



DESIGN4 HEALTH

Extract of the
**Proceedings of the 3rd European
Conference on Design4Health**
Sheffield 13-16th July 2015

Editor: Kirsty Christer

ISBN: 978-1-84387-385-3

Growing Healthier

James Shippen¹, Barbara May¹, Paul Alexander² and Eline Kolk¹

¹Coventry University, School of Art and Design, UK

²Royal Horticultural Society, Wisley, Woking, Surrey UK

Abstract

It is widely accepted that physical activity is beneficial for the elder person to reduce the risk of coronary heart disease, hypertension, type 2 diabetes, osteoporosis, stroke, anxiety and depression but many forms of exercise are unsuitable for the elderly or they quit after a short period of time through lack of motivation or desire to attend a gym (American College of Sports Medicine, 2004; Hui and Rubenstein, 2006; Lee et al, 1991). However, gardening is an activity which many elderly people enjoy (Yusuf et al, 1996), rather than doing it for therapeutic reasons. The potential benefits of gardening as a form of age-appropriate exercise has particular emphasis on maintaining strength and flexibility to avoid fractures resulting from falls or osteoporosis. The gardening activities considered included digging, weeding, pruning, wheelbarrow operation, lifting of heavy objects, lawn mowing and raking.

This project has measured the movement and loads placed on gardeners during a range of gardening activities and calculated the consequential forces occurring within the muscles, tendons, joints and bones of the gardener. The motion of gardeners was measured using a 12 camera 3-dimensional optical tracking system. The forces acting between the gardening equipment and the gardener was measured using force transducers, static weight plus inertia forces.

The loads generated within the gardener were calculated using the Biomechanics of Bodies (BoB) software (Shippen & May 2010). The musculoskeletal model within BoB consists of 36 rigid segments connected with 33 joints whose actions represent their anatomical counterparts and 606 locomotor muscle units. The torques occurring at the joints were calculated using a Lagrangian inverse dynamics method. The force distribution within the muscles were calculated by minimising an objective function defined as the sum of the squares of the muscle activations constrained by the muscle torque equalling the inverse dynamics torque. This study suggests techniques and tool design to minimise the injury risk for the gardener.

Keywords: Gardening, Biomechanics, Health and Well-being, Gardening Tool Design

Introduction

With an increasing global population of ageing citizens, there is a need to better understand how to maintain health and wellbeing in later life. It is reported that regular physical activity contributes to the prevention and reduction of chronic diseases associated with ageing which can help maintain independent living (American College of Sports Medicine, 1998). Evidence-based research into which physical exercises are best suited to promote wellbeing in the older person could support health practitioners and care advisers in their choice of recommendations of exercise as a preventative therapy. This would help preserve an older person's healthy independent living for longer and maintain their quality of life.

Many potential forms of exercise are unsuitable for the older person and although many people may be persuaded to take more physical exercise, many quit after a short period of time arguing that exercise is boring and gyms are 'alien' territory.

However, gardening is a popular leisure activity which many elderly people enjoy. A range of research studies have produced qualitative data to describe how gardening has been associated with improved psychosocial health outcomes and promotes mental and physical stimulation (Infantino, 2004.). The maintenance of healthy lifestyles due to gardening activities has been studied (van den Berg *et al*, 2010) together with wellbeing implications of reduced socialization (Perez Vasquez *et al*, 2005), and increased life satisfaction and greater independence (Wakefield *et al*, 2007).

The design of gardening tools is also significant to the wellbeing of the gardener. The aesthetic properties of good design are relevant (Bloch, 1995), but ergonomics can also be seen as a central aspect of good product design which can positively impact work productivity (Kuijt-Evers *et al*, 2007). Various studies have looked into the impact of tools on the ergonomics and perceived comfort of hand tools (e.g. Harih & Dolšak, 2014) which indicates that the interaction of the product with the user is relevant.

Gardening has been described as a moderately rigorous form of exercise (Armstrong, 2000) which has a positive impact not only on the psychological well-being of the gardener but also on the body's strength and flexibility (Park and Shoemaker, 2009). Gardening tasks which use the upper and lower body such as digging, turning over compost and raking are described as having moderate intensity whereas tasks which mainly use the upper body, such as transplanting seedlings and hand weeding, are classified as low intensity (Park, Shoemaker and Haub, 2008)

There is a lack of evidence on the effects of recreational horticulture on osteoporosis or sarcopenia. Osteoporosis is a condition that affects bone strength caused by the loss of bone mineral density which can lead to bones becoming fragile and breaking easily, resulting in pain and disability.

Sarcopenia is the degenerative loss of skeletal muscle mass, quality, and strength associated with ageing. However it is acknowledged that weight-bearing exercise can reduce the effect of age-related decline in bone mineral density (Turner *et al*, 2002). Activities associated with gardening which include whole-body weight-bearing activities such as pushing a wheelbarrow, mowing the lawn, digging and trimming hedges are expected to have a positive influence on bone mineral density which could help reduce falls in older adults (Chen and Janke, 2012).

However, although there is some evidence of the positive psychosocial health benefits of gardening, there is limited research on the biomechanics of gardening to indicate which activity is a suitable healthy physical activity for the older person.

It has been recognised that knowledge of the joint and muscle loads encountered by the body is important in determining the possible mechanisms and prevention of injuries or for determining rehabilitation regimes following injury (An, Kwak, Chao *et al*, 1984). The purpose of this study therefore is to measure the loads placed on the body during a range of gardening activities which would enable the forces generated within the muscles, tendons, joints and bones of the gardener to be calculated.

Biomechanical analysis will use motion data capture techniques which are often applied analytical tools and widely used within sports and exercise disciplines to help increase human performance and identify injury risks. However, as yet it has not been used within the horticultural sciences.

If it can be proven that there are tangible health benefits from gardening, it is anticipated that long term engagement rates with this therapy will substantially increase and help preserve an older person's healthy independent living for longer.

Methods

Eleven subjects were recruited for the study and each provided informed consent to participate. Three subjects were professional gardeners who had undergone training in horticultural techniques including digging, shovelling and hedge trimming and were routinely engaged in over 8 hours per week of physical gardening activities. The eight amateur gardeners routinely undertook gardening activities ranging from zero hours per week to 3 hours per week. The age range of the subjects was from 20 years to 72 years. Their height ranged from 157cm to 191cm and their masses ranged from 58kg to 96kg. The professional gardeners had no significant injuries but one of the amateur gardeners had rheumatoid-arthritis and two others had previously suffered from (non-gardening related) injuries to their knees.

To measure movements for the subjects during gardening tasks they wore a tight fitting Lycra suit. 39 retro-reflective passive markers were attached to the suit located at:

- Right front head, left front head, right back head, left back head,

- C7, T10, xiphoid process, clavicle notch, right mid back,
- Right shoulder, right upper arm, right elbow, right forearm, right wrist bar, right hand,
- Left shoulder, left upper arm, left elbow, left forearm, left wrist bar, left hand,
- Right anterior iliac spine, left anterior iliac spine,
- Right posterior iliac spine, left posterior iliac spine,
- Right thigh, right lateral femoral epicondyle, right shin
- Left thigh, left lateral femoral epicondyle, left shin
- Right calcaneous, right second metatarsal head, right lateral maleolus,
- Left calcaneous, left second metatarsal head, left lateral maleolus.

Reflective markers were also attached to the gardening equipment used by the subjects so their movements could also be measured.

The movement of the markers were measured using a 12 camera Vicon MX40 3-dimensional optical tracking system. The tracking system was operating at 250 frames per second with a positional error tolerance of ± 1 mm. Ground reaction forces were measured using 2 AMTI OR6-7 forceplates mounted in the floor.

The subjects were instructed to undertake various gardening activities including:

- Shovelling heavy soil
- Light raking of soil
- Wheeling a loaded wheelbarrow
- Hedge trimming with an electric hedge trimmer
- Lifting a heavy bag
- Pruning tree branches

This paper will report on the shovelling activity only. For the shovelling task the subjects were instructed to move two spade loads of heavy soil from the soil-bed on which they were standing into a bucket placed in a self selected position. The subjects were asked to behave normally and undertake the tasks as they would typically do in their gardens.

The torques and loads occurring within the subjects during these tasks were calculated using a musculoskeletal model – the model used for this study was Biomechanics of Bodies (BoB) (Shippen and May, 2010). The BoB skeletal model consists of 36 rigid segments representing the major sections of the skeleton, for example, the skull, the upper arm, the pelvis, the thorax, the foot etc. The mass and inertia properties of the segments were set to similar values to their anatomical counterparts (Modenese *et al*, 2011). The skeletal segments were coupled by 33 joints whose degree of freedom correspond to their physiological counterparts.

BoB also contains 606 locomotor and stabilising muscles. The muscles are modelled using the three-element Hill muscle model (Hill 1938) with the muscles' physiological characteristics derived from numerous sources (Pierrynowski M. 1995, Fick 1920).

BoB applies an inverse dynamics approach using a Lagrangian based method to calculate the joint torques from the body's mass and inertia characteristics and the angle/angular velocity/angular acceleration time histories (Koopman *et al*, 1995). Torques at the joints are generated by forces in the muscles which cross those joints. For many biomechanical analyses the task is to calculate the muscle forces which are required to generate the observed motion and subsequently the contact forces occurring in the joints.

The positions of the markers, measured using the optical tracking system, were used to calculate the joint articulations as Euler angle time series. These time series were then used as enforce joint articulations of the BoB musculoskeletal model. The same musculoskeletal model, with the same height and mass, was used for all of the subjects irrespective of the subjects' actual height or mass. Also, the same external forces were applied to the BoB model and therefore the only information passed from the trial to the musculoskeletal model was the posture of the subject.

Results

Figure 1 shows the maximum torques which occurred at the lumbosacral joint during the soil shovelling tasks for all 11 subjects; the professional gardeners are labelled P1 – P3 and the amateur gardeners are labelled A1 – A8.

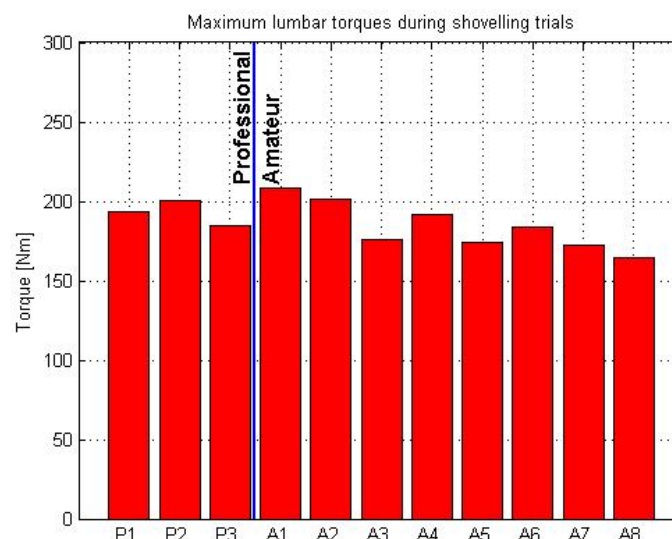


Figure 1: The maximum torque occurring at the lumbosacral joint during the shovelling trials.

Shovelling

From Figure 1 it can be seen that the largest maximum torque at the lumbosacral joint during the shovelling task is experienced by subject A1 (aged 62 years) at 207Nm whereas the smallest maximum torque is experienced by subject A8 (aged 37 years) at 160Nm. Figure 2 shows plots of the torques and joint contact forces occurring at the lumbosacral joint for these 2 subjects during the shovelling task and Figure 3 shows the postures of these subjects at the instant that the maximum lumbosacral joint torque occurs.

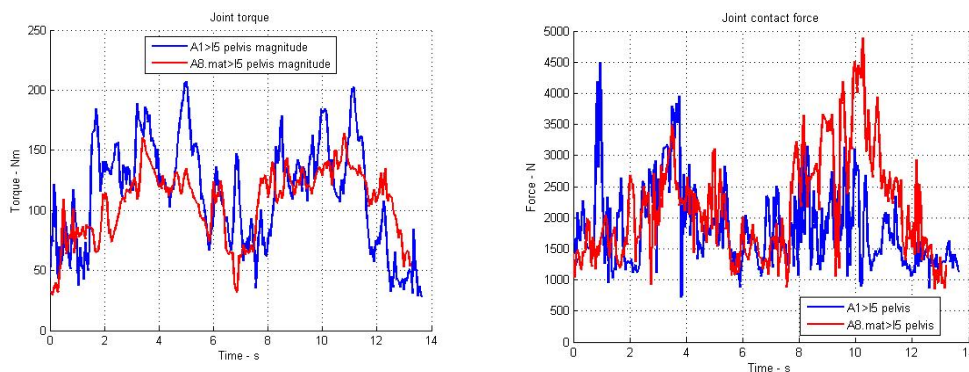


Figure 2: Torques (left) and joint contact force at the lumbosacral joint during the shovelling task

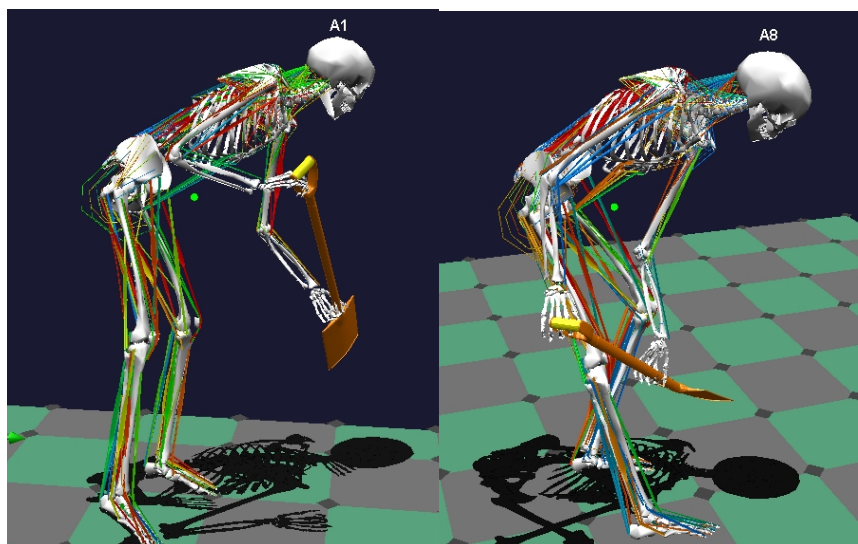


Figure 3: Posture when the maximum torque occurs at the lumbosacral joint for subject A1 (left) and A8 (right)

Conclusions

The lumbosacral joint was chosen for investigation as, anecdotally, gardeners often report back discomfort or pain. The structures in the lumbosacral segment combine together to provide both

a strong and stable base for the spine and a multifunctional joint that allows the torso to twist and bend in all directions. However this spinal segment has several interconnected components, any of which can become inflamed and cause lower back and/or leg pain (sciatica).

There was little variation for both torques and joint contact forces for the lumbosacral joint across all professional and amateur subjects although the highest and lowest torques were found in the amateurs.

The maximum torque corresponded to subjects who lifted the soil in a posture resulting in the maximum distance from the body whereas those with the lower torque held the spade close to the body and adopted a broad foot position. However the small variation in both torque and contact force at the lumbosacral joint suggests that loading is relatively insensitive to variations in posture.

By analysing the muscle torques and joint contact forces for the gardening trials it has been possible to identify the optimum movement patterns which can be achieved by both the professional and amateur gardeners.

Further research will be undertaken to explore the effects of age, training level and task more closely and it is anticipated that the biomechanics of the gardeners might determine best practice gardening performance for both the professional and amateur gardener. It may also have implications on the design of gardening tools in order to optimize the gardeners' body positions and minimise loads generated in the muscle potentially reducing the risk of pain or injury.

References

- American College of Sports Medicine, (1998). Exercise and physical activity for older adults. *Med. Sci. Sports Exerc.* 30: p992-1008
- American College of Sports Medicine. (2004). Physical activity and bone health. *Med. Sci. Sports Exerc.* 36:p1985–1996.
- An K-N., Kwak B, Chao E. and Morrey B. (1984) Determination of Muscle and Joint Forces: A Few Techniques to Solve the Indeterminate Problem *Transactions of the American Society of Mechanical Engineering* 106, p364-367
- Armstrong, D (2000). A survey of community gardens in upstate New York: Implications for health promotion and community development. *Health and Place*, 6, p319-327
- Bloch, P.H. (1995) 'Seeking the Ideal Form: Product Design and Consumer Response.' *Journal of Marketing* 59, p16
- Chen, T.Y, Janke, M C (2012). *J Aging Phys Act.* 20(1):p15-31
- Crowninshield, R.D., Brand, R.A., (1981). A physiologically based criterion of muscle force prediction in locomotion. *Journal of Biomechanics* 14, p793–801.
- Fick, R. (1920) *Allgemeine Gelenk Und Muskel Mechanik* Jena: Fischer
- Harih, G. and Dolšak, B. (2014) Comparison of Subjective Comfort Ratings between Anatomically Shaped and Cylindrical Handles. *Applied Ergonomics* 45 (4) p943–954
- Hill AV, (1938). The heat of shortening and dynamics constants of muscles. *Proc. R. Soc. (London: Royal Society)* 126 (843): p136–195 doi:10.1098/rspb.1938.0050
- Hui E K, and Rubenstein L. Z. (2006). Promoting physical activity and exercise in older adults. *J. Amer. Medical Directors Assn.* (7): p310–314.
- Infantino M. (2004). Gardening: A strategy for health promotion in older women. *Journal of the New York State Nurses Association*, 35(2), p10-17
- Koopman B, Grootenboer HJ, de Jongh HJ. (1995). An inverse dynamics model for the analysis, reconstruction and prediction of bipedal walking. *J Biomechanics* 28, p1369–1376 DOI: 10.1016/0021-9290(94)00185-7
- Kuijt-Evers, L.F.M., Bosch, T., Huysmans, M. a., de Looze, M.P., and Vink, P. (2007) 'Association between Objective and Subjective Measurements of Comfort and Discomfort in Hand Tools.' *Applied Ergonomics* 38 (5), p643–654
- Lee I. Paffenbarger R.S, and Hsieh C. (1991). Physical activity and risk of developing colorectal cancer among college alumni. *J. Natl. Cancer Inst.* 83:p1324–1329.
- Modenese L, Phillips A.T.M, Bull A.M.J. (2011). An open source lower limb model: Hip joint validation. *J Biomechanics* 44 (12), 11 p2185–2193
- Park S and Shoemaker C. (2009) Observing body positions of older adults while gardening for health benefits and risks. *Activities, Adaptations & Aging*, (33)p31-38

- Park S, Shoemaker C and Haub M. (2008) Can Older Gardeners Meet the Physical Activity Recommendation through Gardening? *Hort Technology* 18(4) p639-643
- Perez-Vazquez A, Anderson S and Rogers AW. (2005), Assessing benefits from allotments as a component of urban agriculture in England, Mouget, L.J.A. (Ed.), *Agropolis: The Social Political and Environmental Dimensions of Urban Agriculture*, Earthscan and IDRC, London.
- Pierrynowski M. (1995) Analytic Representation of Muscle Line of Action and Geometry. In Three-Dimensional Analysis of Human Movement. ed. by Allard, P., Stokes, I. and Blanchi, J.-P. Champaign: Human Kinetics
- Shippen J.M, May B. (2010). Calculation of Muscle Loading and Joint Contact Forces in Irish Dance. *Journal of Dance Science and Medicine*, 14(1) p11-18
- Turner L.W, Bass M.A, Ting L and Brown B. (2002) Influence of yard work and weight training on bone mineral density among older U.S. women. *J Women Aging* (14) p139-149
- Van den Berg A, van Winsum-Westra M, de Vries S, van Dillen S. (2010) Allotment gardening and health: A comparative survey among allotment gardeners and their neighbours without an allotment. *Environmental Health: A Global Access Science Source*, 9(74)
- Wakefield S, Yeudall F, Taron C, Reynolds J and Skinner A. (2007) Growing urban health: community gardening in South-East Toronto, *Health Promotion International*, (22)2 p92-101
- Yusuf, H.R., J.B. Croft, W.H. Giles, R.F. Anda, M.L. Casper, C.J. Caspersen, and D.A. Jones. (1996). Leisure-time physical activity among older adults: *Arch. Intern. Med.* 156:p1321–1326.