The Aquatic Therapy Association of Chartered Physiotherapists (ATACP) was formally the Hydrotherapy Association of Chartered Physiotherapists (HACP). It is a Professional Network affiliated to the UK Chartered Society of Physiotherapy (CSP).
I last guest edited Aqualines in 2016 and it is a pleasure to return for this edition, working with Cathy Brown, ATACP committee member and assistant editor.

Many congratulations go to Cecilia de Villiers who has been an excellent editor in the last few years. Her skills will be greatly missed.

I returned to the world of aquatic therapy, in the late summer of 2019, for the UK Aquatic Therapy Conference in Dorking. It was wonderful to catch up, and to meet many new people from the UK and beyond. The conference buzzed with the energy and enthusiasm of delegates and speakers. The scientific quality of the presentations was impressive. The conference indicated recent huge progress in the theory and practice of aquatic therapy. All credit to Jacqueline Pattman (ATACP chair) and the ATACP committee for putting on such a high quality conference.

This edition of Aqualines aims to give an impression of some conference proceedings. That is, reflections from delegates, from the ATACP Research Lead, Olly Krouwel, and from César Sá, chair of the newly recognised International Organisation of Aquatic Physical Therapists (IOAPT).

A keynote speaker at the conference was Sophie Heywood, chair of the Australian Physiotherapy Association Aquatic group. Sophie's paper is a part of her PhD, not previously published, and it contains many of her key points at the conference. I hope you will enjoy reading it and that it will support your practice and research activity.

Future editions of Aqualines will include further papers and reflections from the UK Conference 2019. If you were a delegate, what did you learn and how has it impacted on your practice? Please tell the editor, and share your learning through Aqualines.

Anne Jackson
PhD, MSc, BA (Hons), MCSP, HT
Guest editor of Aqualines
atacpaqualines@gmail.com
ATACP Chair’s Report

Jacqueline Pattman
MCSP, ATACP Approved Tutor, ATACP chair

The ATACP has had a busy year and some highlights are outlined below.

UK Aquatic Therapy Conference 2019 – celebratory conference in Dorking, 31 August–1 September 2019

This international conference celebrated 30 years of the ATACP. Our speakers were from the UK, across Europe, Australia and the USA. The delegates represented many countries. All credit to the ATACP committee for putting on an event of this calibre. Papers and comment from this conference are in this edition of Aqualines and will continue in future editions.

This conference setting was under the iconic wooded Boxhill, which was on the London 2012 Olympic bicycle route. The sun shone for practical demonstrations in the large outdoor pool, the hotel with its gardens was a beautiful setting for the presentations, networking and an array of stalls. The gala dinner was a chance for delegates to relax and continue the discussions of the day.

Education and awards

Tutors: Congratulations go to Sarah Cox who is now an ATACP recognised tutor. She joins the team, which includes Jacqueline Pattman, Sarah Wratten, Susie Harrison, Annette Turner, Heather Epps, Sue Booth and Alison Skinner.

The Education Committee: is the tutors (above) plus Ann Thomson.

Education programmes: We continue to tutor the ATACP Accredited Foundation Course in Aquatic Therapy and also intermediate courses on MSK, neurology, complex needs paediatrics and other bespoke courses, as required. See https://atACP.csp.org.uk/

In addition to teaching in the UK, we have taught in China, India and Denmark.

ATACP Accredited Foundation Course successes: Lucy Moore, Juanita Jordan, Angeliki Kontzoglou and Sue Lee.

Foundation Handbooks: Have been published for sale at a charge of £5 to Accredited Foundation Course participants and those with proof of previous attendance.

MBE: We are delighted that Ann Thomson received an MBE in The Queen’s Birthday Honours List of 2019. Her award was for services to physiotherapy education and to disabled people through swimming exercise.

A Lifetime Membership Award for outstanding contribution to the ATACP: was achieved by Alison Skinner and many congratulations go to her.

Many thanks for all your support and fun throughout the years: to Keith Simmonds, of Therapy World, who retires.
this year and will be missed by the aquatic therapy world.

A special thank you: to Sarah McKewan, a hard working committee member for many years. She has superbly supported our ATACP website and media activity. Sarah and her talents will be greatly missed.

Recent Study Day:
November 2018 at Stoke Mandeville:
• A national survey of NHS hydrotherapy provision for the management of axial spondylarthritis. The physiotherapist and patient perspective. Melanie Martin.
• The antenatal screening tool. Anna Carter.
• Workshops and practicals on women’s health, hypermobility, juvenile chronic arthritis (JCA) and ankylosing spondylitis (AS). Run by ATACP committee members.

Collaboration with outside agencies
World Confederation for Physical Therapy (WCPT): At WCPT congress in Geneva, in May 2019, the International Organisation of Aquatic Physical Therapists (IOAPT) was officially recognised after many years’ work (see paper by César Sá in this edition of Aqualines). Congratulations to all involved, in particular, to César Sá and Alison Skinner.

ICEBAT Las Vegas: Sarah Wratten presented a session on Ai Chi. Sarah Cox, Alison Skinner, Ann Thomson and Jacqueline Pattman, attended. A main message was that exercise prescription and dosage should be included in research programmes and reports.

Swim England: The water well-being model is up and running. There is an aquatic ‘activity for health’ qualification and we have several tutors including Sarah Cox, Julie Dixon and Olly Krowell. Our tutors will train the trainers. https://bit.ly/2sxyrGx

The Swim England Health Commission: has asked ATACP to be part of a committee.

ATACP expects to be supporting the development of fact sheets.

Good Boost: Sarah Wratten and Jacqueline Pattman have worked with Good Boost looking at 10 case studies of aquatic exercise programmes. Presentations have been made to NHS England and, if successful, funding may be available to develop the programmes and associated technology. This work is ongoing.

Pool Water Treatment Advisory Group (PWTAG): Sarah Wratten is our representative.

National Coordinating Committee for Swimming for People with Disabilities (NCCSPD): Sarah Cox is our link.

The National Institute for Health and Care Excellence (NICE):
Susie Harrison registers ATACP’s interest in appropriate NICE topics and alerts the committee and members to relevant activity and meetings.

Alison Skinner attended the NICE osteoarthritis (OA) update for ATACP and stressed the importance of including aquatic therapy in intervention for OA.

Jacqueline Pattman has provided information to the CSP on a NICE quality standard for encouraging physical activity in the community.

Other issues
Our Pool Design Document: is work in progress. Once completed, this will be available for purchase via our website.

Currently we have 288 members. Part of our 5 year goal is to advertise the advantages of being an ATACP member.

Aqualines: There will be one 2019 edition of Aqualines (this edition), published after our conference and edited by Cathy Brown (assistant editor and ATACP committee member) working with Dr Anne Jackson (guest editor).

CSP Professional Network bids: We are working to bid for funding to develop a digital resource to facilitate our educational
activity at both undergraduate and postgraduate level. We are working with Swim England, Nottingham University, Sport England, Moving Medicine, and Public Health England.

**CSP insurance Update for Professional Networks:** There will be changes to the CSP provision of public liability insurance policy for Professional Network activity.

The ATACP committee will follow up on this and act as required.

**Study days 2020 – dates:**
Spring study day and AGM – Saturday 25/04/20 probably in Putney (venue tbc)
Autumn study day Saturday 14/11/20

Thank you for your continued support and enthusiasm for aquatic physiotherapy.
Delegate reflection from the ATACP UK Aquatic Conference 2019

Compiled by the editors

Delegates were invited to consider and share their key learning and impressions of the conference as it closed. Below is a compilation of what delegates said.

Some overall comments
- Truly inspirational speakers, amazing research to back up and support the amazing work done by aquatic physiotherapists all over the world
- This is the best conference I’ve been to in ten years. I realised that so many more patients can get into the pool than I thought, and they can gain the benefits of immersion. I have learned how to structure an aquatic exercise programme much more effectively
- Clinically reasoned aquatic physiotherapy is based on research.

The beneficial physiological effects of immersion
- Immersion benefits for the heart, lungs, cartilage and brain
- Aquatic therapy increases cerebral blood flow and thus is beneficial for people with dementia - ‘happy brains are wet brains’
- The increase in cerebral blood flow, described by Dr Becker, provided an evidential answer as to how aquatic therapy would positively influence cognitive function in profoundly disabled children
- I am fascinated by the effect of immersion on the brain
- There is scientific evidence of the benefits of immersion
- Physiology of immersion has great health benefits without side effects, it has made me think about the physiological effects and what I am doing
- I have renewed enthusiasm for the value and benefit of the properties of water
- Aquatic therapy is beneficial for renal impairment.

New ideas about exercise in water
- Movement is medicine
- Think load and dosage when treating people in the water and record it
- Load, load, load (is important); often with less floating
- Work on power
- FART! (Functional Active Resistance Training)
- Consider plyometrics (exercises in which muscles exert maximum force in short intervals of time, with the goal of increasing power) for all age groups
- To increase power in the pool, short and quick movements with resistance are required
- Smaller, faster movements may be required
- Think about dosage when giving exercises in the pool and how to work on strength
- Increase the specificity of goals for lower limb aquatic therapy. Differentiate goals, that is, improving endurance, strength or power
- Importance of using speeds and load to reproduce and progress treatment
- We must remember to use ‘drag’
- Drag resistance may be more effective in strength training than buoyancy resisted training
- Buy resistance boots
- Considerations for treatment ideas including bounding, landing and skipping
- Cartilage needs loading and difficult to overload
Cartilage can repair if trained early enough
Osteoarthritis is not “wear and tear” or “your bones crumbling” it is an aging process
You will not make it worse loading it so load your knee!

Inspired by evidence
Particularly enjoyed the practical demonstrations and hearing the evidence base
Fantastic weekend learning form inspirational clinicians and researchers. We need to keep widening the body of evidence around aquatic therapy
I’m going to write up a case study
Fantastic opportunity to listen to current research. I feel inspired to ensure my clinical practice is researched and evidence based, thank you
Lots of research for me to follow up
Motivated to make changes to my practice and to try and push me to carry out some research in the future
One of the many benefits of this conference weekend has been to inspire me to start a research project and add more structure to my five year plan
The UK Aquatic Therapy Conference 2019 has promoted exercise in water with high quality evidence and research which was shared by passionate and enthusiastic speakers
A great weekend full of informative research
I loved the focus on aims and measuring progress.

Inspired by specialist techniques and specific services
Ai Chi is cool, the practical was amazing
Really pleased to know how many people are using Halliwick and saying how great it is
Inspiring to hear local success in the description of developing services in Bolton.

Networking, learning and enjoying
There are so many dedicated physiotherapists
I enjoyed meeting like-minded therapists
Many new ideas for working with patients
I want more! It’s been great. Thank you
Thank you for a lovely conference really enjoyed all aspects of the two days
It’s updated my knowledge
Brilliant pool demonstrations showing how patients can work to achieve their full potential
Fantastic conference, thank you
Brilliant weekend, great conference, thank you
Useful and varied information for a group of dedicated speakers, thank you all for a beautiful weekend
Thank you for a great conference, really valuable practical advice and evidence
International presentations have complemented the presentations of those from the UK to produce an excellent conference.

A more in depth reflection from Sue Booth, ATACP committee member, who works with people with learning disabilities
Sue was struck by a key conference point that immersion leads to increased cerebral blood flow. This led her to consider the therapeutic benefits that she observes when treating people with profound and multiple learning difficulties in the pool. She had observed improvements in their attention and cognition. She said, ‘I had thought this was due to parallel processing of sensory information through auditory, visual and sensory channels, but now wonder whether this is being enhanced through the increased cerebral blood flow……. research is needed to prove this’.

From the Aqualines editor
Thank you very much to delegates for their input into this article. The next 30 years
in aquatic therapy is going to be exciting. Going forwards, we would like to publish more of your detailed reflections, subsequent changes in practice, case studies and much more. Please contact the Aqualines editor with your ideas, however sketchy they may be atacpaqualines@gmail.com

Presentations from the UK Conference 2019 are available at https://bit.ly/2sumqSd

Images of the UK Aquatic Therapy Conference 2019

Demonstration of techniques in the pool at the UK conference 2019

Networking

Individual intervention techniques

Questions to the panel

Group activity in the pool
Research, Research, Research was high on the agenda of the UK Aquatic Therapy Conference 2019. The conference celebrated the 30th anniversary of the ATACP with international and renowned speakers disseminating a large body of evidence into their presentations.

The information has made a direct improvement to my clinical practice. For example, using drag a lot more, that is, ‘small and fast movements’ for strength training and encouraging higher intensity training so the patients are slightly short of breath. As Bruce Becker said, increasing circulation also has an effect on the brain.

I certainly spoke to many delegates who were motivated by the conference to complete their own projects, be it controlled trails or publishing audits of their work. The message was loud and clear, it is possible for everyone to help the profession develop a wider understanding on the effectiveness of aquatic physiotherapy. The more evidence we have the better armed we will be when justifying our service to managers and commissioners.

It was truly wonderful to see a master class by Jacqueline Pattman with a patient in in the pool. It really brings home the effectiveness and potentially life changing results of aquatic physiotherapy. In one session Jacqueline could encourage the patient to understand that she could enjoy being in the water and keep fit regardless of her spinal cord injury. Jacqueline is a world leading expert in her field and her clinical knowledge is ginormous, on top of that her ‘soft skills’ such as communication, her caring approach, humour and thinking holistically was clear to see. Sadly these ‘subtle skills’ in clinical practice are difficult to research especially in randomised controlled trials; there are however opportunities in qualitative studies that may help build up the full picture of aquatic physiotherapy.

Not only were we privileged to listen to speakers who are at the top of their field, I hugely valued the more informal discussions between clinicians, often I would hear exchange of emails and ideas for sharing good practice.

If you are motivated to complete a project no matter how small please get in contact with me at the ATACP, I would be very happy to help develop your ideas.

Happy evidence gathering!
Olly
New – International Organisation of Aquatic Physical Therapists (IOAPT)

César Sá

IOAPT president, Grupo de Interesse em Fisioterapia Aquática – Hidroterapia (GIFA) of the Associação Portuguesa de Fisioterapeutas (APFISIO) ft.cesarsa@gmail.com

At the UK Aquatic Therapy Conference 2019, César Sá gave a short introduction about the International Organisation of Aquatic Physical Therapists (IOAPT). IOAPT was recognised as a subgroup of the World Confederation for Physical Therapy (WCPT) at its conference earlier in 2019. César Sá is IOAPT’s first president. He reported as below.

The following countries are members – Argentina, Australia, Brazil, Denmark, Ireland, Mexico, Portugal, South Africa, Spain, UK and USA.

The IOAPT has a mission and vision to advance Aquatic Physical Therapy worldwide.

The objectives of the IOAPT are to:

• Be recognised as a subgroup of WCPT (World Confederation for Physical Therapy) in accordance with the WCPT Articles of Association
• Encourage high standards of physical therapy education, research and practice in particular those of relevance to Aquatic Physical Therapy
• Encourage communication and exchange of information including electronic, print and personal exchanges and organisation of education events for physical therapists
• Encourage scientific research and promote evidence based physical therapy practice in areas relevant to Aquatic Physical Therapy.
• Encourage the development of national organisations of physical therapists that share the objectives of the IOAPT
• Support WCPT in representing Aquatic Physical Therapy internationally
• Engage in all necessary activities to further the best interests of WCPT and Aquatic Physical Therapy.

Membership

Is a great way to link with colleagues who share an interest in aquatic therapy, in the UK, Europe and beyond. ATACP members are invited to contribute and to discuss future aims and objectives. Please get involved via Facebook, LinkedIn and Twitter. You can find the links at https://www.wcpt.org/ioapt

Congratulations from ATACP

Many congratulations to César, and the international team, for achieving official recognition for the IOAPT. Achieving WCPT recognition has been work in progress by many people over many years. It represents a milestone in our ongoing work to raise the profile of aquatic therapy. Our UK Aquatic Therapy Conference has demonstrated the...
benefits of working and sharing internationally. Now we have a platform that we can all use. Whatever your interest in aquatic therapy please get involved. Start by following the link https://www.wcpt.org/ioapt

**Personal reflection on the ATACP conference in Dorking 2019**

César Sá, IOAPT president

What an amazing weekend at the ATACP Conference!

The IOAPT was invited to this conference and I gave a presentation about this new WCPT subgroup, its objectives, goals and membership.

It was an excellent opportunity to meet the ATACP committee and many other delegates.

There were brilliant speakers and excellent presentations. It was a great venue and there was the opportunity to share and connect with aquatic physiotherapists from around the world. There were over than 90 delegates at the conference.

IOAPT thanks ATACP for the invitation and congratulate the organisation for a great job.

See also https://bit.ly/2MDDnQZ
Quadriceps muscle activity, force and kinematics during single limb squatting in water compared to on land in healthy older adults

Sophie Heywood, PhD\textsuperscript{a,b,c}, Jodie McClelland, PhD\textsuperscript{d}, Paula Geigle, PhD\textsuperscript{e}, Ann Rahmann, PhD\textsuperscript{f}, Kelly Bower, PhD\textsuperscript{c}, Elizabeth Villalta, MPhysiotherapy(Musculoskeletal)\textsuperscript{a}, Benjamin Mentiplay, PhD\textsuperscript{d}, Ross Clark, PhD\textsuperscript{g}

\textsuperscript{a}Physiotherapy Department, St Vincent’s Hospital, Melbourne, Victoria, Australia
\textsuperscript{b}University of Melbourne, Melbourne, Victoria, Australia
\textsuperscript{c}The Melbourne Sports Medicine Centre, Melbourne, Australia
\textsuperscript{d}Latrobe University, Melbourne, Victoria, Australia
\textsuperscript{e}School of Medicine, University of Maryland, Baltimore, MD, United States
\textsuperscript{f}Australian Catholic University, Brisbane, Queensland, Australia
\textsuperscript{g}University of the Sunshine Coast, Sippy Downs, Queensland, Australia

Corresponding author: Sophie Heywood, St Vincent’s Hospital, 41 Victoria Parade, Fitzroy, VIC 3065, Sophie.Heywood@svha.org.au

\textbf{ABSTRACT}

\textbf{Background:} Very little data exists on the biomechanics of lower limb closed kinetic chain exercises in water. This limits the specificity of aquatic exercise prescription and in turn, our understanding of the relationship to land-based function.

\textbf{Methods:} 11 healthy older adults (age 68.8 years \pm 5.9) were assessed during maximal voluntary isometric contraction and unilateral squats at slow, medium and maximal speed on land and in water (waist and chest deep). The primary outcomes were: 1) peak vertical ground reaction force measured with force platforms, 2) peak vastus lateralis muscle activity assessed via electromyography and both 3) time to complete the maximal speed squat and 4) trunk, knee and hip range of movement and position of the ankle relative to both the hip and the knee using video.

\textbf{Results:} Peak force and muscle activity were significantly lower in water compared to on land at all speeds (\(p \leq 0.046\), ES\(\geq 1.08\)). There were no significant differences between muscle activity at the different immersion depths (\(p \geq 0.134\), ES\(\geq 0.21\)). More rapid movement in water resulted in comparatively greater force (\(p < 0.001\), ES\(\geq 2.44\)) and muscle activity in vastus lateralis (\(p < 0.001\), ES\(\geq 1.49\)) compared to slow speed squats. Squat duration of maximal speed was similar between conditions (\(p \geq 0.273\)). Most kinematic outcomes including hip range of movement and the position of the hip and knee relative to the ankle were similar between environmental conditions.

\textbf{Conclusion:} Squatting in water predominantly replicates a similar range of movement, exercise duration and joint kinematics compared to land-based exercise. However, the reduced forces and lower quadriceps activity
may make it more appropriate for functional flexibility and neuromotor control exercises in relevant clinical populations. Prescribing greater squatting speeds in water increases force and muscle activation of the quadriceps and this may have value for power training.

**Key words:** squats, quadriceps, electromyography, aquatic exercise, hydrotherapy.

## 1. Introduction

Squats are a key feature of many exercise programs as they utilise similar muscle recruitment and patterns of movement as functional activities, such as standing from sitting (Palmitier et al., 1991; Schoenfeld, 2010; Stensdotter et al., 2003). Specifically, for older adults squats are often used in exercise programs to maintain physical function (Flanagan, Salam, Wang, Sanker, & Greendale, 2003), and squat performance correlates with performance of functional tasks including stair climbing in older adults (Hockings, Schmidt, & Cheung, 2013). Despite squatting being commonly used in aquatic exercise programs (Health Services Research Unit, 2014), the justification for using closed kinetic chain (CKC) exercises such as squatting in water is not validated. As training adaptations are specific to muscle activity, range of motion, and force-velocity characteristics of each exercise (Kraemer & Ratamess, 2004), these aspects of technique and prescription are essential to consider in aquatic exercise prescription.

The hydrostatic and hydrodynamic properties of water will influence the movement technique, the load and the subsequent muscle activity compared with the effects of gravity. This in turn will directly impact squat programming in aquatic exercise. For example, buoyancy assists squat upward movement and resists the downward movement. Weight bearing or vertical ground reaction force (GRF) in standing is lower in water compared to on land. This is due to buoyancy, and is relative to immersion depth due to the upthrust force of buoyancy (Harrison & Bulstrode, 1987). Buoyancy can be advantageous and enables individuals with weakness or pain to exercise (Batterham et al., 2011). Additionally, resistance from drag related to the speed and surface area of the moving part (Edlich et al., 1987) can be graded and controlled during aquatic exercise. Although forces from buoyancy and drag are combined during aquatic exercise (Edlich et al., 1987), limited information on the biomechanics of squatting in water is available, and no studies include squats performed at varied movement speeds.

The single kinematic study investigating slow speed squatting in shallow water (greater trochanter water depth) in younger adults demonstrated differences in water compared to on land for limb segment movement and movement variability (Severin et al., 2017b). More upright trunk and lower leg postures existed with double limb squats, and a deeper squat with greater shank motion during single limb squats occurred in water compared to on land (Severin et al., 2017b). The authors hypothesised more upright postures may minimise spinal compression (Severin et al., 2017b). However, centre of mass forward movement with trunk inclination during squatting on land increases the hip moment and muscle activity (Schoenfeld, 2010) and a more upright position in water may limit hip muscle activation in water. Upright shank postures during squatting in water may also reduce knee load (Severin et al., 2017b). As buoyancy already reduces weight bearing load when standing in water (Harrison & Bulstrode, 1987) this appears less of a benefit and more of a limitation as practicing forward movement of the knee over the foot positioned more posteriorly in activities such as sit-to-stand represents an appropriate functional strategy (Janssen, Bussmann, & Stam, 2002; Papa & Cappozzo, 2000; Shepherd & Koh, 1996).
Vertical ground reaction forces in squats in water have been shown to be significantly less compared to load on land with minimal load in the central part of the squat at slow speeds in water in older adults (Heywood et al., 2019). Increases in force with increasing speed may be useful in facilitating low-load high velocity exercise training in water for improving power.

Few studies have investigated muscle activity during CKC exercises in water compared to on land (Heywood et al., 2016). The limited CKC exercise data available indicated lower levels of quadriceps muscle activity in water compared to on land (Cuesta-Vargas et al., 2013; Fuller et al., 1999). In healthy young adults, quadriceps activity during a single limb squat may be reduced to half of land-based activity in waist-deep water and a quarter in chest deep water (Fuller et al., 1999). It is also previously reported at only 10–47% of land-based muscle activity during sit to stand (Cuesta-Vargas et al., 2013).

The influence of increasing speed and subsequent drag force, frequently used to manipulate resistance in aquatic exercise, upon muscle activity or kinematics in squats has not been investigated. It is also unknown if the maximal squat movement speed is significantly slower in water compared to on land as with other functional exercises such as gait (Heywood et al., 2016). Other squat biomechanical factors such as load and joint moments which influence exercise performance and outcome (Schoenfeld, 2010) and a greater understanding of the kinematics, spatiotemporal outcomes, forces and muscle activity during squats in water compared to on land at different speeds, are required. This knowledge will progress practitioner understanding of squat prescription in water, the benefits and limitations, and the potential of aquatic training to land-based functional task translation.

The primary aim of this study was to compare the vertical ground reaction force and quadriceps muscle activity of single leg squatting between land, waist, and chest depth immersion. The secondary aim investigated the influence of changing speed during a single limb squat. We hypothesised: 1) a reduction in vertical GRF and muscle activity in water compared to on land; and 2) increased speed in all environmental conditions will increase peak force and peak muscle activity. Trunk and lower limb joint range and position and duration of maximal speed squat were also investigated to determine if these parameters contribute to differences found in force and muscle activity.

2. Methods

2.1 Participants

Eleven healthy older adults aged (68.0 ± 5.9) years were recruited via local community advertising in Melbourne, Australia. Inclusion criteria were: aged over 60 years; no back or lower limb pain; no current or past musculoskeletal or neurological conditions; and no history of falls. Participants were excluded if they experienced limitations to exercise or contraindications to immersion in a hydrotherapy pool (Australian Physiotherapy Association, 2015). Screening for inclusion and exclusion criteria was completed via phone after participants answered local advertisements. All participants provided written informed consent prior to any data collection and the study was approved by the relevant institutional Human Research Ethics Committee.

2.2 Procedure

This cross-sectional, observational study assessed participants completing single leg squats at slow to maximal speed on land and in water. To limit the potential fatigue upon performance participants were asked to abstain from resistance training and high intensity exercise for 48 hours prior to the testing sessions. Height, weight, medical and exercise history were recorded prior to testing. To aid kinematic analysis, each participant was marked on the bony landmarks of the greater trochanter, lateral femoral epicondyle and distal lateral malleolus (identified by manual palpation).

The three environments tested were land, waist depth, and chest depth immersion. Land testing was completed first to ensure
the equipment was totally dry, thereby limiting risk related to slips or falls; next immersion in waist deep water (anterior superior iliac spine or up to 5 cm deeper); and then chest deep water (xiphisternal depth or up to 5 cm deeper) in a hydrotherapy pool (34 degrees Celsius) was completed. Any adverse events or episodes of significant discomfort were recorded during the sessions and participants were informed to notify the research team of any concerns in the 48 hours following testing.

2.3 Equipment
The kinetic outcome examined was peak VGRF during each squat. Ground reaction force data were captured using two modified (waterproofed) Nintendo Wii Balance Boards (WBB; Nintendo, Kyoto, Japan). These modified WBB have been validated against a criterion reference and the same procedure for calibration was used as previously described (Heywood et al., 2019).

Peak vastus lateralis (VL) electromyography (EMG) muscle activity outcome was recorded during each exercise via a Myoware muscle sensor chip with electrode connectors (Advancer Technologies, North Carolina, USA). The EMG system incorporated an Analog Devices AD8236 operational amplifier with a common-mode rejection ratio of 110dB at gain >100. This was powered by 5V. Raw data were output to a 14-bit analogue to digital conversion data acquisition device (USB-6001, National Instruments, Texas, USA). The system sampled data at 2000Hz using custom LabVIEW software (National Instruments, Austin, USA). Electrodes (Coviden; Minneapolis, USA; Ag/AgCl; disc diameter 12.5 mm) were used. Anatomical references for electrode placement for VL of the left leg were based on recommendations (Barbero, Merletti, & Rainoldi, 2012; Hermens et al., 1999). The inter-electrode distance is fixed at 30 mm for the system. The reference electrode was placed on the iliotibial band. This system has been validated against a commercial system (Heywood et al., 2018). Waterproofing of electrodes followed guidelines (Silvers & Dolny, 2011) and included two layers of dressings (Nexcare™ Tegaderm™ Waterproof Dressing, 3M, St. Paul, USA) with the margins locked down with skin glue (see appendix). Maximal voluntary isometric contraction (MVIC) for quadriceps was used to normalise the EMG data. This occurred in sitting with the knee flexed to 80 degrees, thigh stabilised with a seatbelt and resisted torque recorded using a wireless hand-held dynamometer placed on the distal tibia (C.I.T. Technics 3002; Haren, The Netherlands). All participants completed a single practice trial prior to testing. Participants were instructed to push as hard as possible and hold an isometric contraction for five seconds. Two maximal contractions were completed following two warm-up submaximal contractions.

Kinematic outcomes of trunk inclination, hip flexion, knee flexion and ankle position relative to hip and knee position in the deepest part of the squat in the sagittal plane were measured with a two-dimensional video camera (HERO+ GoPro, San Mateo, USA). These were positioned using multi-axis spirit levels in a fixed position lateral to the participant. Data were captured at 60 frames per second with 1280×720 pixel resolution, and calibrated for nonlinear distortion, perspective and spatial accuracy in two dimensions using a multi-dot calibration grid (see Appendix). Trunk inclination was defined as a line bisecting the lower half of the trunk with the vertical; hip flexion range was defined as the angle between a line bisecting the lower half of the trunk with the thigh (i.e., the line along the greater trochanter to the lateral epicondyle); and knee flexion was defined as the angle between the thigh and the lower leg (i.e., the line from the lateral femoral condyle to the lateral malleolus). The position of the lateral malleolus was measured vertically and compared to the position of the greater trochanter (representing the position of the pelvis) and the lateral femoral condyle (representing the position of the knee). Temporal outcomes included time to complete the maximal speed squat, kinematic (joint angles) and spatial outcomes
(position of the hip and knee relative to the ankle) were captured using a camera. Researchers manually counted heel lift during the exercise for each participant from the respective video.

2.4 Exercises
The exercises included left single limb squats at slow, medium and maximal speed (the left leg was tested as it allowed appropriate space for the camera). As the access to the testing space was time limited, only one key exercise was included in the testing. The exercise was demonstrated first, and then practiced prior to testing. Auditory feedback was provided for slow (three seconds lowering into knee flexion as far as could be controlled and three seconds rising back to the starting position) and medium (one second lowering and one second returning) speeds using a metronome set at 60 beats per minute. One fingertip balance was utilised on a rail at waist height using the right hand. If the instructor determined the participant overbalanced or completed the exercise out of time with the metronome, that trial was marked on a data collection sheet to be discarded and the exercise was repeated. Three successful repetitions of each exercise were completed.

2.5 EMG data processing
The raw EMG signals were first digitally passband filtered (Butterworth 20–500 Hz, 12 poles, zero-phase shift), with a notch filter included to remove powerline noise (Butterworth 45–55 Hz, 12 poles, zero-phase shift) and an additional notch filter for the custom system addressed significant noise present centred around 150Hz (Butterworth 140–160 Hz, 12 poles, zero-phase shift). Data were rectified before a linear envelope was applied (5Hz lowpass Butterworth, 12 poles, zero-phase shift). The Teagar Keiser Energy Operator method for automatic thresholding was utilised (Li et al., 2007) as has been previously described (Heywood et al., 2018). Peak muscle activation (mV) for the average of the three repetitions were normalized and expressed as a percentage of the highest value obtained during the MVIC.

2.6 Statistical analysis
Descriptive statistics for each participant, as well as peak force, muscle activity and range of movement and limb position were assessed and compared in each condition and at each speed. Outliers were checked using box plots and assumptions of normality of each distribution and the variance of homogeneity were assessed using Shapiro Wilk’s test and the Levine test, respectively. If the data violated any of these assumptions, median and interquartile range were used to describe the outcomes for each exercise and non-parametric tests (for repeated measures) compared outcomes between environmental conditions and different speeds for all exercises. Peak force, muscle activity and range of movement for the same speed on land, in waist and chest deep water was tested using the Friedman test (three environmental conditions, one speed) with pairwise comparisons using the Wilcoxon signed-rank test as appropriate. The second hypothesis related to increasing speed in each environmental condition was also tested using the Friedman test (three speeds, one environmental condition) and Wilcoxon signed-rank pairwise comparisons. Effect size calculations were completed using Hedge’s g (Review Manager. Version 5.3; Copenhagen, Denmark). Significance was set at p<0.05 for all tests. Statistical analysis was performed using IBM SPSS® software (Version 24). The data files for some of trials were blank, indicating operator error during testing or failure of the Bluetooth system to transmit the data. In these circumstances, participant data did not contribute to the analysis. This represented approximately 6% of trials.

3. Results
Characteristics of the 11 participants are presented in Table 1. There were no adverse events during the testing.
3.1 Squats with changing environment

Both the peak vertical GRF and quadriceps muscle activity during squats were significantly different between land and water (p≤0.046; Table 2 and 3). Peak vertical GRF was significantly greater on land than in water (p≤0.046, ES=6.02), and greater in waist depth water than chest depth (p≤0.046, ES=1.10). Quadriceps activity was significantly higher on land than water (p≤0.024, ES=1.08) but no significant differences existed between muscle activity at the different immersion depths (p≥0.134, ES=0.21, Table 3).

In water, the sagittal plane movement pattern was not significantly different from on land for hip flexion range of motion (p≥0.067; Table 4), displacement of the knee anteriorly relative to the ankle (p≥0.202) and the displacement of the hip posterior to the ankle (p≥0.202); however, participants demonstrated greater knee flexion in waist depth water compared to on land at medium and fastest speeds (p≤0.007). Three of the 11 participants lifted their heels during the squat at waist and chest depth. No time difference occurred to complete maximal speed squats across the environments (p≥0.273) (Table 4).

3.2 Squats with changing speed

Peak vertical GRF and peak quadriceps muscle activity were significantly greater when performed at fastest speed than for squats performed at slow speed in all environmental conditions (p≤0.001; Table 2 and 3). The most consistent change in movement pattern with increasing speed was that in both water conditions, hip and knee flexion increased significantly at fastest speed compared to slow speeds (p≤0.007; Table 4).

4. Discussion

This study establishes that both vertical GRF and quadriceps muscle activity are greater during a single limb squat on land compared to immersion in waist or chest deep water. Muscle activity was similar between the two depths of immersion, despite the increased force in the shallower condition, indicating lower limb muscle activity synergies require further investigation. For key kinematic and spatiotemporal measures, squatting in water replicates squatting on land. The position of the hip and knee relative to the ankle in the sagittal plane is similar in the deepest part of the squat in water compared to on land. This movement, the knee anterior to the ankle, is an important consideration in replicating functional patterns of movement in sit to stand on land (Shepherd & Koh, 1996). The subsequent increases in force and quadriceps activity in squatting at greater speeds offers a potentially valuable tool for modifying resistance and subsequent muscle activity during closed chain exercise in water with older adults. The time to complete a maximal speed squat is the same duration in water as on land, offering power-based training potential in water.
<table>
<thead>
<tr>
<th>Speed</th>
<th>FORCE (BW) Median (IQR)</th>
<th>Changing environment</th>
<th>Changing speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Land</td>
<td>Waist</td>
<td>Chest</td>
</tr>
<tr>
<td>Slow</td>
<td>1.08</td>
<td>0.45</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.04)</td>
<td>(0.05)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fastest</td>
<td>1.27</td>
<td>0.63</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>(0.17)</td>
<td>(0.12)</td>
<td>(0.14)</td>
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<tr>
<td></td>
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<td></td>
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</tbody>
</table>

IQR: Interquartile range; n: number of participants; p: level of significance set at 0.05(*<0.05); ES: Effect size - Hedges’ g
Table 3 Vastus Lateralis muscle activity (percentage of MVC) with changing environment and changing speed

<table>
<thead>
<tr>
<th>Speed</th>
<th>MUSCLE ACTIVITY (%MVC)</th>
<th>Changing environment</th>
<th>Changing speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (IQR)</td>
<td>Friedman (p)</td>
<td>Pairwise comparison</td>
</tr>
<tr>
<td></td>
<td>Land</td>
<td>Waist</td>
<td>Chest</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>98 (40)</td>
<td>52 (33)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>114 (60)</td>
<td>58 (23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fastest</td>
<td>140 (82)</td>
<td>75 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

IQR: Interquartile range; n: number of participants; p: level of significance set at 0.05(*<0.05); ES: Effect size - Hedges’ g
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Speed</th>
<th>Median (IQR)</th>
<th>Changing environment</th>
<th>Changing speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Land</td>
<td>Waist</td>
<td>Chest</td>
</tr>
<tr>
<td>Trunk inclination</td>
<td>Slow</td>
<td>30.10(14.42)</td>
<td>22.23(10.13)</td>
<td>19.99(6.13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>36.03(12.73)</td>
<td>26.20(6.61)</td>
<td>22.05(3.67)</td>
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<tr>
<td></td>
<td>Fastest</td>
<td>35.20(9.08)</td>
<td>27.70(7.93)</td>
<td>24.58(5.89)</td>
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<tr>
<td>Hip flexion</td>
<td>Slow</td>
<td>69.60(29.13)</td>
<td>70.45(30.08)</td>
<td>77.30(13.41)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>76.87(28.08)</td>
<td>78.53(23.48)</td>
<td>69.13(9.03)</td>
</tr>
<tr>
<td></td>
<td>Fastest</td>
<td>73.80(20.38)</td>
<td>87.65(20.40)</td>
<td>80.23(11.09)</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>Slow</td>
<td>74.13(9.78)</td>
<td>81.10(14.72)</td>
<td>77.30(13.41)</td>
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<tr>
<td></td>
<td>Medium</td>
<td>76.90(7.23)</td>
<td>86.50(11.85)</td>
<td>76.67(13.85)</td>
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<tr>
<td></td>
<td>Fastest</td>
<td>77.47(14.48)</td>
<td>94.70(15.10)</td>
<td>80.45(10.06)</td>
</tr>
<tr>
<td>Parameter</td>
<td>Speed</td>
<td>Median (IQR)</td>
<td>Changing environment</td>
<td>Changing speed</td>
</tr>
<tr>
<td>---------------------------------</td>
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<td>---------------</td>
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<tr>
<td></td>
<td></td>
<td>Land</td>
<td>Waist</td>
<td>Chest</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>4.04</td>
<td>4.03</td>
<td>4.55</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>2.69</td>
<td>4.19</td>
<td>3.24</td>
</tr>
<tr>
<td></td>
<td>Fastest</td>
<td>4.20</td>
<td>5.67</td>
<td>4.16</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>17.64</td>
<td>18.70</td>
<td>20.05</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>19.00</td>
<td>20.94</td>
<td>21.14</td>
</tr>
<tr>
<td></td>
<td>Fastest</td>
<td>18.53</td>
<td>20.76</td>
<td>19.62</td>
</tr>
<tr>
<td></td>
<td>Lowering</td>
<td>44.67</td>
<td>49.00</td>
<td>46.33</td>
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<tr>
<td></td>
<td>Rising</td>
<td>38.00</td>
<td>39.67</td>
<td>38.33</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>83.00</td>
<td>86.67</td>
<td>85.33</td>
</tr>
</tbody>
</table>

IQR: Interquartile range; n: number of participants; p: level of significance set at 0.05(*<0.05); ES: Effect size - Kendall’s W statistic; PC pairwise comparison;
Reduced vertical GRF and muscle activity in water compared to on land offers benefits and limitations in exercise and rehabilitation. The lower load produced during squats in water is in agreement with a previous investigation (Heywood et al., 2019) and may better enable exercise for individuals with weakness or pain (A. Barker et al., 2014; Batterham et al., 2011) and offer a successful starting point and opportunities for progression to functional land-based activities (Hochberg et al., 2012). Squats in water have been shown to provoke less pain in people with knee osteoarthritis compared to performing the exercise on land (Heywood et al., 2019). However, these lower loads do limit the opportunity for resistance in closed kinetic chain exercise. Although lower ground reaction forces are linked to the depth of immersion, Vastus Lateralis activity is similar between the two depths. This finding contrasts with the only other study measuring quadriceps activity (Vastus Medialis) during single leg squats (Fuller et al., 1999) finding progressively lower activity from land to waist depth to chest depth immersion. The speed of movement was not defined in that study, limiting the opportunity to hypothesize on the reason for this difference. Vastus Lateralis represents only one muscle group in the complex muscular synergy of the lower limb during squatting in water. Theoretically at faster speeds, the hip and knee flexors may play a greater role in the lowering component of the squat, resisting both buoyancy and drag force.

The potential to elicit greater vertical GRF and quadriceps muscle activity by increasing speed with squatting in all environments offers not only a tool for modifying resistance but a potential focus for effective exercise prescription to improve lower limb power. Typically, closed chain lower limb exercise focuses upon progressing weight-bearing load and resistance in the exercise by reducing water depth; however, with no change in muscle activity between waist and chest depth, speed appears to be the more valuable parameter to modify. With only a moderate difference in immersion depth between chest and waist depth, this may also limit any differences in muscle activity, but these water depth changes are frequently utilized clinically to progress clients. Power reduction occurs due to aging, but is vital to completing functional activities such as sit to stand and stair ascent (Shumway-Cook & Woollacott, 2007). Therefore, power training as a function of both strength and speed, is included in exercise programs for older adults (Porter, 2006). The evidence for power-based training to improve and maintain function in older adults (Cadore & Izquierdo, 2018; DeVos et al., 2005; Porter, 2006) and clinical populations (Williams et al., 2019) is evolving, even at lower load or resistance (De Vos et al., 2005). Similar maximal squatting movement speed in water and on land increases transferability of functional movement training across environments. In the aquatic environment, to maximise power training, focus upon increasing squat speed characteristics may be important. This attention upon exercise speed may be one of the most important areas for successful exercise prescription in an aquatic environment to maximise potential training adaptations in power based aquatic exercise programs.

Movement parameters indicate more similarities than differences in squatting technique in the water compared to on land. This offers specificity in training in water for retraining. Despite this finding, there will be individual variation in exercise technique and movement pattern and there is value for appropriate feedback from the aquatic physiotherapist in rehabilitation.

This study includes limitations. While this is the first study measuring quadriceps muscle activity in water with changing speed in conjunction with other biomechanical parameters, our participant numbers limit the power of these findings. Low participant numbers related to restricted access to the clinical testing space and the time available from participants. Additionally, only Vastus Lateralis activity was assessed and more understanding of muscle activation of the other quadriceps muscles as well as those in the entire lower limb is needed to optimally
prescribe exercise programs although this is difficult due to the large amount of time required to apply and waterproof the electrodes. Using finger touch for support during squatting may impact squat patterns, and there would be benefits in future studies in measuring both unilateral squatting and bilateral squatting (without upper limb support).

5. Conclusion
Single leg squatting in water demonstrated lower forces and quadriceps muscle activity compared to on land. Predominantly similar range of movement, lower limb joint positions and maximal exercise durations during the unilateral squatting between water and land reinforces functional technique and movement speed specificity for use of this exercise in aquatic rehabilitation. Additionally, increasing squatting speeds in water increases ground reaction force and muscle activation of the quadriceps, which may have implications for prescribing water-based exercise programs.

Appendix: Kinematic data collection, camera calibration and data analysis
Bony landmarks were palpated and circular dots were marked in a permanent pen on the pelvis (anterior superior iliac spine), hip (greater trochanter), knee (mid-patella, lateral femoral condyle), ankle (lateral malleolus, talus) and foot (base of the fifth metatarsal, between the heads of the second and third metatarsals). The video data used spatial calibration and a grid of equally sized and spaced dots as recommended by the software manufacturer (National Instruments, U.S.A.). The grid provides a known size and spacing of markers (dots), allowing the custom software to determine the distortion characteristics for each pixel in the image. By accounting for these distortion coefficients the image is modified to correct for perspective and lens distortion. This is important, as we also used the calibration grid to perform a scale calibration to allow for measurement of displacement in the horizontal and vertical plane. As such, if present, distortion would introduce a source of error to the analysis. The calibration grid was used prior to each testing session and in each environment, which also assisted with limiting any issues with distortion in the underwater images.

Kinematic and spatiotemporal outcomes were captured using a camera calibrated in two dimensions using a grid to limit errors from distortion. Calibration frames with control points have been used previously and in two-dimensional reconstruction accuracy analysis have been shown to have a reported RMS of 5.5 mm (Kwon and Kwak 1996). The calibration grid used (see Figure 1) was printed on A0 size (841 mm × 1189 mm) paper, and provided 400 circular dots with a fixed real-world constant size and spacings in the x- and y- directions. This was mounted to a flat board and positioned in the testing field using a three-dimensional spirit level in the position of the lower trunk and legs at the start of each group of exercises in each environment (land, waist and chest depth immersion). The calibration grid was then used to convert pixel coordinates into real world positions after correcting the image to lower distortion. This was achieved by specifying scaling factors or the real-world distances between the dots.

Figure 1. Representation of calibration grid used
in the calibration grid in the x- ad y- directions using a customised software program (LabVIEW, National Instruments, Texas, USA).

The steps involved in the kinematic and spatial data collection included

1. Video footage was converted into individual frames using video processing software (V1.10.4, VirtualDub.org)
2. The still frame with the calibration image for each testing session and each environment was identified and a Region of Interest (ROI) was chosen (defining the part of the calibration grid you want to use in the software program as seen in the red box from an underwater testing session in the image below)
3. Applying a nonlinear distortion algorithm to the region of interest (LabVIEW) to convert the image
4. Measuring the parameters of interest by fixing the points to the bony landmarks within the converted image software program

Kinematic and spatiotemporal parameters of interest included trunk inclination, hip

Figure 2. Calibration board underwater and Region of Interest

Figure 3. Confirming Region of Interest
Quadriceps muscle activity in squatting in water

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Flexion, knee flexion and ankle position relative to hip and knee position in the deepest part of the squat in the sagittal plane, in addition to time to complete the maximal speed squat. Researchers manually counted heel lift during the exercise for each participant from the respective video. These parameters were measured with video cameras (HERO+ GoPro, San Mateo, USA) positioned using three-dimensional spirit levels in a fixed position lateral to the participant with data captured at 60 frames per second with 1280×720 pixels resolution. Bony landmarks were palpated and circular dots were marked in a permanent pen on the hip (greater trochanter), knee (lateral femoral condyle), ankle (lateral malleolus) and foot (base of the fifth metatarsal). Trunk inclination was defined as a line bisecting the lower half of the trunk with the vertical; hip flexion range was defined as the angle between a line bisecting the lower half of the trunk with the thigh (i.e., the line along the greater trochanter to the lateral femoral condyle); and knee flexion was defined as the angle between the thigh and the lower leg (i.e., the line from the lateral femoral condyle to the lateral malleolus). The position of the lateral malleolus was measured vertically and compared to the position of the greater trochanter (representing the position of the pelvis) and the lateral femoral condyle.
Quadriceps muscle activity in squatting in water

(representing the position of the knee). For the duration of each squat, the number of frames from the commencement of flexion of the knee to full knee flexion and commencement of extension of the knee until full knee extension were counted and converted based on 60 frames per second.

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