the orientations of the arms and trunk. Whereas the force between the subject and the tools is a function of mass distribution and geometrical properties of the tool and hence invariant, the neurological system will react to limit these torques and forces to acceptable, non-injurious magnitudes by re-orientations of the anatomical segments. Furthermore, though all participants got a fair amount of practice for each obstacle height, there may have been limited participant learning effects, as the height order was not randomised.

For all obstacle heights, the highest recorded torques were lumbar torques. Compared to literature on the maximal motor torques for an average male (75 kg, 1.75 m) in the flexion/extension direction of 190 N·m (Robert et al. 2014), the overall lower back torque magnitudes measured for the older women during the trials were substantial, with several over 100 N·m and one participant even generating JTs in excess of 190 N·m for the puncture proof wheelbarrow. Safe limits for joint torques for older women are unknown, but these findings are cause for concern and warrant further investigation, as the loads used in these trials (7 kg) were lower than several of the loads seen moved in the garden by older women (Chapter 6).

7.4.3 Impact of the individual

As indicated in other research, prior experience in pushing and pulling reduced the lumbar contact forces and reduced muscle activation and this experience as well as the technique used were main contributors to total load in the back (Lett and McGill 2006). The participant with the most experience overall generated the lowest JCFs and JTs whilst for most tools the manual forces were in similar ranges (range p1: 84.8-193 N, p2: 42.5-222 N, p3: 80.2-325 N). An example of this can be seen in Figure 7.21, whereby this

Figure 7.21: Foldable sack truck pulled across using upper body (green) vs. leaning in (purple).

participant used her bodyweight to leverage the tool across and another participant actively lifted the tool. The experienced participant considered herself to not be very strong anymore, and this lack of strength combined with her experience are expected to have been contributors to the lower JCFs and JTs. Furthermore, her previous back injury may have induced more conservative pulling behaviour.

Other studies have shown that pushing and pulling on level surfaces results in relatively low back loads but can cause shoulder complaints (Hoozemans et al. 2002) and it has been suggested that the lower back may be at risk to unexpected loading when hitting an obstacle. Recommended safe limit for low back loading as defined by Waters et al. (1993) is 3.4 kN. In this study, some of the L3-L4 lumbar joint contact forces were over the recommended limit. Participant 2 experienced JCFs of 3.83 kN using the step climber on the medium obstacle. Participant 3 experienced spinal contact forces of 3.61 kN using the puncture proof wheelbarrow on the medium height obstacle. The only participant that had reported previous back injuries generated lower back loads (range: 0.60-1.77 kN) than the other two (range: 1.00-3.83 kN). Her technique tended to reduce load on her back and as such she successfully avoided excess loading.

The participants experienced higher forces and loads in different joints through differences in strategy (Figure 7.22). In the shoulders, participant 3, who leaned forward and pulled in a single motion experienced overall higher JCFs in the shoulders (range: 1.98-3.63 kN vs. other participants on initial bump: 0.68-2.55 kN) and lower back (range: 2.62-2.75 kN vs. other participants on initial bump: 0.95-3.83 kN), as well as the highest JTs in the lower back (range: 143-150 N·m vs. other participants on initial bump: 76-103 N·m). This difference was not observed in the other joints. The same participant also generated greater manual forces than the other participants (range: 80.2-368 N vs. other participants: 42.5-216 N). Lack of experience in optimising the use of her body to reduce overall impact may have contributed to her relatively high manual forces, as well as the high manual forces generated by all participants using the step climber. More experience with the tools provided therefore would potentially reduce the forces used and gotten the participants closer to the theoretical minima.

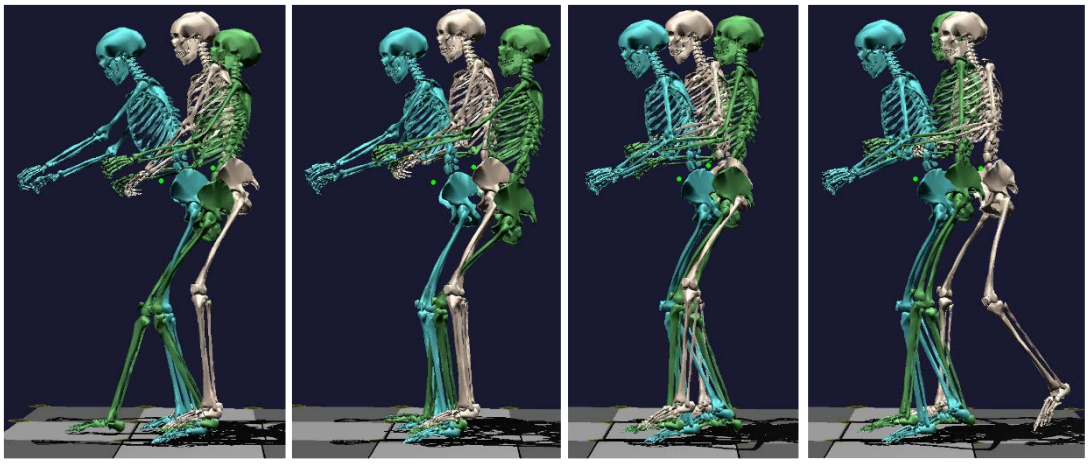


Figure 7.22: Sequence of the three participants pulling the step climber sack truck across the highest obstacle. One participant (green) used her bodyweight, whilst the second (grey) stayed upright and the third participant (blue) even leaned forward.

Alternatively, the difference in strategies may have been a method of compensation for reduced musculoskeletal capabilities, as was suggested to be the case in unaided stair ascent of elderly people (Reeves et al. 2009). One participant that had suffered a back injury in the past generated the lowest JCFs and JTs overall. However, the participant that had had a knee replacement did not have significantly lower JCFs or JTs in the knees and more research is required into the role of compensation.

Shoulder JCFs were in the range of 0.64-7.24 BW, with most below 4.00 BW (Appendix N). In comparison, abduction with a straight arm and no additional weight was found to be approximately 0.9 BW and doing push-ups more than 7 BW (Anglin et al. 2000). Though it was expected the higher JCFs would occur for the instances in which participants used one hand to pull a tool across an obstacle, a clear relation between these could not be established.

Knee JCFs were mostly in the range between 1-4 BW (body weight), comparable to activities like cycling, walking and stair ascent and descent (Mow and Hayes 1991). There were however a few exceptions whereby knee JCFs were larger than 4 BW. These higher JCFs did not seem tool dependent, as it occurred at least once for each tool, nor participant dependent, as it occurred at least twice for each participant. Instead, they occurred if participants leaned on one leg only whilst pulling the tool across. Where this occurred, generally a high hip JCF (>5 BW) occurred on the same side. In comparison, 'normal' walking generates hip JCFs of 2-3 BW (Bergmann et al. 2001) whilst

stumbling can generate hip JCFs of >8 BW (Bergmann et al. 1993). High lower extremity JCFs seemed to relate mostly to the timing of stepping backwards and pulling the tools, with unfortunate timing mid-stride causing high JCFs. Furthermore, they related somewhat to the height of obstacle, with only one of the high JCFs occurring on the lowest obstacle height, four on the medium height obstacle and five on the highest obstacle. More data would be required to accurately determine the influence of obstacle height and timing. All JCF lower extremity data expressed in proportions of bodyweight can be found in Appendix O.

The third participant had indicated on the body diagrams that she experienced some discomfort in her left knee during both wheelbarrow trials, but no pains in her shoulders or back. She had JCFs and JTs somewhat higher for the left knee during the puncture proof wheelbarrow trials, but not during the inflatable tyre trials. However, the wheelbarrows made her bend her knees somewhat to grab and lift the handles, and although these parts of the trials were not on the force plates and thus no data exists on the JCFs and JTs at that time, they may have caused the discomfort felt in the knees. The other participants did not make note of any discomfort in their knees.

The participants were all given the same instructions and the RPE scales were explained exactly as suggested by Borg (1998), but one participant gave all trials the basic RPE rating of 6, corresponding to “no exertion at all”, even lower than the score of 9, which was described by Borg as “[…] walking slowly at his or her own pace for some minutes”. Other research considering RPE for horticultural activities also found participants underestimating the intensity of the activities (Park et al. 2017). As Argubi-Wollesen et al. (2017) mentioned, the RPE scale is based on a strong cardiovascular response to an activity and as such is more suitable to activities that are more intense. Furthermore, two participants seemed to struggle to distinguish between the rating system of the RPE and the discomfort scale, instead using the RPE rating values on the body diagram. Although these RPE values could not be translated into the 0-5 discomfort scale, it did indicate some discomfort in the marked areas on the body diagrams.

7.4.4 Limitations

The main limitation to this study was its small sample size, similar to many of the studies on the usability of tools and their impact on the overall body and particular joints (Argubi-Wollesen et al. 2017). The implication is a lack of generalisability through statistical analysis and replication with a larger group would thus provide greater confidence in the accuracy and representativeness of the results. However, even with 3 participants the quantitative results gave indications on various trends and the difference between tools on their impact on the body was made visible in these trends. As such, rather than assuming every older woman will generate these same exact loads, the simple fact that these women with different physiques and experience generated these loads still provides valuable insight.

Another limitation was inherent in the tools selected in this study. Though they were chosen to cover some of the variety on the market, other models or similar tools would potentially have provided other insights and as such the differences between these tools could not be generalised to e.g. all wheelbarrows or all sack trucks.

Because the force plates were of limited size, accurate foot placement was difficult to achieve. During the trials there was insufficient time to check each trial's data for this, so instead the study relied on visually establishing whether feet were on the force plates at the time the tool was being pulled onto the obstacle. Even though several repetitions were undertaken for any trials which were deemed potentially insufficient, in the end there were still missing data points in 4 trials, where the peak of the manual forces occurred prior to the participant being fully on the force plates.

For any study in lab settings naturalistic conditions are difficult to achieve. Due to the difficulty of needing two feet on the force plates, participants became increasingly aware of their foot placements and thus the postures adopted and techniques displayed may not have been entirely naturalistic.

Furthermore, the combination of footwear and ground surface material is likely different in actual gardens. One of the participants was wearing slippers rather than full shoes and none of the participants wore footwear designed to prevent slipping (Figure 7.23). This may have influenced their ability to use friction with the floor to pull or push the tools across and may have changed their postures, similar to findings on trolley pushing and pulling (Boocock et al. 2006).

Trials were repeated where feasible to ensure a trial with sufficient data quality was captured and to initially determine appropriate obstacle distance, which led to some tools being used a few more times than the others. The effect of this is expected to be limited as all tools were used a roughly equal number of times and at least twice.

A muscle model is used to calculate the load distribution, however the model is crude and based on Hill's 3-element muscle model. It did not consider fatigue or ageing effects. Furthermore, the external markers, though placed with care by someone with considerable expertise, are prone to move or slip during the movements. To minimise marker errors, a 12 camera system was used and carefully positioned to ensure optimal visibility from every side. Any missing marker data through obscured movement or marker failure was replaced by filling the trajectories through assumption of rigid structure in the case of a missing hip, head, torso or foot marker, or by trajectory estimation for other markers. The expected impact of these errors is limited (order of magnitude 5 mm), as small sections of missing data were replaced and trials with extended missing data points were excluded from subsequent analysis.

Although the tools were randomised, the impracticalities of randomising the order of the obstacle heights within this study meant that the heights were each time executed in order of increasing height. This might have caused some learning effects, with participants becoming better at using the tools and judging the amount and direction of force required better for the higher obstacles than the lower ones, thus relatively lowering the manual forces applied for the higher obstacles. However as one of the participants stated in the post-trial interview when asked to compare the tools:

Figure 7.23: Inappropriate and non-standardised footwear may have reduced participants' capability to use their feet as fulcrum during the trials.

"To give it a fair trial, you'd probably need to use it for half a day". The participants used each tool for only a few minutes during the trials and got some practice for each obstacle height, and as such learning effects are expected to be limited.

The assumption was made that the acceleration of the centre of mass was small compared to 1g, and as such the hand forces could be estimated by taking away the weight of the participant from the vertical component of the measured GRF in the force plates. However, in reality the acceleration of mass due to participant movement will cause the force peaks to be somewhat lower or higher than bodyweight. A normal stride will encompass breaking and propulsion which cause peaks and an intermediate valley (Figure 7.24), during which the vertical component of the GRF encompasses only approximately 75% of the normalised force (Giakas and Baltzopoulos 1997). Most trials encompassed only a step backward from static start. Therefore, because the participants generally did not perform what could be classified as close to 'normal gait', limited fluctuation of the GRFs is expected to have occurred. The only exception was the second participant, for whom some of the forces measured were lower than theoretically possible manual forces. These were the trials for which she was taking several steps and was mid-stride at the moment of peak force occurring. In addition, in these very dynamic trials it is expected that the acceleration of the mass of the tools given prior to the participant stepping onto the force plates was such that the total force needed was less. This is similar to the findings of Young et al. (1997), who found that when moving sack trolleys up steps a higher average force would accompany a lower peak force and vice versa. This study did not have the setup required for calculation of average forces as only part of the trial occurred on the force plates.

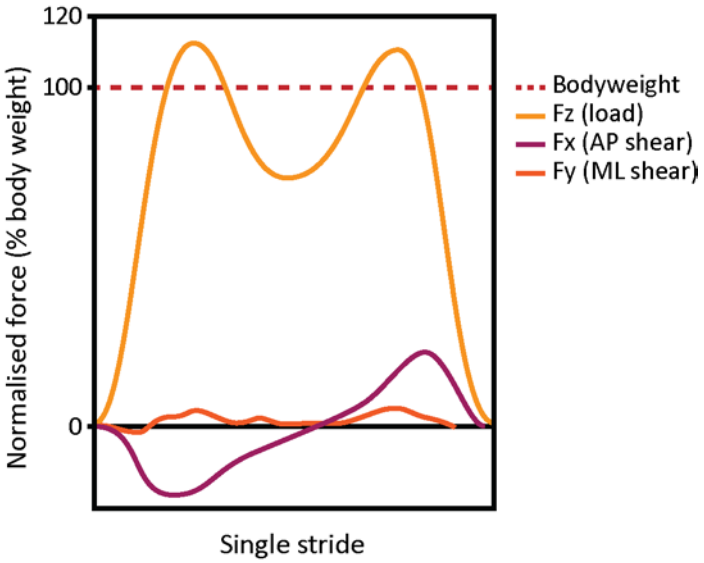


Figure 7.24: The three components of the ground reaction force during a single stride of normal gait, modified with permission from Kirtley (2006). The vertical component Fz exceeds the body weight upon initial impact (breaking peak) and upon pushing off (propulsive peak), and in between will be only approximately 75% of bodyweight (Giakas and Baltzopoulos 1997). The initial peak and the valley both reduce with slower walking speeds, creating a profile closer to the dotted line for slower speeds.

7.5 Conclusions

This study was conducted to investigate the combined influence of tool, obstacles and personal factors and provide recommendations on tool design and tool use for this common gardening situation. This was undertaken through a lab-based study in which the tools used, and obstacle height, varied. The main research question addressed in this chapter was: which factors influence the problem of moving heavy objects across obstacles of varying heights and to what extent? The following findings resulted:

- Among the tools tested, the step climber was found to be least favourable tool for overcoming the height differences, with little difference identified between the other tools.
- Increased obstacle height led to increased forces required and experienced in the older women's joints.
- As the force required depends on both the size of the obstacle and the size of the wheels, increasing wheel diameter increases the size of obstacles that can be overcome without fully lifting tool and load weight and as such improve design of all tools used.

- Even with limited load (7 kg), some lumbar torques for the puncture proof wheelbarrow and the step climber were found to be high compared to maximal lumbar torques generated by average males and warrant further investigation.
- None of the tools were used in the most theoretically optimal way and increased obstacle height seemed to increase inefficiency; greater difference between the measured and theoretical optimum. Training in the use of the tools could decrease inefficiency, but redesign of tools to ensure pulling or pushing across obstacles can be done in line with the direction of movement for the tool may prove more achievable.
- The impact of strategy of pulling or pushing seemed significant; provision of tools that are more adaptable to user's anthropometry would be beneficial. Furthermore, training to adopt more efficient postures and exert forces in a more optimal direction might reduce impact in specific joints (e.g. lower back) and thus prevent injury.
- Wheelbarrows were generally pulled by the participants, as pushing across the higher obstacles was impossible, but in real life settings this may cause imbalance due to participants having to move backwards. Combined with the inherent instability of single-wheeled wheelbarrows the risks should be investigated further.
- As different strategies were seen with hand grips for the sack trucks and garden trolley, the recommendation of Argubi-Wollesen (2017) to include various grips to fit personal preference was reinforced. Variety in grip would also benefit more variety in situations, thus likely benefitting height differences as well.
- The garden trolley should be redesigned to position wheels back far enough to prevent the back of the tub hitting the obstacle instead of the wheel. The handle height should be considered in future work as it was commented on in this study for being too low.

The study highlighted the importance of the appropriate use of tools and designing appropriate tools to deal with these obstacles as often occurring in the garden. Furthermore, specific design deficiencies in some tools were identified, thus the opportunity exists for the industry to develop improved tools.

Chapter 8 Conclusions and future work

The aim of this thesis was to investigate the barriers and coping strategies of older women in their leisurely gardening pursuits, in order to identify beneficial modifications to behaviour and tools, so that they may continue their horticultural activities more successfully as they age. In this chapter a summary of the thesis results and conclusions are discussed. The significance of the results of the studies are considered and recommendations for further work regarding older women and gardening are presented.

8.1 Thesis summary and conclusions

Although it is known gardening can contribute to both physical and mental health, the barriers experienced and coping mechanisms applied by older people and older women in particular were not well-known. If the successful continuation of horticultural activities for older women is the aim, knowledge of the barriers perceived and experienced and the methods of overcoming these barriers is imperative in order to support and encourage older women to continue gardening.

To obtain insight into the needs and issues of older women with gardening, the objectives of the research were:

1. To explore motivation to undertake gardening as an activity.
2. To understand factors affecting motivation to garden.
3. To investigate perception of specific gardening tasks.
4. To identify specific challenges that may act as barriers to moving heavy objects in the garden.

5. To determine the impact of navigating environmental obstacles in the garden on the body.

The research encompassed an investigation of existing literature. The existing knowledge on the ageing woman and her relation to the garden was reviewed, and the potential role of gardening for the older woman's health and well-being was investigated. It was found that the benefits of an active lifestyle as both preventative measure and to counter already occurring effects of the ageing physique were established (Section 2.1). Furthermore, gardening was found to have many of these benefits (Section 2.2). Increased participation or continued participation in gardening for this group would thus be beneficial. However, in investigating both their motivations to participate and the barriers older women observe in gardening, some gaps in literature were found.

Firstly, motivations to garden have sparsely been investigated, with only nine relevant studies found (Section 2.3). These studies each utilised different research methods, had varying focus and included different participant groups from a multitude of cultural backgrounds. Though the results of the studies point to the significance of inner directed, experience and results oriented motivations, no indication of the importance of individual reasons for gardening could be given for the older woman in the United Kingdom. It was concluded that further studies examining the motivators to garden would help to identify what makes gardening such a popular pastime amongst older women.

Secondly, actual and perceived barriers to gardening for older women have not been a topic of significant research (Section 2.5). Though it is clear the ageing body affects the older person's ability to garden, the influence of the older physique and other factors such as the situation in the individual's garden and the tools available is unclear. It was concluded that investigation of these factors would be beneficial as it would indicate areas in which the gardening experience could be improved and thus the older woman could be aided in successful continued participation.

Furthermore, the actual and perceived barriers relating to individual tasks is unclear (Section 2.4). Though the intensity of many different gardening tasks has been investigated and expressed in metabolic equivalent units, little is known about the older woman's perception of individual gardening tasks. For leisure activities, perception of the tasks at hand is argued to be of great consequence, as perception drives behaviour.

In this mixed methods sequential research, results from prior studies provided direction for further research. It was found that moving heavy objects in the garden is a task many older women consider difficult and leave to others because they considered it too hard. Furthermore, the task was the least enjoyed, and as a relation between enjoyment and difficulty was found, their lack of enjoyment may at least in part be related to the lack of success in completing the task. This task was therefore seen to be in need of change and the existing knowledge about the task of moving heavy objects in the garden was investigated. The supporting task in the garden was found to be similar to other manual materials moving tasks, occurring in settings such as warehouses, building sites and even airplanes. However, the garden environment and the tools used by older women in their gardens were not included in prior research; little is known about their impact on the older woman's ability to move objects, nor on how helpful tools are to overcome them. This research gap was addressed within the research through a biomechanical study which provided novel and objective new information.

The three aforementioned research objectives were addressed in four studies. The sequential research design consisted of large to small scale studies, to scope out and focus in on barriers to gardening for older women and how to overcome them. In an online survey, the views of older women around motivations to garden, factors influencing motivation and comparison of gardening tasks were incorporated to identify the most significant motivators, influences and tasks most in need of change. In subsequent focus groups, the motivators and influences on motivations were linked to specific tasks to further understanding of the impact of individual tasks on overall gardening appreciation. In the focus groups the task of moving heavy objects in the garden was also more closely examined, leading to the identification of the problem scenarios related to this task. Observations of older women provided identification of the root causes underlying the scenarios. Steps and other height related obstacles were frequently seen and seemed to have a strong impact on the stability, difficulty and safety of moving heavy objects. A lab-based biomechanical study was undertaken to examine the impact of steps and different tools on the older woman's body and perception of the activity.

The results for each objective are discussed below.

8.1.1 Motivations to garden and influences on this motivation for older women

To understand motivations to garden and influences on this motivation for older women, a survey study (Chapter 4) and series of focus groups (Chapter 5) were held.

Motivations to garden

Other research had found that intrinsic, experience and result based motivators tend to be more important than social and competitive motivators for non-community gardeners of various ages (Section 2.3) and the findings of this research were mostly in agreement with existing knowledge. Both inner directed experience and inner directed results were found to be the most important reasons to participate in gardening, with intrinsic happiness the most important motivator. In contrast, though older men agreed that intrinsic happiness was their main reason for gardening, for them the results driven motivations were main drivers, rather than experience driven motivators. These results indicate that for older women, gardening has great potential to serve as a means of keeping up physical activity; rather than the exercise programs with low adherence, gardening is undertaken by the older women not just for its results, but also for the activity itself. As the physical and mental health benefits of gardening are established (Section 2.1), helping older women successfully continue if challenges arise and even encouraging those with some hesitation to try the leisure pastime could increase the amount of years lived in good health.

Other research had found varying results on the importance of the healthy exercise aspect of gardening for leisure gardeners (Section 2.3). In this research it was found that healthy exercise was important, but not one of the most important reasons for older women to participate in gardening. However, in comparison to younger generations of women, it was found to be a more important motivation for the older women, indicating an increased awareness in older women of the role of gardening in keeping them healthy. This may indicate that whilst for younger women, exercise may come from other activities, for older women gardening may present one of their main forms of exercise, further strengthening the argument for successful continuation of gardening activities as women age.

As evidence is growing for the role of gardening as a means of prevention of ill health and to counter effects of ageing already experienced by older women (Section 2.2), it is recommended that gardening be

considered more in the health and wellbeing policies of councils and government, and horticultural initiatives are enabled through either home or community based initiatives.

Motivation relating to enjoyment of gardening tasks

In focus group sessions among female leisure gardeners of 50+, it was found that reasons for older women to enjoy particular tasks related back to the overall motivations for gardening, with tasks being enjoyed for specific motivators. As this was the first study to consider enjoyment and motivation on a gardening task level, the results could not be compared to other findings, but these findings present a valuable indication of the complexity of the gardening experience.

An awareness of the difference in perception of gardening tasks and the motivations behind doing them could aid in the planning of gardens and community gardening initiatives. For example, it can be expected that for those tasks engaged in primarily for the results obtained (e.g. weeding, gathering leaves and cuttings), these should not be too plentiful, as failure to complete the whole task (e.g. not being able to clear the whole garden before new weeds crop up or additional leaves fall) may cause discouragement. Planting, sowing and pruning, enjoyed for their contact with nature or relaxing feeling, should occur as much as possible, as they will keep older women engaged. This could be applied by growing annuals, which will require yearly renewal and fast-growing plants and shrubs that require frequent pruning. As part of the gardening experience is the connection with nature, loud tools were explicitly disliked for disrupting the quiet around them. As such, quieter power tools seem to have significant potential for the older female group. Healthy exercise was mentioned too, with satisfaction for some older women deriving from the physicality of the activities and even from the potential pains and aches after.

8.1.2 Influences on motivation

The potential influences on whether older women are motivated to undertake gardening tasks were also considered in the online survey study. It was found that the effect on the garden was the main influence, in line with the motivations for gardening discussed above. Women under 50 experienced time related constraints significantly more than older men and women, but overall the groups were largely in agreement. As the groups over 50 contained more retirees, this was along the lines of expectation.

Aside from the effects on the garden afterwards, several environmental conditions and tool characteristics played a role in (de)motivating older women to undertake gardening. Unsurprisingly, weather and the consequent soil conditions in the garden were important, but surprisingly, older women also considered tool characteristics relevant. The tool characteristics found to be most important were suitability and ease of use of the tool, followed by tool weight and comfort of the tool handle. Finally, tool quality was of some importance.

What these results seem to indicate is that older women seem to be very aware of the tools needed for the task and how the right tool may help and the wrong tool may inhibit them. Through the effects of ageing (Section 2.1), it can be expected that older women have increasing difficulty handling the gardening tasks, and availability and provision of appropriate tools is therefore important. Coupled with the popularity of gardening among this group it is therefore recommended to the tool industry to consider this target group more in the development of their tools, as older women have a keen eye for the right tools and have an increasing population. Several recommendations to this end are made within the following sections.

8.1.3 Improving gardening tasks for older women

Both the online survey (Chapter 4) and the focus group study (Chapter 5) included sections which compare gardening tasks and identify those in need of change for older women. This research project was the first to compare participation in and perception of gardening tasks. Moving heavy objects in the garden was the least enjoyed, most difficult and least participated in by older women. The results point most clearly to a need to investigate the task of moving heavy objects in the garden in more detail, and this was therefore done within this research project.

Participation

It was found in the survey study that participation amongst older women was relatively low for mowing the lawn, trimming hedges and moving heavy objects in the garden. As increased or continued participation in gardening is desired and all three tasks have been found to be moderate to high intensity tasks, further investigation to establish the barriers in participation for these three tasks was required.

More men over 50 participated in mowing and moving heavy objects in the garden and more women under 50 mowed the lawns, whilst no significant differences compared to older women were found for

trimming hedges. These results indicate that mowing is a gendered activity for the older generations, but that for younger women this is not the case. Though gender roles may be difficult to break for the older generations, further investigation could take place to establish whether there are ways to encourage the older woman to mow their own lawn, e.g. through improved tool design. In the focus groups and observations, one participant saw great potential for a mower in similar style to the now increasingly common upright vacuums for the home. A similar styled mower might be easier to manoeuver and handle and it is recommended further research into innovative new design for lawn mowers aimed at older women is undertaken.

Furthermore, it was found women generally are less likely to lift and move heavy objects than men and it was shown in the study for the majority of older women, other people would do this task and around one third of older women that did not move the objects themselves considered it too hard to do. This indicates lack of independence for older women to move heavy objects and a need to consider this activity. In subsequent focus groups, it was found that older women often lack assistance at the time they need it and as such, supporting tasks like moving heavy objects impede the older women's ability to do gardening successfully and frequently.

Enjoyment

Enjoyment of gardening tasks varied, with planting being the most enjoyed task, followed by sowing and plant pruning. Women over 50 were found to enjoy weeding more than both younger women and men over 50. The older women also enjoyed pruning more than the older men. Tasks enjoyed the least by older women were found to be trimming hedges, gathering leaves and cuttings, mowing and moving heavy objects in the garden. For those tasks that are enjoyed, participation was also high and as such, no argument was made to consider these tasks in more detail. However, those tasks not enjoyed did require further exploration. Reasons not to enjoy tasks were found to be: considering tasks tedious, boring, frustrating when unable to do, heavy and cumbersome, a chore or causing a participant to feel unwell. Lack of enjoyment for gardening tasks thus seems to stem from mostly problems with the execution and lack of enjoyment was not found to be related to the results. As for any leisure task enjoyment is at least a component to the motivation and thus participation, increased enjoyment is desired and could come from reducing the identified negative characteristics of gardening tasks. Whilst the repetitive nature of e.g. weeding is difficult to remove, certainly there is potential to improve the tasks that older women are

unable to complete (moving heavy objects), make someone unwell (lawn edging) or are seen as heavy and cumbersome (watering) and it is recommended these incidental reports be investigated to potentially make gardening as a whole more enjoyable.

Difficulty

Perceived difficulty of gardening tasks was investigated in both the online survey and in the focus group study. The task found to be significantly more difficult than nearly all other tasks was moving heavy objects, which was agreed upon by both younger women and the older men in the study. In addition to moving heavy objects, pruning trees and trimming hedges were considered somewhat difficult by the older women. The weight of hedge trimmers was a frequent topic of discussion in the focus groups and getting up on ladders (associated with both these tasks) was considered unsafe. Furthermore, the older women indicated struggling with thick branches. Participation in pruning trees was high among older women that had trees and as such no indication for further investigation was established. However, participation in trimming hedges was relatively low (61% of older women) making this is a task warranting further investigation. From this research trimming hedges was the task most clearly benefitting from improved, lighter weight tool design as this is expected to increase participation by older women in this task.

Relation between enjoyment and difficulty

A link was found between enjoyment and perceived difficulty of gardening tasks; tasks considered more enjoyable were tasks that were less difficult and vice versa. Though relation was established, causation was not. In the focus group study, explicit links between enjoyment and difficulty were made in few instances, but insufficient evidence exists to clearly define the relation between enjoyment and perceived difficulty. It is speculated that more difficult tasks are enjoyed less, but simultaneously when tasks are more enjoyable for their results or connection to nature, older women may also be less aware of their difficulty or more able to cope with this.

In this research, some support to this theory was found for a few of the tasks. It was expected that the requirement to bend down and work on ground level, e.g. when planting or weeding, and the repetitiveness in the hand motions of e.g. pruning would make these tasks somewhat difficult for ageing women, many of whom suffer from arthritis. Planting, pruning and weeding were however not

considered difficult by participants in the survey. In the focus group study, difficulty of these tasks was discussed and several women did mention bending and repetitiveness as negative aspects to these tasks, though most would not change the order of difficulty of tasks. As planting, pruning and weeding were quite enjoyed by the older women, and the survey had established a link between enjoyment and difficulty, the enjoyment of the activities may have influenced perception of difficulty for the women; their enjoyment may have lead them to consider the task less difficult than it is. More research is required to establish validity of this finding and whether it can be generalised to other gardening activities. Understanding the connection between enjoyment and difficulty could help understand engagement of older women in specific gardening activities and gardening overall and thus be used to develop suitable tools, gardens and community gardening initiatives. If a connection is there, it begs the question whether this can be exploited further to 'trick' older women into undertaking more unpleasant (aspects of) tasks more willingly. However, realistically, making difficult tasks more doable for the older women is more likely to have a direct positive influence on successful participation.

The overall recommendation arising from the above is to ensure older women have the facilities and tools required to do the tasks they enjoy and do not consider difficult, and to further investigate mainly those tasks with low participation: mowing the lawn and trimming hedges. This should benefit increased and successful participation in gardening.

8.1.4 The challenges associated with moving heavy objects in the garden for older women

Moving heavy objects in the garden was found to warrant further investigation based on low participation rates, lack of enjoyment and high perceived difficulty of the task for older women. This task was therefore explored to identify the challenges and coping methods associated in focus group sessions, observations in older women's gardens and a lab-based biomechanics study (Chapter 5, 6 and 7).

Problem scenarios

Moving items purchased in store, most notably compost bags, into the garden or shed was found to cause problems for many older women. A similar scenario was put forward in each focus group (Chapter 5): the older woman would purchase compost bags and shop employees would aid in putting them in the boot of a car, but once home the bags had to be taken from the boot and moved to sheds or other places, often in

the back garden. Another scenario was found to be moving potted plants. To both rearrange them for aesthetic or functional purposes or to protect potted plants from frost in winter by moving them to shelter, potted plants were considered to be in frequent need of moving.

Notably, heavy tools and moving them around was also found to be an issue for many older women, with hedge trimmers, lawn mowers, spades, sheers, wheelbarrows, leaf blowers, watering cans and loppers coming to mind for the older women. The older women identified lack of consideration by tool developers for them, the older women, as a problem needing to be addressed: tools should be made not for young, strong men but for them. It is recommended manufacturers of tools consider the older woman more in their tool development, and create lighter weight, smaller sized tools for the older women to enable them to do even the 'hard jobs' in the garden themselves.

Issues with moving heavy objects

Older women in the focus groups (Chapter 5) discussed their difficulties surrounding moving heavy objects and this resulted in a prioritised list of problems, some of which were observed in subsequent observation sessions in older women's gardens (Chapter 6). The most pressing issues were found to be:

- **Lack of assistance.** Help was not around when required, and waiting for it or asking for it was not acceptable. Lack of assistance is a complex problem to solve and though community initiatives may work for some situations, independence from others is considered preferable within this research.
- **The older woman's physique.** Insufficient strength, joint and balance problems and overall frailty got in the older women's way when wanting to lift and carry items. The ageing body has its limitations and though forms of exercise can negate these to an extent, any person and the older person in particular can be expected to have trouble lifting and carrying heavy items. It is therefore imperative to make the job itself more doable.
- **Garden environment.** Steps, stairs, and other height related obstacles made moving items from A to B more difficult and varying terrains and limited space to manoeuver added to the challenges. Steps and other smaller height differences were also observed and the combination of the relatively small wheels and these height differences complicated moving of objects and increased risk of injury for the older women. Furthermore, use of a sack truck on steps caused

instability and thus induced a risk of falling. Though in some gardens these issues may be solved by improved garden design, the cost implications and the aesthetic implications were both mentioned as drawbacks in the focus groups. For some it may be possible to reduce or remove height differences in their gardens, change to smooth pathways and flatten out doorway thresholds, but for many, a tool that would make overcoming these obstacles easier could be beneficial.

- **The objects to be moved.** Because of quantities desired or cost-effectiveness of larger compost bags, the older women often ended up with heavier loads than theoretically necessary. Dehydrated compost was offered as a solution by some, but the relatively high price and the limitations in different qualities and contents are downsides. If prices were to reduce to parity with non-dehydrated variants and different kinds would be offered in dehydrated form, this may be a suitable solution for many older women. It would allow them to mix the desired amount and this activity may reduce heavy lifting and increase time spent in the estimated medium-intensity activity and as such provide them with more enjoyable ways of adding compost to their gardens. For potted plants, it was brought up that as plants grow, pots grow too and bigger plants require sturdy pots to stay upright. Inevitably, at some point the older woman will no longer be able to move the pot. Avoiding this is difficult, as it is inherent to gardening, and often desired, that plants grow. However, light-weight plastic pots with wide bases may delay the problem somewhat, as would light-weight drainage materials. If sufficiently stable, the major remaining consideration is in aesthetics. Alternatively, improved design of the mechanical helpers available may also prolong the older woman's ability to move bigger potted plants; in the observations the loading and unloading phases of moving were found to be in need of change, as the older women lifted or pulled whilst bending without use of their knees. The results indicated a clear need for mechanical movers to aid in the loading and unloading phases of the moving, not just the carrying phase. It is recommended a tool be developed that would avoid this awkward posture and aid in loading and unloading.
- **Specific tool characteristics.** The older women identified several problems with wheeled bases used to move potted plants: wheels would break, pots would slide off, and it required them to both bend and drag at the same time. The wheels were also considered too small as they would

snag on any unevenness in surface terrain, making them unsuitable for use on e.g. gravel. The women themselves saw opportunities for the addition of a handle to pull the potted plants along without having to bend down and for improvement of the loading and unloading by removing the need to lift the potted plants onto the devices, suggesting instead that the wheeled bases have an opening so they can be rolled around the pot, and then lifting the pot through some kind of mechanism. It is recommended manufacturers of these wheeled bases consider the challenges with their products and innovate to make this easier. Opinions on different types of wheelbarrows varied, whilst those who made use of sack trucks or trolleys were generally pleased with their tools.

8.1.5 To determine the impact of navigating environmental obstacles in the garden on the body.

A lab-based biomechanics study (Chapter 7) was done to test existing mechanical movers for the garden on their ability to work on height differences in the garden. With increasing obstacle height, manual force required rose and forces and torques in the body consequently rose too. The least favourable tool to use to move heavy items across the limited height differences (up to 90 mm) was the step climber, whilst wheelbarrows and garden trolleys were the best tools to use. Wheel size was the main contributor as larger wheels reduce the amount of vertical force required to overcome the obstacle. As such, larger wheels are recommended for any tool that is used in garden setting, as it will also make moving over different terrains such as gravel easier.

Even though limited load of only 7 kg was used in the biomechanics study, several lumbar torques were found to be close to the maximum lumbar torques as generated by younger men, and two were even over this maximum. This is some cause for concern, as it indicates a risk of injury for the older women and it is recommended larger replication studies are done to validate these findings.

None of the tools were used in the theoretically most efficient way, with differences between participants large. This indicates training or practice could be beneficial, but more importantly, tools should be redesigned to align natural force direction better with alignment of handles. Various grips (at different heights too) should be incorporated to accommodate personal preferences and ideal angles in different situations. For wheelbarrows, it was observed that pulling onto obstacles was preferred and the force

exertion is better this way, however there is a risk of imbalance and tripping if this were done in real gardens and as such, pushing or pulling whilst facing forward may be preferred in actual gardens.

8.1.6 Recommendations towards tool designers

This research has led to recommendations for tool designers to improve the user experience for older women. In Table 8.1 these recommendations are summarised. These recommendations should be seen as a first attempt to formulate advice and guidance for design innovators. Further investigation would be needed to identify at which stage or how they might be integrated most effectively in practice.

Table 8.1: Recommendations for tool design.

Topic identified	Recommended steps to take
General design process	
Older women feel tools are not designed with them in mind.	User centred design offers several tools to incorporate users into design processes. All the methods used in this research have provided valuable input, but for rapid and clear insights during the design process observations of actual users would be highly recommended to incorporate into garden tool design practice. Furthermore, in the focus group sessions it has become clear older women can critically analyse their own experience and especially lead users could provide invaluable insights. Inclusion of older female users in the design process would likely lead to improved gardening tool design for older women.
Encourage independence	The older women indicated a desire to retain their independence. Especially those tasks traditionally viewed as more suitable for young, strong, male professional gardeners should not be ignored for this group. This means the gardening tools most in need of improvement towards older women are tools like lawn mowers and hedge trimmers.
Context: steps and other garden situations	In the analysis of existing tools it became clear that the tools were not optimised for the obstacles encountered in the garden. To improve design of these tools, the context should be taken into account more explicitly. It is suggested this may be accomplished through observation sessions or lived experience by the tool developers in different typical garden settings. The obstacles identified in this research relate to the moving of heavy objects within the garden and include: • Height differences, • Different terrains, e.g. gravel, grass, mud, slabs, and • Narrow paths, including sharp turns. For other garden related products other environmental obstacles may occur. One example that came up in the focus group sessions is the depth of flower beds, meaning space to manoeuver is limited when trying to avoid damaging plants and flowers.
Identify bottlenecks in activities	Moving heavy objects in the garden is not an activity that immediately springs to mind when considering gardening tasks. However, supporting tasks like this can become bottlenecks in the successful completion of gardening tasks. Identification of bottlenecks can be done through the systematic evaluation of existing tasks in observation sessions, using methods like hierarchical task analysis (Stanton and Walker 2013) to identify problematic subtasks.
Older women value the exercise and leisure pastime components of gardening	Gardening activities are not just done for their results and as such the experience should be made as enjoyable as possible, whilst providing the older woman with a suitable form of exercise. It requires a paradigm shift from seeing gardening as a chore to an enjoyable experience in itself. One clear example of this is through the

	development of quieter tools.
General gardening tool design recommendations	
Weight of tools	For the following tools weight was mentioned as an issue and thus should be addressed: hedge trimmers, lawn mowers, spades, shears, wheelbarrows, leaf blowers, watering cans and loppers. Whilst perhaps some headway can be made through application of lighter weight materials and technological advances of motors, it is recommended tool designers also look towards other industries such as home maintenance for improvements as this is a product category where (older) women have been considered main users for longer.
Smaller size	Though less frequent than weight issues, some women indicated wanting smaller sized tools, suited to their hands and statures. Ergonomic tables of average human sizes should be used when designing gardening tools, and perhaps variants of tools will need to be made to ensure usability for all users.
Avoid bending	Solutions could be in the direction of long handled tools, assistive devices to get down and back up and improvement of existing tools such as kneelers to increase comfort.
Hand tools	As many older women suffer from arthritis of the hands or age-related strength decline, hand force required for hand tools should be minimised. Furthermore, though it is partly up to end users to avoid continuing repetitive movements for extended periods of time, design can play a part in this through e.g. powered secateurs that snip automatically when needed.
Mechanical helpers for moving heavy objects	
Loading / unloading	Improved solutions regarding loading and unloading phases of moving heavy objects should be developed to negate bending during loading and unloading.
Larger wheels	Gardening tools should have larger wheels; increased wheel diameter will make overcoming height difference easier as well as crossing varying terrains. Preferably these wheels should not have spokes to avoid getting snagged.
Handle angle alignment	Handles should be positioned to allow optimal grips. This includes aligning them to the direction of pushing/pulling when moving heavy objects.
Grips at different heights	To accommodate the individual user (e.g. taking into account arthritis of the hands) it is recommended to include grips at different (or adjustable) heights and even allow different types of grips to accommodate users with varying abilities.

8.2 Future work

The research has answered many questions in regards to the barriers experienced by the older person wishing to engage in gardening activities and some techniques and tool design modifications to overcome the obstacle. However the thesis also has some limitations and inevitably more research should be undertaken to derive the maximum health benefit for the older woman from gardening. Some of the limitations of the research are discussed and recommendations for further research are made.

The target group within the thesis has been older women, however older women are a diverse group. By incorporating the broad definition of women over 50, relatively young and employed women were grouped together with those in the final phases of their lives. Generational differences, individual

differences and situational differences coupled with the geographical and socio-economic backgrounds of individuals mean that what has been considered a single group within the research, is in fact a heterogeneous mix of women. A varied group of older women were included in the focus group sessions and observations, from different backgrounds e.g. former canine beautician, long distance driver and accountant and participating in gardening to varying degrees. This research focused on the commonalities between these different women, however if separate groups were investigated more closely, differences between those of varying socio-economic backgrounds may be found. Future work should consider the impact of these differences, as e.g. generational differences are likely to underpin traditional role patterns in the garden and socio-economic background affect simple factors like garden sizes and tools available.

This research has been the first to consider the gardening experience from the perspective of older women on a task level. The online survey data could be contrasted against younger women and older men, but these groups were for practical feasibility not included in the subsequent studies. More knowledge on these other groups could aid in identifying both unique and shared characteristics of older women in their gardening experience.

Within the research, the methodology of honing in on more and more specific problems provided both overview and in-depth analysis, but also had the consequence that not all findings could be explored further. For example, though moving heavy objects was the task most in need of change, lawn mowing and hedge trimming were also found to have some issues. Investigation of these tasks and subsequent implementation of change could further improve the gardening experience of older women.

A relation between enjoyment and perceived difficulty of gardening tasks was found, however causality was not established and the strength of the relation was also not tested. It is recommended further work explores this relation. In addition, the relation between participation, enjoyment and perceived difficulty requires further exploration. This is relevant, as it concerns the motivational-action gap.

The perceived difficulty of gardening tasks may differ depending on when asked; if participants were asked during or straight after an activity they may have scored it differently. Inherent to the seasonal nature of gardening, by running the survey over the summer period, this may have influenced scores for

certain tasks as they were fresh in participants' minds. Replication in different times of the year would reduce the influence of this parameter and thus increase certainty of reliable results.

Though incidental, some participants in the focus groups indicated difficulty could be seen as not just physical difficulty, but also lack of knowledge. The example given by a participant related to pruning, where one may be able to wield a pair of secateurs, but if one does not know where to make the cut, this can make pruning difficult. Lack of knowledge did not seem a concern for many of the participants in the focus groups, but it may be a barrier to those with little experience. More research amongst those less experienced gardeners into the influence of knowledge on their motivation may help get women started and continuing to garden.

The most salient problem scenario for moving heavy objects in the garden actually related to retrieving purchased goods from shops and moving them to their desired location. It is expected that this scenario is an issue for non-gardening related products too, e.g. the weekly shop or purchase of home goods. As such, the influence of moving heavy objects by older women on general daily life requires further investigation.

The biomechanics study incorporated limited participants, and though the trends were useful to identify direction for improvement, larger participant groups are required to establish the impact on the older woman's body with greater accuracy. The set-up of the study is replicable as standard components were used and it is thus recommended to increase participant numbers and compare results to other tasks of moving using manual movers.

The biomechanics study showed the influence of different tools on varying obstacles and the results of this study are transferrable to obstacles in the home. As such, a tool that would aid older women with moving objects in their gardens may have further use in comparable tasks of daily living. This tool would require testing in real life conditions as well as lab settings with more subjects.

For policymakers and local organisations: evidence from this thesis shows the potential for gardening as a form of exercise that does not suffer from the problems of adherence many exercise programs suffer from. As such, it is recommended that opportunity for or assistance with gardening is provided.

As part of the gardening experience was found to be the connection with nature, loud tools were explicitly disliked for disrupting the quiet around them. As such, quieter power tools seem to have significant potential for this target group and it is up to manufacturers to innovate.

8.1 Overall conclusions

This research has involved the examination of the gardening experience and problems with this experience for older women. Gardening in most research had been considered a single activity and through this research it has become clearer which activities that are part of gardening are problematic for older women and how best they can be encouraged to increase participation. The research has investigated moving heavy objects as one such problematic activity and the results highlight areas for mainly tool improvement. The key contributions, applicable to women over 50 in the UK are:

- An overview of the motivators to gardening.
- A mapping of the factors affecting motivation to garden.
- A task based study of gardening.
- An overview of the particular challenges experienced during moving heavy objects in the garden which were a function of the garden environment, characteristics of the task, the tools used and personal factors.
- A quantified biomechanical analysis of the physical impact of the task of moving heavy objects across obstacles.

Many unexplored areas of research still exist within the broad topic of gardening by older women. It is hoped that through this thesis, more attention is drawn to the potential of gardening for the health and wellbeing of the older woman and that their gardening experience is considered further by researchers, policymakers, local initiatives and tool manufacturers.

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Appendices

Appendix A. Ethical approval and associated documentation for online survey

Appendix B. Ethical approval and associated documentation for focus groups

Appendix C. Ethical approval and associated documentation for observations

Appendix D. Ethical approval and associated documentation for motion capture sessions

Appendix E. Medians, range and quartiles for motivations to garden

	Women >50			
	Median	Range	25th percentile	75th percentile
It makes me happy	100.0	27-100	91.00	100.00
I feel in touch with nature	94.0	0-100	69.00	100.00
Influence how the garden looks	89.0	0-100	62.00	100.00
Relaxing	88.0	0-100	73.00	100.00
Feeling of accomplishment	85.0	0-100	71.00	100.00
Getting some fresh air	84.0	0-100	57.00	100.00
The quiet and solitude	84.0	0-100	69.00	100.00
Growing something out of nothing	72.0	0-100	41.00	100.00
Healthy exercise	72.0	0-100	43.00	98.00
Sense of ownership	52.0	0-100	2.00	82.00
Create nice environment to have friends round	43.0	0-100	7.00	67.00
It needs to be done	35.0	0-100	0.00	64.00
Allows me to develop skills	32.0	0-100	4.00	75.00
I like that I can control it	22.0	0-100	0.00	60.00
It gives me something to do	14.0	0-100	0.00	54.00
Sense of being in a garden community	2.0	0-100	0.00	41.00
Other reason	0.0	0-100	0.00	9.00
Partner/spouse wants me to do it	0.0	0-100	0.00	8.00
I do it to help someone else out	0.0	0-100	0.00	3.00
I am paid to do it	0.0	0-58	0.00	2.00

Appendix F. Medians, range and quartiles for influences on motivation

	Women >50			
	Median	Range	25th percentile	75th percentile
Effect on garden	89.0	7-100	71.00	100.00
Suitability of the tool	82.0	0-100	38.00	93.00
Ease of use of the tool	74.0	0-100	53.00	92.00
Hardness of the soil	71.0	0-100	40.00	98.00
Amount of precipitation	70.0	0-100	40.00	88.00
Weight of the tool	64.0	0-100	34.00	89.00
Working at heights	64.0	0-100	11.00	94.00
Tool handle comfort	63.0	0-100	37.00	89.00
Wetness of garden	62.0	0-100	31.00	86.00
Wetness of soil	59.0	0-100	40.00	88.00
Quality of the tool	56.0	0-100	29.00	88.00
Amount of sun	54.0	0-100	26.00	81.00
Temperature	54.0	0-100	24.00	78.00
Busyness of day	49.0	0-100	32.00	84.00
How much fun it is	49.0	0-100	18.00	77.00
The tool's condition	48.0	0-100	12.00	77.00
Gardening advice from magazines/online resources	47.0	0-100	25.00	65.00
Amount of wind	46.0	0-100	13.00	74.00
The physical effort required	39.0	0-100	11.00	70.00
Time required to do it	39.0	0-100	6.00	58.00
Your physical fitness	38.0	0-100	14.00	80.00
Energy required to do it	32.0	0-100	13.00	66.00
How tiring it is	30.0	0-100	7.00	64.00
People will see the garden	30.0	0-100	5.00	54.00
Ease of tool maintenance	26.0	0-100	0.00	66.00
Time of day	25.0	0-100	0.00	60.00
Hurts at the time	21.0	0-100	0.00	70.00
Gardening advice from friends	20.0	0-100	1.00	47.00
The clear-up time	20.0	0-100	0.00	48.00
Getting up and down	18.0	0-100	0.00	74.00
Bending down	16.0	0-100	0.00	55.00

Risk of physical discomfort	15.0	0-100	0.00	50.00
Risk of injury	14.0	0-100	0.00	53.00
Working down low	13.0	0-100	0.00	52.00
Repetitiveness of task	12.0	0-91	0.00	35.00
How boring it is	11.0	0-94	0.00	43.00
Hurts the next day	10.0	0-100	0.00	31.00
Stretching	8.0	0-100	0.00	37.00
Cost of the tool	7.0	0-100	0.00	42.00
The set-up time	6.0	0-100	0.00	21.00
Need to change clothes	4.0	0-100	0.00	15.00
What people will think	3.0	0-100	0.00	16.00
People will see you work	0.0	0-100	0.00	6.00

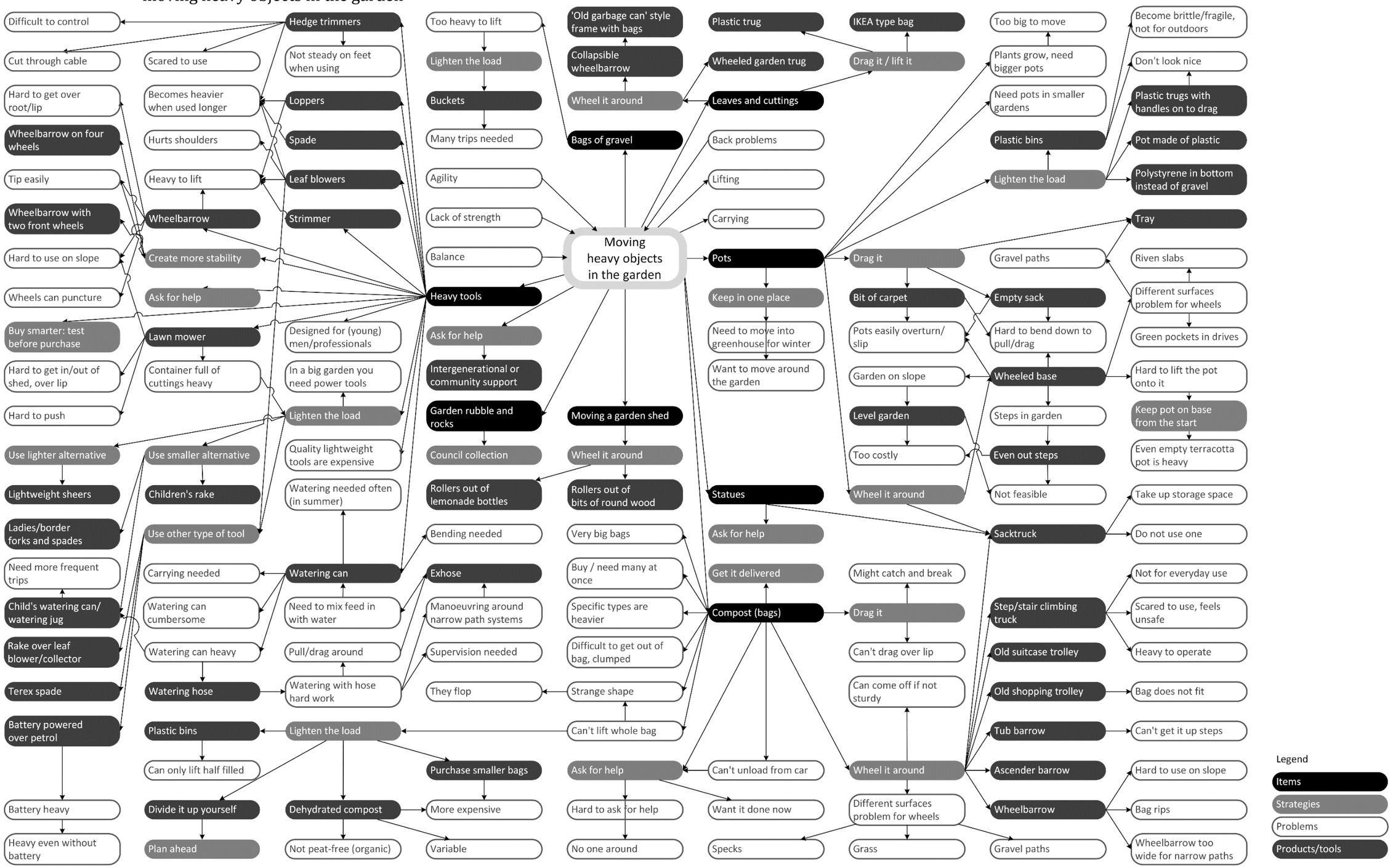
Appendix G. Questioning guide for focus group sessions

	Timing
Welcome, introduction to the session and researchers, practical announcements.	
Opening	
To help you get to know each other, let's do a round table and introduce yourselves and *name your favourite plant or flower / briefly describe your garden*?*	5 min
Main session part 1	
Last year I conducted a survey amongst people that like to do gardening in the UK and in this we asked everyone to evaluate several gardening tasks. I'd like to show you some of these results and hear your thoughts on them. *[Show A3, walk through list of tasks in order of how enjoyable they were thought to be]* I'd like you all to take a minute to look through the list and then tell me whether you feel that for you there are any in the wrong place. *[Give a minute]* Would you create the same order? Are there any that for you are in the wrong place?	6 min
If you consider your own gardening experience, could you try to explain what makes certain gardening tasks more enjoyable than others?	5 min
Laddering from their answers, encourage discussion	5 min
So if we try to explain why moving heavy objects was found to be the least enjoyable task, is there anything else that might explain it?	5 min
In the same survey we also looked at how hard people think the same tasks are, so here I'd like to show you the list that was created that way. You'll see that this is not the same order. I'd like you all to take a minute to look through the list and then tell me whether you feel that for you there are any in the wrong place. *[Give a minute]* Would you create the same order? Are there any that for you are in the wrong place?	6 min
If you consider your own gardening experience, could you try to explain what makes certain gardening tasks harder to do than others?	5 min
Laddering from their answers, encourage discussion	5 min
So if we try to explain why moving heavy objects was found to be the hardest task by some distance, is there anything else that might explain it?	5 min
Break	
Now we will have a short break, and then after the break we will go into the task that was considered the hardest and least enjoyable: moving heavy objects around in the garden. But as I said, first a short break so I will get some tea refills for those that want, have some cake and use the toilet if you need to.	5 min
Main session part 2	
As I said before the break we will now go into the task of moving heavy objects in the garden. What I'd like to do is go around the table again. Could you think back to an instance where you needed to move something heavy in your garden? What was this and if you managed to, how did you do it? It can be things that you did yourself, tried yourself and couldn't or that you got someone else to move for you.	10 min
When thinking about moving heavy objects in the garden, are there any other situations that come to mind in which you move something heavy? *[Once group has finished suggesting, add suggestions made by previous groups that were not yet included and get feedback on whether these should be included]*	5 min
If we are going to improve or develop new tools to help you move heavy objects around yourself more easily, without needing others to help you, I'd like to know what is the most in need of improvement according to you. So what situation or situations would you like to see improved? *[Prompt with examples they previously mentioned and challenge them with those they didn't mention. Settle on top 1-3 things they mentioned, summarise to ensure everyone is on board.]*	10 min

If you could give any advice to the people that will develop the new products to make these situations better, what would it be?	5 min
Session closure	
Having one last look at it, do you have any final remarks to add?	5 min
Thanking for participation, opportunity to sign up for future studies	

Appendix H. Problem scenarios diagram of

moving heavy objects in the garden



Appendix I. Identified underlying issues when moving heavy objects in the garden per group

Focus group 1	
Category	Related issues
Environment	Steps or stairs: challenge of moving items on steps, even with step climber.
	Slopes or ramps: challenge of moving items on slope.
	Space available: limited space for storing tools.
	Obstacles: having to go through the house to get things to the back garden.
	Space available: limited space to manoeuvre.
	Compatibility: plants in pots keep growing until they are too big to move.
Personal	Strength: heavy compost bags too heavy for any age
	Age: the ageing body has reduced strength and height.
	Anthropometry: impact of limited stature making moving big, heavy bags more difficult.
	Training and task knowledge: several have no experience with sack trucks
Task	Load: shape, size and weight of compost bags: 'odd' and 'they flop'.
	Distance: participants want to move pots around.
	Load: different types of compost have different weights, dehydrated compost weighs less.
	Availability of assistance: availability of (someone with) a car.
	Availability of assistance: option of delivery of compost bags.
	Direction of motion: having to drag and bend at the same time when moving pots with or without wheeled bases.
	Frequency and duration: when splitting up loads, having to walk back and forth often.
	Motion phases: difficult to get pot on carpet moving.
Tool	Load securing system: wheeled bases with pots are easily overturned.
	Other: though not used often, sack trucks may be used for other things than moving objects in the garden and are nice to have when you need them.
	Other: participants would spend £25-30 on a tool to move objects in the garden.
	Load securing system: hard to get pot onto wheeled base.
	Weight: limited weight of a foldable sack truck:
	"[…] our little black treasure, […] it's light, it's brilliant." (P1.5)
	Size and weight: children's sized watering can reduces weight.
	Weight: tri-star configurated step climber considered too heavy to safely use.

Focus group 2	
Category	Related issues
Environment	Slopes and steps: difficulty of steps and slopes to move items for those that have them, ease for those that don't have this:
	"I'm lucky mine's all flat." (P2.4)
	Terrain – floor surface: gravel and wheels of wheeled bases do not work well together, pockets of alpines are a tripping hazard.
	Space available: storage space for tools, shopping trolleys can fold away, as can foldable sack trucks.
	Obstacles: pulling lawn mower across lip of shed.
Personal	Age and strength: reduced strength to lift heavy items (2 participants)
Task	Load: some compost types heavier than others.
	Availability of assistance: help available at garden centres, but not when unloading at home.
	Load per trip: reduced quantities by dividing up makes it easier to carry compost.
	Load: terracotta pot heavy to lift onto wheeled base, even empty.
	Direction of motion: sack truck 'great' to pull loads up steps according to one participant, whilst other doubt.
	Direction of motion: pulling and pushing hurts vulnerable back (one participant).Distance: participants want to move pots around.
	Load: smaller bags are cheaper.
	Availability of assistance: one participant wishes they could do heavy lifting together as a team.
	Frequency and duration: frequency of watering in (late) summer (one participant).
Tool	Weight: builder's wheelbarrow is heavy.
	Load securing system: builder's wheelbarrow tips easily, two-wheeled could be better, though participants have no experience with it.
	Wheel type and size: two-wheeled or four-wheeled better than single-wheeled wheelbarrow, ball barrow great for corners but unstable.
	Wheel type and size: cheap wheeled bases wheels will buckle.
	Interface: compost bags are hard to hold on to according to one participant.

Focus group 3	
Category	Related issues
Environment	Terrain – floor surface: wheels do not work well on gravel, grass, specks, shady areas that are not entirely dry.
	Steps or stairs: use sack truck to move compost down steps. One participant:
	"Well I just bump it down and then truckle it along" (P3.4)
	Compatibility: one participant modified the garden to make it easier: wider paths, harder surfaces, and straight lines.
Personal	Age, strength and physical health: participant (3.4) identified herself as getting 'frailer and frailer' and having reduced strength to lift and move items.
Task	Load: flexible plastic trug with handles drags easily, regardless of weight of load.
	Frequency and duration: moving heavy objects not done often, though some disagree. Watering done very frequently and also heavy lifting.
	Availability of assistance: several (four) participants ask neighbours for help, whilst one would not want to ask and thus would not purchase items she could not carry herself.
	Load per trip: reducing load increases frequency for watering:
	"My watering can is plastic but you need to put in 10 litres otherwise it's not worth me walking down on the way to there." (P3.5)
Tool	Interface: participants would like to see a handle on the wheeled bases to enable moving them.
	Load securing system: potential was seen for a system with removable bags on a wheeled frame.
	Load securing system: pots easily slide off wheeled bases.
	Wheel type and size: tri-star configurated shopping trolleys were mentioned as being good.

Focus group 4	
Category	Related issues
Environment	Not mentioned in relation to moving heavy objects.
Personal	Age: reduced balance, strength, agility and increased back pain, knee pain and stiffness.
	Strength: lack of strength when lifting and holding heavy items.
	Motivation: frustration accompanies reduced capabilities with ageing:
	"The trouble is you th, you-you can do easy things and you think ooh this is fine, and then you come to something and you think I can't do that." […] "It hurts inside." (P4.5)
Task	Load: smaller compost bags reduce weight, but are:
	'an extravagant way of buying' (P4.3).
	Frequency and duration: pots are very labour-intensive and require frequent watering.
	Availability of assistance: help available at garden centre to load items in car, but not when unloading at home.
	Availability of assistance: both hard to ask for help and hard to find available in time of need for one participant.
	Direction of motion: combination of bending and lifting to move pots difficult.
	Direction of motion: carrying is also an issue, but lifting more crucially.
Tool	Platform: ascender barrow has a tub that can be lowered down, considered very good by one participant.
	Platform: wheelbarrows can be placed next to car, to roll compost bags straight in.
	Platform: sack trucks can be placed on car boot, and their backside can be used to slide compost bags down.

Appendix J. Summary of observations relating to moving heavy objects

Item	Task	Tool used	Obstacles encountered	Type of data*	Participant
Compost	Carrying compost bags from front of house to shed in back garden.	-	Steps, slope, grass, door thresholds	O	1
	Moving compost bags down steps and to the green house in back garden.	Sack truck	Steps	O	2
	Moving compost bags from car boot to garage.	Sack truck	Car boot edge, thresholds	O	3
	Lifting compost bag from car boot to sack truck.	Sack truck	Car boot edge	O	4
	Moving compost	Sack truck	Step, gravel	D	5
	Moving compost bags from car to back garden.	-	Slopes	PO	7
	Moving compost bags from car boot to garage.	Sack truck	-	D	8
Potted plants	Moving pots on terrace.	Sack truck	-	O	3
	Moving pots in and out of greenhouse.	-	Threshold	O	3
	Moving small pots.	Old wash rack	Uneven surfaces	O	5
	Moving pots and compost, carrying around tools, collecting cuttings.	Sack truck, shopping trolley	Step, gravel	PO	5
	Lifting and moving pots, compost, stones.	Wheelbarrow	Step, gravel	D	6
	Moving pots.	-	-	PO	7
Leaves and cuttings	Carrying cuttings to bin from back garden to front of house.	Plastic trug	Narrow paths, door, steps	O	2
	Carrying around tools, collecting cuttings.	Sack truck, shopping trolley	Gravel, uneven surfaces, steps	PO	5
Water	Lifting and using watering cans.	Watering can	Narrow paths	PO	2
	Watering plants in greenhouse.	Watering cans	Narrow space	D	3
	Watering pots.	PVC pipe, hose	-	PO	5
Other	Moving concrete slabs.	-	-	D	6

* O = observation, PO = partial observation, D = description only.

Compost moving

Participant 1

Participant used a half-filled bag of compost that she had brought to the front from her back garden. She therefore did not take the bag out of the car but picked it up from the ground.

Participant used two hands to pick up the bag, keeping her knees straight with left leg in front of the other.

To open the sliding door, participant held on to the bag with one hand. She did not seem to have a strong preference for using one hand over the other here as on the way back she held on to the bag with her left hand.

Once through the door, participant grabbed the bag with both hands again. She did not take any brakes or set the bag down at any point.

As she moved up, her left knee hit the bag every time she stepped up and she used her left hand to keep the bag in place at her side. It took her 4 seconds to climb the six steps.

The participant stepped up the final step and used both hands again to move the bag into place in the shed. The entire route took 45 seconds to complete.

The participant demonstrated her route to move compost from her car to her greenhouse, using a sack truck. At the time she did not have compost bags to demonstrate with. The participant held on to the railing for most of the way down. She bumped down the sack truck simultaneous to walking down a step and would then set the other foot down on the same step. She initially alternated which foot stepped down first, but for the other steps stepped down with the right foot first.

Once the sack truck was down, the participant had to manoeuvre the sack truck to get it around the corner. She started doing this whilst still on the lowest two steps. Once down, she pulled back the sack truck and then stepped sideways, pulling the sack truck handle sideways to obtain the right angle. She then pushed it to move it along the path. This took about 13 seconds and overlapped somewhat with going down the steps.

She pushed the sack truck across the slabs for about 9 metres until just before the gate. This took her 23 seconds. The entire task took 93 seconds to complete.

Participant 3	
Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	Participants worked together to slide and then lift the compost bag from the car boot. There was no discussion of who does what.
	The participant at the lower end seemed unable to hold the bag for the last 20 cm down and let the bag fall down for the last bit whilst the other participant held on to the top of the bag.
	The other participant rotated the sack truck and used one foot as a stop to get the sack truck to lean back in the position for rolling.
	The participant then walked the sack truck over to the garage, pushing with her right hand only and navigating the sack truck around the plant.
	The participant bent down to show how to fold the sack truck back up, using her left hand to pull the bottom up and keeping the rest of the sack truck down by keeping her right hand on the handle. She flexed her knees somewhat during the bend.

Participant 4	
Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	Participants worked together to slide and then lift the compost bag from the car boot. There was no discussion of who does what.
	The participant at the lower end seemed unable to hold the bag for the last 20 cm down and let the bag fall down for the last bit whilst the other participant held on to the top of the bag.
	Participant 7 had moved the compost bags she had together with her daughter and as such was unable to show how she moved them without her daughter present.
	Once the bags were sufficiently empty, she would be able to lift it. The bag was one third full and she lifted this with ease, grabbing it single-handed by the top corner. Because the bag was sitting upright, she did not have to bend down much to grab hold of it.

Moving potted plants	
Participant 3	
Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	Participant bent over to open the foldable sack truck.
	Participant picked up plant to move it closer to sack truck. She remarked she did this because this was a lightweight pot-plant combination, for heavy ones she would put the sack truck directly next to the pot.
	Participant lifted the side of pot slightly by the edge and pulls it onto the sack truck platform, whilst keeping the sack truck in place with the other hand.
	Participant used her right foot to push the sack truck off, pushing the handle down.

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	Participant pushed the sack truck forward and started walking forward. She used both hands throughout.
	Participant slid the pot back off the sack truck platform by pulling the pot sideways using the edge of the pot.

Participant 3

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	Participant moved a couple of potted plants out of the greenhouse. The strategy for lifting a bigger plant was different to the smaller; the bigger plant was used as a lever to create a slight lift of the pot edge on the opposing side. This was where the participant then grabbed hold of the pot edge. The smaller plant was picked up by the pot edge with both hands.
	The strategy for moving a bigger plant was different to the smaller one; the big plant was held by the pot edge with one hand whilst holding the plant itself with the other arm. For the smaller plant the participant used both hands on the pot edge.
	Whilst lowering, the participant let pots go just above the ground rather than lowering them completely.

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	To move the pot further slightly, the participant used one hand on the greenhouse, keeping the plant upright with the other hand. Simultaneously, she pushed the pot with her right foot, nudging it along about 10 additional cm and rotating it so that the plant would no longer fall over. This entire task took 15 seconds to complete for the big plant and 8 seconds for the smaller plant.

Participant 5

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	The participant used an old washing rack to put pots on. Although largely empty at this time of year, normally she would attach pots all around the top and had hung hanging baskets from the sides as well. She had taken this into use specifically to be able to easily move herbs and spices to sun or shade as required. The participant would lift the washing rack using one hand.
	The participant lifted the washing rack off the ground, requiring her to bend the arm and lift her shoulder. She then walked with the washing rack at her side for a few metres to demonstrate.
	The participant set the rack back down without bending. The entire task took the participant 12 seconds to complete.

Participant 5	
Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	The participant kept the foldable sack truck in unfolded state in her shed, however she demonstrated the folding function of the handle by squeezing the red handle and black top handle together and pushing down.
	To move the empty sack truck, she lifted it with both hands on the top black handle and swinging it down the step from the wooden deck, landing it on the paved path.
	She pushed the sack truck forward using both hands and walking after it.
	She lifted the sack truck with both hands at either side of the sack truck on the vertical ribs to set it down at the correct position to lift the pot onto the sack truck.
	The participant reached down with her body rotated sideways to go around the handle of the sack truck. She pulled up the pot by one side and attempted to lift it onto the sack truck. She lifted it slightly, but then left it in its place. She explained that 'some people [..] just pull [the pot] on, but I tend to wiggle [the sack truck] underneath'.

Participant 7	
Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester	The participant bent down to grab the pot, holding it with both hands and with her head slightly to the side to keep away from the plant itself.

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

The participant lifted the pot, turning around briefly mid-conversation and turned back around.

The participant bent down to set the pot back down in its original place, again keeping her head to the side, away from the plant. It took the participant 15 seconds to complete this task.

Moving leaves and cuttings

Participant 2

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

After filling a tub with cuttings in her back garden, the participant wanted to take these cuttings to her bin for green waste, at the front of her house. The lifted the tub by its two handles. She was also still holding a pair of secateurs in her right hand.

The participant lifted the tub to her left side, which allowed her to see where she could step on the narrow and somewhat overgrown paths.

The participant set down the tub in between to pick up more cuttings and to put the pair of secateurs away, as well as to open the garden door. She dropped the tub the last few centimetres, not setting it down all the way on the ground.

On wider paths, the participant carried the cuttings in front, lifting the tub high enough to avoid hitting her legs.

When reaching a stairs, the participant set the tub down as far and high as she could, which was the third step.

The participant then stepped up the first two steps.

After which she picked the tub up from her side and set it down a further two steps ahead. She repeated this again to overcome all eight steps.

After opening the bin, the participant lifted the tub to the edge of the bin, and used one of the handles to tip it on this edge, whilst holding on to the edge of the bin. This task took the participant 3:08 minutes to complete.

The participant demonstrated using hand gestures how she used a shopping trolley to collect cuttings and tools.

The participant showed how she moved the shopping trolley by pulling it along behind her.

Moving water(ing cans)

Participant 2

The participant indicated watering with watering cans was an issue for her. She placed a watering can underneath a rainwater collection tank and opened and closed the tap by twisting the lever. To reach, the participant had to bend sideways to keep her head from hitting the tank.

In a similar posture, the participant lifted the partially filled watering can from the ground.

The participant carried the watering can with one hand, holding it with a somewhat bent arm as she walked to avoid hitting her legs and allow her to keep her balance.

The participant set the watering can back down.

Participant 5	
Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.	The participant demonstrated technique for watering, for which she used an end of PVC piping.
	Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of
	The participant stuck the PVC pipe into the pot next to the base of the plant. Once in place, she gestured being able to water the plant through the pipe with her hose, allowing her to water straight to the roots whilst avoiding bending.
	The PVC pipe was pulled out with a single hand after the demonstration.

Appendix K. Total manual force vector magnitude in N for all participants

	Obstacle height	Participant 1	Participant 2	Participant 3
Puncture proof wheelbarrow	30 mm	96.5	45.8	80.2
	60 mm	106	42.5	179
	90 mm	193	146	164
Inflatable tyre wheelbarrow	30 mm	107	51.2	111
	60 mm	127	72.0	95.4
	90 mm	160	170	118
Garden trolley	30 mm	84.8	105 [r]	127 [l]
	60 mm	136	143 [r]	
	90 mm	134	55.7 [r]	172 [l]
Foldable sack truck	30 mm	95.5	110 [r]	120
	60 mm	146	177 [r]	226
	90 mm	160		368
Step climber	30 mm	162		248
		137*		-**
	60 mm		216	265
		161*	222*	-**
	90 mm	185	216	325
		186*	222*	-**

Empty cells indicate missing data points.

[a] Tool was pushed. Without this indication, tools were pulled.

*Secondary peak observed where participant pulled the step climber up in two phases.

**No secondary peak observed; participant pulled the step climber up in a single motion.

[r] Single-handed operation, right hand only

[l] Single-handed operation, left hand only

Appendix L. BoB estimated joint contact forces for all participants

Participant 1								
Tool	Obstacle height (mm)	Joint contact forces (kN)						
		L-Shoulder	R-Shoulder	L-Hip	R-Hip	L-Knee	R-Knee	Lumbar
Puncture proof wheelbarrow	30	0.64	1.13	1.55	1.85	0.88	1.03	0.65
	60	1.13	1.07	1.62	2.15	1.41	1.66	0.85
	90	1.01	1.13	1.30	1.31	1.31	0.90	0.93
Inflatable tyre wheelbarrow	30	0.67	0.73	1.11	1.31	0.90	1.09	0.66
	60	1.06	1.08	2.08	1.63	1.48	1.09	1.47
	90	1.64	1.50	2.32	1.61	1.92	1.45	1.10
Garden trolley	30	0.59	0.82	1.02	0.90	0.73	0.63	0.83
	60	1.39	1.52	1.20	1.23	1.09	0.86	0.85
	90	1.07	2.25	1.74	1.32	0.98	1.18	0.68
Foldable sack truck	30	0.88	0.86	1.36	1.25	1.02	1.12	0.60
	60	1.64	0.94	1.44	1.93	1.18	1.02	0.83
	90	0.67	1.60	2.19	1.25	2.17	1.03	0.87
Step climber	30	0.69	0.68	1.21	0.99	0.89	0.96	0.95
		0.90*	0.95*	1.46*	1.63*	1.13*	1.40*	1.77*
	60							
				1.57*	1.64*	1.21*	1.26*	
	90	1.06	1.06	4.66	1.72	3.36	1.56	1.40
		0.85*	0.82*	1.70*	1.18*	1.22*	0.95*	1.23*

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JCF graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 2

Tool	Obstacle height (mm)	Joint contact forces (kN)						
		L-Shoulder	R-Shoulder	L-Hip	R-Hip	L-Knee	R-Knee	Lumbar
Puncture proof wheelbarrow	30	1.45	1.46	1.32	1.36	1.38	0.94	1.20
	60	1.11	0.66	1.47	1.00	1.45	1.84	1.68
	90	1.00	1.31	1.81	1.50	2.11	1.46	1.50
Inflatable tyre wheelbarrow	30	1.33	0.81	1.76	2.55	1.63	1.85	1.00
	60	1.47	0.82	1.60	2.43	1.43	2.12	1.19
	90	1.89	1.00	3.10	2.27	1.81	1.21	1.86
Garden trolley	30	1.43	1.70	1.64	2.00	1.48	1.64	1.61
	60	0.84	1.78	1.85	3.28	1.60	1.92	1.98
	90	0.49	0.72	1.23	1.40	1.41	2.01	1.06
Foldable sack truck	30	0.71	3.91	2.89	2.35	1.16	2.38	1.67
	60			2.44	1.27	3.41	1.13	
	90							
Step climber	30							
	60	2.55		4.92	2.76	3.42	2.36	3.83
		1.25*	2.98*	3.23*	1.75*	2.38*	1.49*	1.42*
	90	1.48	1.85	3.31	3.60	2.21	2.28	1.68
				6.61*	2.95*	2.79*	1.71*	

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JCF graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 3

Tool	Obstacle height (mm)	Joint contact forces (kN)						
		L-Shoulder	R-Shoulder	L-Hip	R-Hip	L-Knee	R-Knee	Lumbar
Puncture proof wheelbarrow	30	2.38	2.31	2.97	1.47	3.13	1.54	2.50
	60	2.87	2.21	2.09	2.63	2.16	2.15	3.61
	90	2.85	2.58	2.19	2.38	1.78	2.44	2.91
Inflatable tyre wheelbarrow	30	1.86	2.95	1.55	1.44	1.46	1.29	1.28
	60	2.00	1.13	1.63	1.84	1.36	2.77	1.63
	90	1.90	1.19	1.94	1.88	1.95	2.11	1.81
Garden trolley	30	3.11	0.54	1.69	2.36	1.42	3.61	1.36
	60							
	90	2.32	1.00	1.45	2.26	1.46	2.39	1.80
Foldable sack truck	30	3.88	1.52	1.19	1.53	1.04	2.13	1.22
	60	3.29	3.44	2.04	2.98	1.69	2.64	3.01
	90	4.84	5.87	2.26	4.00	2.24	4.63	2.20
Step climber	30	1.98	2.30	1.65	2.28	1.45	2.03	2.75
	60	2.61	2.41	1.46	3.59	1.92	2.42	2.71
	90	2.53	3.63	1.59	2.97	1.57	2.36	2.62

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JCF graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Appendix M. BoB estimated joint torques for all participants

Participant 1								
Tool	Obstacle height (mm)	Joint torques (N·m)						
		L-Shoulder	R-Shoulder	L-Hip	R-Hip	L-Knee	R-Knee	Lumbar
Puncture proof wheelbarrow	30	8.57	18.2	44.8	45.4	25.2	25.5	52.3
	60	13.0	16.2	55.7	70.2	19.0	25.1	71.1
	90	24.6	21.8	77.1	28.8	11.7	18.5	76.5
Inflatable tyre wheelbarrow	30	12.2	8.30	36.5	28.4	14.6	22.6	48.6
	60	16.9	11.7	72.2	52.3	27.2	17.9	95.3
	90	36.6	24.5	88.6	26.5	35.3	13.0	97.1
Garden trolley	30	3.59	4.78	29.0	30.0	9.16	9.12	63.0
	60	12.6	13.3	50.8	34.2	16.6	30.3	60.1
	90	15.0	16.7	79.8	21.6	23.5	17.6	60.8
Foldable sack truck	30	7.10	6.20	36.8	37.0	16.1	25.0	43.0
	60	13.2	11.9	45.3	55.9	15.1	38.7	64.2
	90	12.6	12.2	53.2	20.0	98.6	4.35	64.9
Step climber	30	11.6	10.6	38.8	20.7	14.8	35.9	76.0
		12.6*	12.1*	34.4*	55.5*	19.8*	39.4*	111*
	60							
		8.00*		42.9*	35.2*	17.7*	33.5*	
	90	13.5	20.1	116	24.7	58.9	5.35	103
		12.1*	9.45*	67.9*	34.6*	26.9*	34.1*	89.5*

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JT graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 2								
Tool	Obstacle height (mm)	Joint torques (N·m)						
		L-Shoulder	R-Shoulder	L-Hip	R-Hip	L-Knee	R-Knee	Lumbar
Puncture proof wheelbarrow	30	15.6	19.4	25.0	62.0	11.9	25.4	47.2
	60	17.4	10.0	23.8	36.1	3.75	66.6	83.5
	90	16.4	11.2	59.8	38.2	85.2	9.43	121
Inflatable tyre wheelbarrow	30	25.6	9.31	33.9	87.0	10.5	45.8	43.2
	60	28.5	11.4	29.6	95.2	10.6	64.1	91.6
	90	20.6	18.4	67.8	55.2	56.7	40.5	107
Garden trolley	30	14.5	39.3	26.1	105	7.61	68.6	77.4
	60	8.64	46.1	33.8	96.2	10.5	81.3	99.9
	90	6.41	8.31	40.3	49.5	7.12	76.8	47.9
Foldable sack truck	30	9.39	38.4	60.5	89.9	29.9	84.0	85.2
	60			105	25.8	133	14.2	
	90							
Step climber	30							
	60	21.4		127	88.9	18.2	27.9	
		9.86*	24.6*	97.1*	78.2*	29.5*	53.7*	99.4*
	90	13.8	16.1	84.0	86.7	15.7	25.9	99.2
				159*	53.5*	6.63*	44.6*	

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JT graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 3

Tool	Obstacle height (mm)	Joint torques (N·m)						
		L-Shoulder	R-Shoulder	L-Hip	R-Hip	L-Knee	R-Knee	Lumbar
Puncture proof wheelbarrow	30	29.3	17.2	126	55.2	103	16.8	159
	60	38.1	25.3	126	89.6	65.0	85.1	221
	90	32.5	41.7	106	90.8	51.1	114	191
Inflatable tyre wheelbarrow	30	24.7	43.5	49.7	25.1	61.4	7.87	82.0
	60	20.8	16.6	65.4	54.9	13.3	123	91.8
	90	16.9	16.9	50.9	76.8	12.5	83.8	127
Garden trolley	30	60.1	6.37	43.1	104	9.61	140	87.6
	60							
	90	47.8	6.40	44.9	116	74.0	15.3	131
Foldable sack truck	30	26.6	26.7	35.2	32.6	10.7	103	69.8
	60	35.3	35.4	95.1	116	61.3	32.0	163
	90	60.8	62.2	64.5	189	63.1	81.9	173
Step climber	30	30.8	30.9	75.4	73.9	50.5	57.8	150
	60	40.1	38.2	79.1	104	45.8	48.6	143
	90	48.1	48.6	79.7	116	57.8	35.7	143

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JT graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Appendix N. Joint contact forces shoulders expressed in proportion to bodyweight

Participant 1			
Tool	Obstacle height (mm)	Joint contact force / bodyweight	
		Left shoulder	Right shoulder
Puncture proof wheelbarrow	30	1.58	2.78
	60	2.78	2.64
	90	2.49	2.78
Inflatable tyre wheelbarrow	30	1.65	1.80
	60	2.61	2.66
	90	4.04	3.69
Garden trolley	30	1.45	2.02
	60	3.42	3.74
	90	2.64	5.54
Foldable sack truck	30	2.17	2.12
	60	4.04	2.32
	90	1.65	3.94
Step climber	30	1.70	1.67
		2.22*	2.34*
	60		
	90	2.61	2.61
		2.09*	2.02*

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JT graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 2			
Tool	Obstacle height (mm)	Joint contact force / bodyweight	
		Left shoulder	Right shoulder
Puncture proof wheelbarrow	30	1.91	1.92
	60	1.46	0.87
	90	1.31	1.72
Inflatable tyre wheelbarrow	30	1.75	1.06
	60	1.93	1.08
	90	2.48	1.31
Garden trolley	30	1.88	2.23
	60	1.10	2.34
	90	0.64	0.95
Foldable sack truck	30	0.93	5.14
	60		
	90		
Step climber	30		
	60	3.35	
		1.64*	3.92*
	90	1.94	2.43

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JT graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 3			
Tool	Obstacle height (mm)	Joint contact force / bodyweight	
		Left shoulder	Right shoulder
Puncture proof wheelbarrow	30	2.93	2.85
	60	3.54	2.73
	90	3.51	3.18
Inflatable tyre wheelbarrow	30	2.29	3.64
	60	2.47	1.39
	90	2.34	1.47
Garden trolley	30	3.83	0.67
	60		
	90	2.86	1.23
Foldable sack truck	30	4.78	1.87
	60	4.06	4.24
	90	5.97	7.24
Step climber	30	2.44	2.84
	60	3.22	2.97
	90	3.12	4.48

Empty cells indicate missing data points and removal of outliers based on unrealistic results and confirmation of visual anomalies in time-JT graphs.

*Secondary peak observed where participant pulled the step climber up in two phases.

Appendix O. Joint contact forces lower extremities expressed in proportion to bodyweight

Participant 1					
Tool	Obstacle height (mm)	Joint contact force / bodyweight			
		Left hip	Right hip	Left Knee	Right knee
Puncture proof wheelbarrow	30	3.82	4.56	2.17	2.54
	60	3.99	5.30	3.47	4.09
	90	3.20	3.23	3.23	2.22
Inflatable tyre wheelbarrow	30	2.73	3.23	2.22	2.68
	60	5.12	4.01	3.65	2.68
	90	5.71	3.97	4.73	3.57
Garden trolley	30	2.51	2.22	1.80	1.55
	60	2.96	3.03	2.68	2.12
	90	4.29	3.25	2.41	2.91
Foldable sack truck	30	3.35	3.08	2.51	2.76
	60	3.55	4.75	2.91	2.51
	90	5.39	3.08	5.34	2.54
Step climber	30	2.98	2.44	2.19	2.36
		3.60*	4.01*	2.78*	3.45*
	60				
		3.87*	4.04*	2.98*	3.10*
	90	11.48	4.24	8.28	3.84
		4.19*	2.91*	3.00*	2.34*

Empty cells indicate missing data points.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 2

Tool	Obstacle height (mm)	Joint contact force / bodyweight			
		Left hip	Right hip	Left Knee	Right knee
Puncture proof wheelbarrow	30	1.73	1.79	1.81	1.24
	60	1.93	1.31	1.91	2.42
	90	2.38	1.97	2.77	1.92
Inflatable tyre wheelbarrow	30	2.31	3.35	2.14	2.43
	60	2.10	3.19	1.88	2.79
	90	4.07	2.98	2.38	1.59
Garden trolley	30	2.16	2.63	1.94	2.16
	60	2.43	4.31	2.10	2.52
	90	1.62	1.84	1.85	2.64
Foldable sack truck	30	3.80	3.09	1.52	3.13
	60	3.21	1.67	4.48	1.48
	90				
Step climber	30				
	60	6.47	3.63	4.49	3.10
		4.24*	2.30*	3.13*	1.96*
	90	4.35	4.73	2.90	3.00
		8.69*	3.88*	3.67*	2.25*

Empty cells indicate missing data points.

*Secondary peak observed where participant pulled the step climber up in two phases.

Participant 3

Tool	Obstacle height (mm)	Joint contact force / bodyweight			
		Left hip	Right hip	Left Knee	Right knee
Puncture proof wheelbarrow	30	3.66	1.81	3.86	1.90
	60	2.58	3.24	2.66	2.65
	90	2.70	2.93	2.19	3.01
Inflatable tyre wheelbarrow	30	1.91	1.78	1.80	1.59
	60	2.01	2.27	1.68	3.42
	90	2.39	2.32	2.40	2.60
Garden trolley	30	2.08	2.91	1.75	4.45
	60				
	90	1.79	2.79	1.80	2.95
Foldable sack truck	30	1.47	1.89	1.28	2.63
	60	2.52	3.67	2.08	3.26
	90	2.79	4.93	2.76	5.71
Step climber	30	2.03	2.81	1.79	2.50
	60	1.80	4.43	2.37	2.98
	90	1.96	3.66	1.94	2.91

Empty cells indicate missing data points.

*Secondary peak observed where participant pulled the step climber up in two phases.