

THE EFFECTS OF HANDHELD LOAD ON HORIZONTAL JUMP PERFORMANCE IN FEMALE ATHLETES

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MSpEx

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Chapters 2 to 4 of this thesis represent three separate papers that have either been published, have been submitted, or will be submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined at the beginning of the thesis. All co-authors have approved the inclusion of the joint work in this masters' thesis.

A handwritten signature in blue ink, appearing to read 'C. McKenzie', is centered within a light purple rectangular box.

Chloe McKenzie

May 2014

LIST OF PUBLICATIONS FROM THESIS

Chapter 2.

McKenzie, C, Brughelli, M, Whatman, C, and Gamble, P. Enhancing jump performance with handheld loading. *Strength and Conditioning Journal* 36:32-38, 2014.

Chapter 3.


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Chloe McKenzie



Matt Brughelli



Chris Whatman



Scott Brown



Paul Gamble

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ETHICAL APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 13/162, with approval granted originally on 10 of July 2013.

ABSTRACT

There is evidence to show that approximately 3000 years ago, handheld load was used to enhance human athletic performance. A primitive form of dumbbell ("halteres") was held in each hand during long jump events at the ancient Olympic Games, supposedly to increase jump performance. This thesis has sought to gain knowledge on the effects of handheld load on horizontal jumping biomechanics and performance in female athletes. On the basis of the literature review, jump distance was found to increase with handheld load in all reviewed studies; however, methodological concerns and a lack of studies investigating female athletes made it clear further research was needed on this topic. As horizontal motion is a common component in court sport movements, and the review of literature highlighted the scarcity of research in female athletes, this thesis focused on female netball players. The aim of the thesis was to investigate the effects of handheld load in horizontal jump performance in female netball players. Findings in Chapter 3 suggest handheld load increases horizontal jump performance. In a group of 12 female netball players, jump performance significantly increased from 170.7 ± 15.3 cm to 176.7 ± 15.4 cm (Effect size [ES] = 0.39, $p=0.04$) with a handheld load of 4 kilograms (kg). An average optimal load (relative to body mass [BM]) based on curve fitting, where the greatest enhancement of jump distance occurred, was determined to be 6.4 ± 4.0 % BM, eliciting an increase in jump distance of 9.5 ± 6.8 cm (ES=0.61). Chapter 4 presents findings from 13 female netball players performing standing horizontal jumps with and without an individualised optimal handheld load, as determined by the curve fitting method from Chapter 3. Jump distance was found to significantly increase with optimal handheld load (ES=0.39, $p<0.05$), as was concentric ground reaction forces (ES=0.43-0.72) and the technical ability of force application (i.e. the ratio of horizontal to resultant ground reaction force) (ES=0.55). Underlying mechanisms involving arm swing motion and the ratio of force application were applied to the finding. It was concluded that handheld load could help improve the production and technical application of horizontal forces in female athletes during sports movements requiring

horizontal force production; thus, achieving a successful sporting performance. Further research focusing on the chronic adaptations of horizontal jumping with handheld load is needed to determine appropriate training protocols.

CHAPTER 1

INTRODUCTION AND RATIONALE

Background

The concept of loaded horizontal jumping dates back to 700 B.C. where athletes of the ancient Olympic Games performed jumping activities while holding load, termed "halteres", in their hands (1, 5). The handheld loads, made out of stone or lead, weighed from two to nine kilograms (kg). Such implements, shaped like a primitive form of a dumbbell, were presumably used to increase jump distance (5, 16, 32, 35). Ancient athlete Phayllos is reported to have jumped 16.76 metres with handheld load (27, 36) and pictographs illustrating athletes jumping with load in their hands have been discovered on ancient artefacts. Researchers have suggested that holding load in each hand during a standing horizontal jump can affect the mechanics of a jump and consequently improve jump performance; supporting the possible feats of ancient Olympic jumping events (1, 5, 9, 27). Handheld load may therefore be one of the earliest tools invented to actively enhance human athletic performance (32).

Several researchers have reported increases in jump distance when jumping with handheld load (5, 23, 35-37). Furthermore, some of these researchers have also reported an optimal loading range where the greatest enhancement of jump distance can be observed. The reported improvement in jump distance with handheld load can be explained by four main theories involving the mechanics of arm motion (i.e. arm swing): 1) joint torque augmentation theory, 2) hold back theory, and 3) pull theory, and 4) take-off angle theory. The use of arm motion, during a vertical or horizontal jump movement, has been shown to improve jump distance by optimising the position of the body centre of mass (CM) at take-off, and increasing take-off velocity (2, 3, 6, 11, 14-16, 19-21, 26, 38). With the addition of load in the hand, the effect of arm motion is

possibly amplified to augment jump performance. Although there have been positive findings from research on this topic (5, 23, 35-37), low methodological qualities of studies have resulted in inconsistencies in the literature. However, given it is important to maximise horizontal jump distance in many different sports activities, and previous research has indicated promising results for the acute effects of handheld load on horizontal jumping, jumping with loads has been seen as a valuable training mode to investigate further.

Athletes need to generate a certain amount of horizontal momentum to be able to achieve successful performance in many court sport activities; for example volleyball, basketball, and netball (28). To date, the existing literature has shown that performing horizontal jumps with handheld load improves jump performance; thus, based on the acute enhancement of jump distance with handheld load, if loaded horizontal jumping is repeatedly applied in training, muscular adaptations could occur due to the demands placed on the body (10). Additionally, handheld load could help improve the technical application of horizontal force during sports movements, based on the ratio of force application (i.e. the ratio of horizontal to resultant force) (33). Sports that involve movements with strong horizontal components such as acceleration, short sprints and horizontal jumping, could also benefit from this training exercise (25).

Netball is one sport in particular that could benefit from this possible method of training (16). There is very limited research into netball performance and no studies have investigated the effects of handheld load on horizontal jumping in the sport of netball. In game analysis of netball, the frequency of jump direction (vertical, horizontal and lateral) has been recorded. An average of 173 horizontal, 134 vertical, and 109 lateral jumps were found (22). Furthermore, mid-court players were most likely to perform forward, or horizontal jumps compared to end-court players who most frequently jumped vertically (22). Therefore, training with handheld load in netball could have positive impacts on performance due to muscular adaptations and technical changes, resulting in enhanced horizontal force production.

Purpose Statement

The purpose of this thesis was to investigate the effects of handheld load on horizontal jump performance in female netball players. It attempted to verify the historical veracity of the loaded horizontal jump and determine the potential for improved jump performance based on the acute enhancement of jump distance with handheld load. Firstly, the current literature examining the effects of handheld load on horizontal jumping was reviewed. Secondly, the effects of handheld load were investigated in female netball players. Arm motion during jumping was also investigated and applied to the discussions in the chapters of this thesis, which attempted to explain the underlying mechanisms of the improvements in jump distance with handheld load. This thesis contributes new knowledge on this topic, specifically for female netball players, adding context to current discussion and making practical recommendations to guide training for performance enhancement.

Study Aims

The aims of this research were as follows:

1. To review the published literature for the effects of handheld load on horizontal jumping.
2. To investigate the optimal load for improving horizontal jump performance in a single, standing, horizontal broad jump in female netball players.
3. To determine the effects of optimum handheld load on ground reaction forces, joint mechanics, and jump distance during a horizontal broad jump in female netball players.
4. To provide practical recommendations to strength and conditioning coaches, specialist coaches, players, and netball

organisations for training prescription with handheld load to enhance performance.

Structure of the Thesis

This thesis consists of five chapters (see Figure 1) that culminate in an overall discussion. Some of the study chapters have been submitted for publication in journals, which has allowed the author to gain international peer reviewed feedback on the content, improving the chapters. Each chapter is therefore written in the wording of the journal for which they were written. Consequently, there is some repetition in the introduction and methods between the review and experimental chapters. References are not included at the end of each chapter; rather, as required by AUT for thesis submission, an overall reference list from the entire thesis has been collated at the end of the final chapter. The reference format selected is the specific style required for submission to the *Journal of Strength and Conditioning Research*, based on the numerical style.

Chapter 2 contains a review of literature relating to the effects of handheld load on horizontal jumping. This review draws attention to the limited research on this topic and addresses the methodological concerns in current studies. It provides practical recommendations based on current findings and direction for further research.

Given Chapter 2 highlighted many limitations to current research, particularly the fact that there is no studies on female netball players on this topic, Chapter 3 investigated the acute effects of handheld load on horizontal jump performance and biomechanics during a single standing horizontal jump in female netball players. This chapter is the paper submitted to the *Journal of Strength and Conditioning Research*, where key findings suggest that jump performance is enhanced with optimum handheld load in this population of athletes. Furthermore, individualised optimum loads, relative to body mass, for enhancing jump distance were determined.

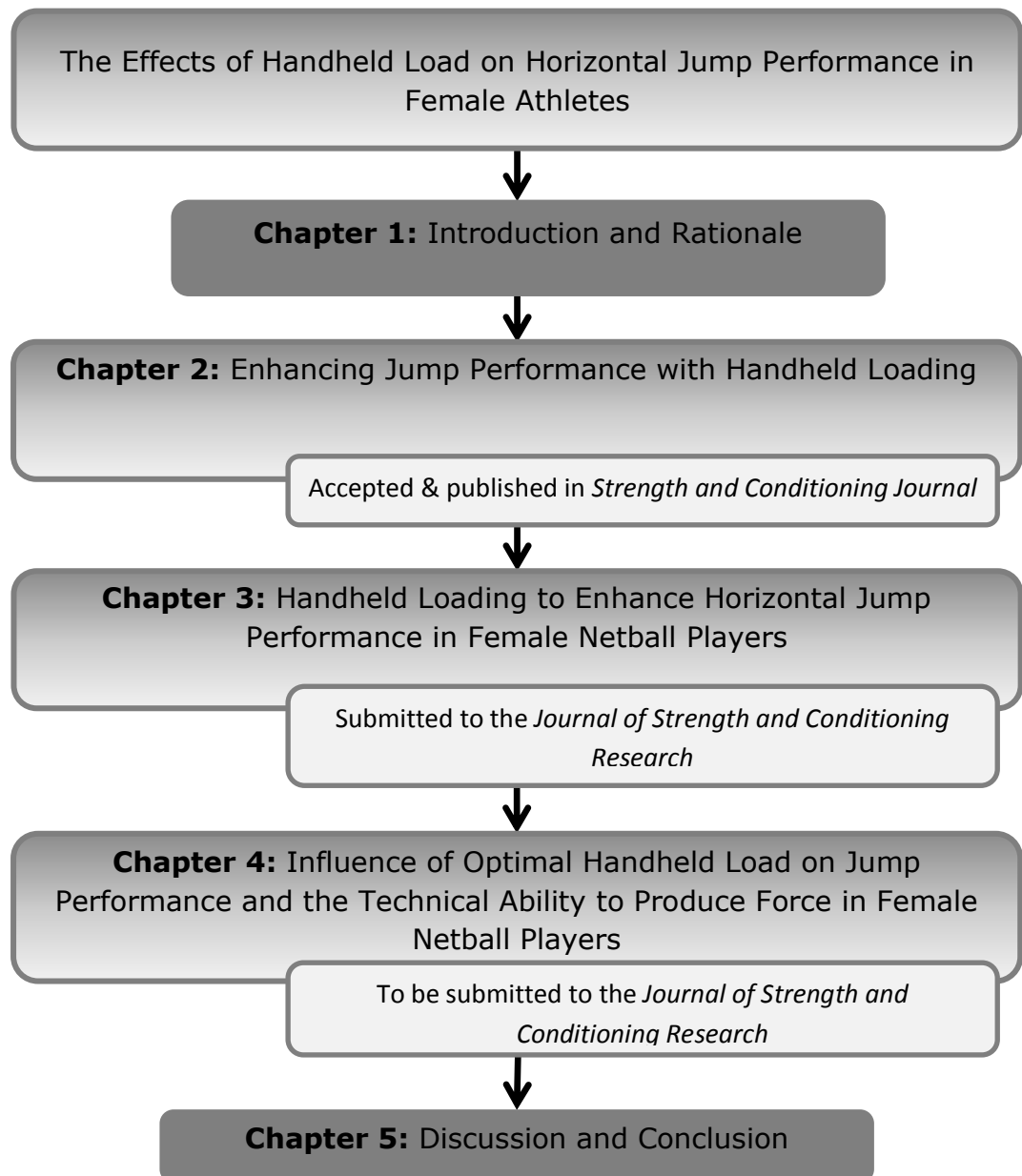


Figure 1. Overview of master's thesis chapter flow

As a result of the findings from Chapter 3, the fourth chapter of this thesis examined the biomechanical and technical changes involved when jumping with optimal handheld load in female netball players. Optimal handheld loads for individual participants were prescribed from findings in Chapter 3 for loaded conditions. This chapter found enhancements in horizontal jump performance attributed to arm motion mechanics and the technical ability of force application. Furthermore, the findings provide reason for future research and practical implications.

Chapter 5 consists of an overall discussion of findings from the presented research projects, comments on limitations to the research studies, provides areas for future research, and provides some concluding statements on the key findings from the thesis.

CHAPTER 2

ENHANCING JUMP PERFORMANCE WITH HANDHELD LOADING

Abstract

The concept of using handheld loading during a standing long jump dates back almost 3000 years to ancient Greece. This may have been one of the earliest attempts to passively enhance athletic performance. Despite numerous limitations in the more recent literature, researchers have reported acute enhancements in horizontal jumping distance. However, the long term effects of handheld loading have never been investigated. The purposes of this review are to provide: 1) a comprehensive review of literature on the acute effects of handheld loading on horizontal jumping performance, 2) direction for future research, and 3) practical recommendations for strength and conditioning. A Video Abstract discussing this article is found in Supplementary Digital Content 1 (see supplementary file, Editorial Video).

Introduction

Researchers have suggested that holding loads in each hand during a standing horizontal jump can affect the mechanics of a jump and consequently improve jump performance (1, 5, 27). This concept dates back to ancient Greece when the standing long jump was performed at the Olympic Games nearly 3000 years ago (~700 B.C.) (1, 5). Ancient sources reported athletes jumped more than 15 metres (m) with loads in their hands during a continuous succession of five broad jumps (27). According to legend, ancient athlete Phayllos jumped 55 feet (27). Interestingly, pictographs illustrate ancient athletes carrying load in their hands while performing various manoeuvres. The stone or lead loads ranged from two to nine kilograms (kg) and were shaped in a primitive form of a dumbbell (5, 32). Handheld load may therefore be one of the

earliest tools invented to passively enhance human athletic performance. Even though the standing long jump has been excluded from the Olympic Games since 1912, it continues to be a popular test of explosive leg power in field testing today (38).

Given the importance of maximising horizontal jump distance in many different sports activities, jumping with loads has been seen as a valuable training mode to investigate (1, 23). Based on the acute enhancement of jump distance with handheld loads, the training effects of enhanced jump performance, when loaded horizontal jumping is repeatedly applied, may prove to be useful in many sports and sporting activities. Long jump is clearly an example of a sport that could benefit from such training; however in other sports such as volleyball and basketball, athletes need to produce a certain amount of horizontal momentum, in addition to jumping vertically, to be able to achieve successful performance (34).

The purpose of this review is to attempt to verify the historical veracity of the effect of handheld loads on jumping (both vertical and horizontal) mechanics and performance, and provide practical recommendations for future research and training. In addition, the four main theories of arm motion mechanics will be used to help explain why jumping may be enhanced with handheld loads.

Proposed Mechanisms

The effects of arm motion (i.e. arm swing) during both vertical and horizontal jumping have been investigated by several researchers. Performing jumps with free arm motion has been shown to increase jump distance and/or jump height, compared to jumping with the restriction of free arm motion (2, 3, 6, 11, 14-16, 19-21, 26, 38). Improved jump performance can be explained by an increase in the height or distance of the centre of mass (CM) at take-off (TO) as well as an increase in velocity of the CM at TO (6, 14, 15, 26). The underlying mechanisms for such results can be partly attributed to four main theories which affect

the mechanics and motion of the body during a jump: pull theory, joint torque augmentation theory, hold back theory and take-off angle theory. The same theories have been proposed for the augmentation in jump performance with handheld loading.

Pull Theory

During a vertical or horizontal jump with an arm swing, the work created by the muscles at the shoulder and elbow joints imparts energy, transferring it to the rest of the system (2). The transfer of energy from the shoulders and elbows is termed "pull theory". Arm swing begins to decelerate near TO during the end propulsive phase of a jump, causing the torque at the shoulder joint to pull the trunk up (in a vertical jump) or forward (in a horizontal jump) (6). This causes energy to be transferred from the arms to the rest of the body, increasing jump performance (2, 6, 26). Work reported at the shoulder joint was fairly similar in the studies by Lees et al. (26) and Domire and Challis (11) and was shown to contribute to approximately 33 % of performance enhancement. These results were slightly lower than the findings in a simulation study by Cheng et al. (6) who reported that shoulder joint work was responsible for approximately half (52 %) of additional energy caused by arm motion. Cheng et al. (6) also found the arms to pull the body up for a shorter amount of time than that measured by Lees et al. (26). These inconsistent findings are most likely due to methodological differences. One study used human participants (11), and the other computer modelling (6).

Joint Torque Augmentation Theory

An increase in jump height with an arm swing has also been associated with "joint torque augmentation" (6, 11, 14, 15, 20). Swinging the arms during the early propulsive phase of a jump generates a downward force at the shoulder which is transferred to the trunk and the rest of the body (2). This downward force slows the shortening of the major lower body muscles when they are in an optimum position to produce force (15). Additionally, a decrease in shortening velocity allows the relevant muscles to produce more force according to the force-velocity

relationship (2, 11, 20). Feltner et al. (14) reported a decrease in torques at the hips, knees and ankles during the early propulsive phase of a jump, but augmented later in the propulsive phase, referred to as "joint torque augmentation". Torques at the hip and ankle were also reported to be significantly augmented with arm swing by Hara et al. (20), contributing 66 % of work from the lower extremity joints towards the total increase in overall joint work. Hip joint torque was also found to considerably increase (47 %) in the study by Cheng et al. (6) when the use of free arm motion was compared to no arm motion (163 Nm vs. 240 Nm). However, joint torque augmentation was confirmed only in the hips and not the knees (joint work 7 % less with arm motion) and ankles (joint work 18 % less with arm motion). As a direct consequence of hip joint torque augmentation, ground reaction forces (GRF) increased in the latter half of the propulsive phase of a jump (6, 21).

Hold Back Theory

Ashby and Heegaard (3) investigated horizontal jumps with and without free arm motion in order to determine if arm swing improved jump distance. The results of this study showed the participants jumped an average 21 % further with free arm motion than without. A 13 % increase in TO velocity when free arm motion was allowed accounted for the majority of the increase in performance, while the remaining increase was due to an increase in the horizontal displacement of the CM before TO. Jumping with restricted arm motion was found to cause a decline in the vertical GRF just before TO resulting in a backwards rotation moment about the CM (3). It has been suggested that without the ability to swing the arms, the jumper must overcome excessive forward rotation that would prevent correct landing. To do so the jumper must "hold back", or limit lower limb extensor activation during the propulsive phase, hence the "hold back theory" (2). Thus, for a successful jump the additional balance and control provided by free arm motion (ability to swing the arms backwards during flight phase) is necessary to correct excessive forward rotation about the CM (3).

Take-Off Angle Theory

The direction of arm swing as well as TO projection angles are also indicators of horizontal jump performance (21, 38). Velocity of the CM at TO has been shown to decrease with an increase in TO angle, and thus negatively affect flight time and performance during the long jump. The optimum TO angle was determined to be 19-27° (38), much lower than the expected optimum angle for projectile motion of 45°. It is only when the magnitude of the projection velocity of a jumper is the same for all projection angles that the projection angle of 45° is optimal (38). As the projection velocity is known to decrease as the projection angle increases in long jumpers, the 45° projection angle is not optimal. Thus, identifying methods of increasing the projection angle at TO (above the found optimum TO angle of 19-27°) while still maintaining TO velocity would appear to augment horizontal jump performance.

The Effects of Handheld Loading on Performance

The technique of the ancient Greek long jump has been investigated to determine the credibility of the athletic achievements described in ancient sources. It has been suggested that the most likely explanation of the great feats of the ancient Greek long jump is a jump comprising a continuous succession of five bilateral jumps (five-fold jump) where the athlete was able to gain balance and momentum between each jump. Lenoir et al. (27) investigated the effects of handheld loading and reported a 5 % to 6 % average increase in jump distance. Therefore, the five-fold jump technique suggests trained athletes are able to jump distances over 15 m, indicating the jump of Phayllos is an acceptable possibility (27).

Researchers have also found positive increases in horizontal jumping distance using a single-standing long jump (5, 23, 35-37) or a vertical jump approach (32) (see Table 1). An increase in jump distance was recorded by Tang and Huang (37) who found that an unloaded jump distance of 2.68 m increased to 2.82 m ($p < 0.05$) with a 6 to 8 kg handheld load. Butcher and Bertram (5) reported the biggest increase in

Table 1. Effects of handheld loading on horizontal jumping performance

Study	Participants	Loading (TL)	Changes in Maximum Jump Distance	Optimal Load	Significance
Minetti & Ardigo (32)	Computer simulation 2D, four segments 4 human participants	0-20 kg	↑ in jump distance 0.17 m in a 3 m long jump	5-6 kg	Not reported
Butcher & Bertram ^c (5)	1M: 90.9 kg 1F: 57.3 kg	0 kg 2.8 kg 4.6 kg 7.2 kg	M: 0 kg: 2.81 ± 0.04 m 7.2 kg: 3.06 ± 0.07 m ↑ F: 0 kg: 1.98 ± 0.02 m 4.6 kg: 2.14 ± 0.03 m ↑	M: 7.2 kg (8 % BM) F: 4.6 kg (8 % BM)	Not reported
Ashby ^a (1)	Computer simulation 2D, seven segment link model	0 kg 4 kg 6 kg 8 kg 10 kg 12 kg	2.35m 2.74 m ↑ All loads ↑	8 kg	Not reported
Huang, Chen & Peng ^a (23)	12 M Age: 21.8 ± 1.7 yrs Weight: 67.8 ± 12.0 kg Height: 1.75 ± 5 m	0 kg 2 kg 4 kg 6 kg 8 kg 10 kg	0 kg: 2.92 ± 0.16 m 2-4 kg: 2.98 ± 0.17 m ↑	4.24 kg (6.25 % BM)	Not reported
Huang, Chen & Peng ^a (22)	8M Age: 23.6 ± 2.5 yrs Weight: 70.6 ± 3.9 kg Height: 1.79 ± 3.9 m	0 kg 2 kg 4 kg 6 kg 8 kg 10 kg 12 kg	2.67 ± 0.13 m 2.79 ± 0.19 m ↑ Average 12 cm ↑	5.6 kg (8 % BM)	Not reported

Table 1 continued

Lenoir, de Clercq & Laporte (27)	4 M Age: 20.0 ± 1.4 yrs Weight: 79.2 ± 12.0 kg Height: 1.86 ± 0.06 m	0 kg 4.6 kg	13.88 ± 0.70 m 14.64 ± 0.76 m ↑ (x5 consecutive jumps)	Not reported	p=0.001
Tang & Huang (36)	8 M	0kg 2-4kg 6-8kg 10-12kg	Landing distance ↑ with loading but no significant difference found between the four loads.	5.3 % BM	Not reported
Tang & Huang ^a (37)	14 M Weight: 73.07 ± 11.3 kg Height: 1.75 ± 6.2 m	0 kg 2-4 kg 6-8 kg 10-12 kg	2.68 m 2.78 m ↑ 2.82 m ↑ 2.70 m↑	6-8 kg	p<0.05
Papadopoulos et al. (35)	15(13 M, 2F) Age: 19.8 ± 0.8 yrs Weight: 67.69 ± 8.2 kg Height: 1.7 ± 7 m	0 kg 3 kg 6 kg	2.62 ± 0.21 m 2.69 ± 0.22 m ↑ 2.67 ± 0.27 m ↑	3 kg	p=0.006
Filush ^b (16)	4 M Age: 21.75 yrs Weight: 81.87 kg Height: 1.87 m	0 kg 4.6 kg	2.41 ± 0.06 m 2.50 ± 0.07 m ↑	Chosen load based on 6 % of BM.	p=0.004

M= male; F= female; BM= body mass; 2D= two dimensional; total load (TL)= total load of both hands combined; ↑= increased

^aConference paper

^bMaster's thesis

^cUniversity publication

jump distance was found between an unloaded jump and a jump with a handheld load of 7.2 kg. Minetti and Ardigo (32) showed increases in jump performance of 5 to 7 % using handheld load in the mass range of 2 to 9 kg. However, this study involved vertical jumping and therefore improvements in horizontal distance can only be estimated (at least 17 cm during a 3 m jump).

The optimal loading range where horizontal jump distance is maximised has also been investigated. The sequential increase of load in the designs of several studies has allowed this to be investigated (23, 35, 36). Common loading between studies consisted of no extra load, light load (2 to 4 kg), heavy load (6 to 8 kg) and super heavy load (10 to 12 kg) (22, 36, 37). Tang and Huang (36) found the optimal load to enhance jump distance was approximately 5 % of the participant's body mass. This was in accordance with Huang et al. (23) who found the optimal load to enhance jump distance was 6 % of the participant's body mass (approximately 4.24 kg). The loading range used by Filush (16) was based on 6 % of body mass as determined by Huang et al. (23). Jump distance in this study increased from 2.41 m (no loading) to 2.50 m ($P=0.004$), supporting 6 % of body mass loading has positive effects on performance (16). Despite Papadopoulos et al. (35) using slightly different loads (no load, 3 kg and 6 kg) compared to Tang and Huang (36) and Huang et al. (23), the results are consistently identifying an optimal load of 4 to 8 kg. A slightly higher optimal load of 8 % of body mass has also been identified in the literature (5, 22). Collectively, these findings indicate ~5 to 8 % of body mass is the optimal load for an enhanced jump distance of ~9 to 15 cm. It should be noted that the ~5 to 8% of body mass is a combined load for both hands. In other words, ~2.5 to 4 % of body mass for each hand could be considered optimum. Minetti and Ardigo (32) also observed a decline in performance when handheld load exceeded 10 to 12 kg. Similar findings suggest that jump performance is negatively impacted once load exceeds the optimum (5, 37).

Computer simulation studies have also shown that handheld load can increase jump performance (1, 32). Two computer simulations have been conducted with the use of a two-dimensional (2D) software model of a long jumper; one created from four body segments (32) and the other from seven body segments (1). The horizontal jump distance improved in both studies; however, the extent of improvements was not consistent. An improvement in performance of 39 cm was found by Ashby (1), compared to a smaller improvement of 17 cm found by Minetti and Ardigo (32). The reason for this finding is most likely due to the differences in jump methods between studies. Minetti and Ardigo (32) measured vertical jump distance, and Ashby (1) measured horizontal jump distance. Other reasons could involve the different number of body segments analysed when measuring the jumps and the different loads applied (0 to 20 kg and 4 to 12 kg, respectively). In addition, simulation results by Ashby (1) determined 8 kg to be the optimum load to enhance jump distance, which is slightly higher than the values produced by studies involving human participants (23, 35, 36). In comparison, optimal loads as determined by Minetti and Ardigo (32) were similar to those suggested by the studies involving human participants.

The Effect of Handheld Loading on Jump Kinematics

The ability to perform effectively in many sports, such as basketball and volleyball, requires a certain amount of horizontal momentum (mass x velocity) (34). Therefore, when investigating the effects of handheld load on horizontal jumping to determine jump performance, it may be useful to measure horizontal force, jump duration and ultimately horizontal impulse. These measures have been considered in previous studies utilising force plates (22, 23, 32, 35-37). The use of handheld load results in greater peak horizontal forces (22, 23, 32, 36, 37) with a strong, positive correlation found between jump performance and peak horizontal force ($r=0.85$; $p=0.007$) (35). Tang and Huang (37) found an increase in peak horizontal force from 736.5 N with no load, compared to 821.3 N with a heavy load. Increases in jump duration and horizontal impulse have also been reported with handheld loading (23). Huang et

al. (22) and Tang et al. (36) suggested the improvements in jump distance were most likely due to the increases in horizontal impulse.

Limitations of Previous Literature

All of the studies reviewed on the effects of handheld load on performance in the standing long jump have come from conference abstracts (1, 22, 23, 37), case-series designs (27, 32, 35, 36), a university publication (5) and a master's thesis (16). Currently there are no studies published in this area in an international peer-reviewed journal. Furthermore, these studies have included: low participant numbers, homogeneous participants, simulation studies, inadequate familiarization and limited reporting of reliability. Additionally all of the reviewed studies have used predominantly male participants. Therefore, further studies are needed involving female participants and addressing the methodological issues noted above.

Practical Applications

Although the evidence for the effectiveness of handheld load on jump performance is currently limited there are several possible practical applications. One application of handheld loading is as a coaching aid to help develop jumping technique. Arm swing has been shown to be a key contributor to vertical jump performance, and individuals do vary in their ability to utilise the arm swing action effectively to optimise jump performance. In this context, handheld loading allows the individual to focus and refine their arm swing technique, which is likely to improve their (unloaded) vertical and horizontal jump scores. In sports where vertical and standing long jump measures are employed for talent identification and selection (a notable example being the American National Football League combine), maximising an athlete's height or distance scores on the particular jump assessment is a goal in itself. A complex training approach might be adopted for this purpose, alternating handheld loaded jumps and unloaded jumps with arm swing. Indeed this

may help to reinforce technique whilst avoiding any potential disruption in timing for the unloaded jump movement.

Alternatively a handheld loading exercise may be employed solely as a potentiation exercise to increase neural drive and power output for another activity. In this manner, handheld loaded jumps might be performed prior to sets with heavy speed-strength training modes such as barbell jump squats and Olympic lifts. Similarly, handheld loaded jumps might be used as a primer for maximal acceleration efforts (e.g. sprint start), sprint bouts, or even throwing efforts.

The other major application of handheld loading is as a training tool (see Figure 2). Authors previously identified that a major limitation of the majority of conventional strength and power-oriented exercise modes is that they have a vertical bias, and as such there is a need for training modes that provide the development of horizontal ground reaction force production (17, 40). Mainly, the standard 'horizontal' speed-strength exercise options available to the practitioner involve only body weight resistance. For example, the 'horizontal' speed-strength training modes most commonly employed comprise (bodyweight) plyometric training exercises in a horizontal direction. Handheld loading offers a means to add external resistance for these horizontal speed-strength and plyometric exercises that involve arm swing.

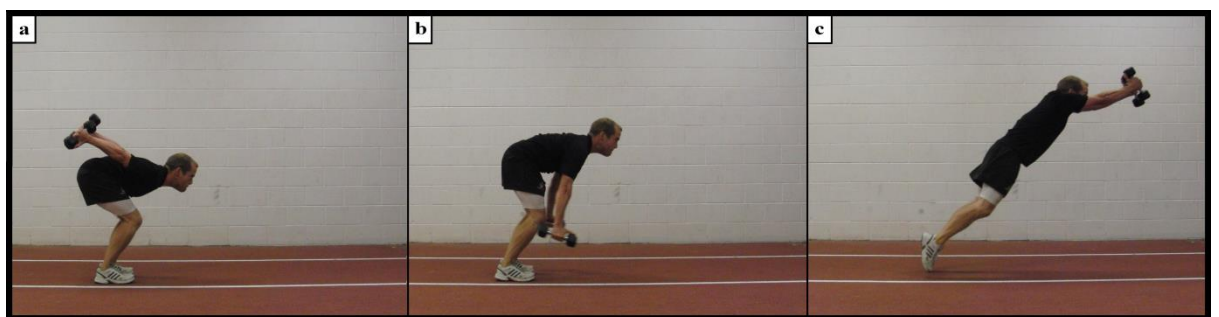


Figure 2. The standing long jump with handheld loading during initial propulsion (a), mid-propulsion (b) and toe-off (c).

From this viewpoint, in addition to single jump efforts with countermovement, handheld loading might also be considered for drop

jumps in vertical and horizontal directions. Similarly, handheld loading has been successfully employed with repeated jumps. Other possible applications include vertical jumps performed with a run up, with options for either single- or double-leg take-off.

Handheld loaded repeated jumps for height performed in a forwards direction similarly offer an alternative to jumps performed in series onto and off boxes or jumps over hurdles. Stair bounds with handheld loading is another option available to the practitioner. Stiff-legged bounds (performed with abbreviated arm swing) similarly offer a means to provide lower leg conditioning with augmented eccentric loading.

There are also a number of modifications and progressions available for handheld loading. These include single-leg variations for the various vertical and horizontal jump modes described. Single-leg single and repeated jumps with handheld loading might also offer a means to identifying and correcting differences in function and performance between limbs.

Conclusions

Despite methodological concerns highlighted in this paper, results found in the reviewed studies support the use of handheld loading to improve jump performance. Four main theories of arm motion were used to explain possible increases in jump performance with handheld loads. A five-fold jump was identified as being a likely explanation of the great feats of the ancient Greek long jump, in particular the recorded jump of Phayllos. Practical applications to implement the use of handheld loading involve eccentric pre-loading or potentiation exercises during training, and using handheld loading as an aid to help develop jump technique; all of which can be modified and progressed. Further, well designed, studies are needed to investigate the effects of handheld loading on jumping biomechanics and performance of female athletes. Furthermore, future studies should also focus on determining appropriate training protocols for performance enhancement.

CHAPTER 3

HANDHELD LOADING TO ENHANCE HORIZONTAL JUMP PERFORMANCE IN FEMALE NETBALL PLAYERS

Abstract

The purposes of this study were to determine the acute effects of handheld load on horizontal jump distance and biomechanics during a single standing horizontal jump in female netball players, and to determine individualised optimum loads relative to body mass (BM) for enhancing jump distance. Twelve netball players performed single, standing horizontal jumps while holding load in each hand. The loaded jumping conditions included: baseline (0 kilograms (kg)), 2 kg, 4 kg, 6 kg, 8 kg, and 10 kg. A significant increase in jump distance was found at the 4 kg load. Distance increased on average from 170.7 ± 15.3 cm to 176.7 ± 15.4 cm (Effect size [ES] = 0.39, $p=0.04$). The handheld loads of 4 kg and 10 kg resulted in significant increases in vertical and horizontal ground reaction forces (GRF) during the concentric phase only (ES=0.25-0.62 (4 kg) and 1.19-0.22 (10 kg)). The predicted optimal relative load to enhance jump distance was 6.4 ± 4.0 % BM, eliciting an increase in jump distance of 9.5 ± 6.8 cm (ES=0.61). In conclusion, handheld loading enhanced horizontal jump performance in female netball players, most likely through augmentation of concentric GRF. These findings could have implications for potential mechanisms involved in enhancing jump performance. Future research should consider investigating further biomechanical analysis with individualised handheld loading, and the chronic adaptations of training with handheld load in a variety of populations.

Introduction

Jumping events were a part of the Ancient Olympic Games, approximately 700 B.C. (1, 5). Pictographs illustrating ancient athletes

performing various long jumping manoeuvres, with handheld load, have been found on various artefacts, supporting investigations into the concept of loaded horizontal jumping. Athletes held a primitive form of a dumbbell, termed "halteres", made from stone or lead in each hand (32). The halteres ranged from two to nine kilograms (kg) and were designed to be easily held by the athletes (5). Such handheld loads may have been the earliest tool developed with the purpose to enhance human athletic performance (32).

Several published studies have shown an increase in jump distance with handheld load during a 5-fold or single jump approach (5, 16, 22, 27, 35, 37). The load where the greatest enhancement in jump distance is recorded has been reported in studies as the optimal load. An optimal load of ~5 to 9 % of body mass (BM) (i.e. % BM is a total load for both hand) has been reported to achieve an improved jump distance of ~9 to 15 cm (5, 9, 16, 22, 23, 35, 36). Previous studies have highlighted the influence of arm swing mechanics on jump motion suggesting the use of arm swing during a horizontal or vertical jump movement can significantly enhance jump performance (2, 3, 6, 11, 14-16, 19-21, 26, 38). Furthermore, when load is added to the hand, the effects of arm motion are possibly augmented to increase jump performance. However, it has also been shown that once the load exceeds the ideal range in handheld load, jump distance is negatively impacted (5, 9, 37).

In court sports such as volleyball, basketball and netball, athletes are required to have a strong vertical jump for successful performance. However, athletes also need to generate a certain amount of horizontal momentum to be able to achieve successful performance (34). To date, the existing literature has shown that performing horizontal jumps with handheld load improves jump performance; thus, based on the acute enhancement of jump distance with handheld load, when loaded horizontal jumping is repeatedly applied in training, muscular adaptations could occur due to the demands placed on the body (assisted jump-training method) (10). Sports that involve movements with strong horizontal components such as acceleration, short sprints and horizontal

jumping, could also benefit from this training exercise (28). As such, netball is one sport in particular that could benefit from this possible method of training (18). There is very limited research into netball performance and no studies have investigated the effects of handheld loading on horizontal jumping in the sport of netball. In game analysis of netball, the frequency of jump direction (vertical, horizontal and lateral) has been recorded, with an average of 173 horizontal, 134 vertical, and 109 lateral jumps found (25). Furthermore, mid-court players (centre, wing attack, wing defence, and goal attack) were most likely to perform forward, or horizontal jumps compared to end-court (goal shoot, goal keep, and goal defence) players who most frequently jumped vertically (25). Therefore, training with handheld loads in netball could have positive impacts on performance due to muscular adaptations resulting in enhanced horizontal force production.

When the stretch-shorten cycle (SSC) is applied during a ballistic movement the level of concentric muscle action is greater than that achieved by a concentric-only contraction (i.e. without SSC) (8, 29). Thus, movements involving a SSC result in maximal muscular power. The SSC involves the sequential combination of eccentric and concentric muscle action (i.e. the activation, stretch, and immediate shortening of a muscle fibre); therefore, sport movements very rarely require the isolation of eccentric or concentric muscle action (8, 30). Concentric performance during SSC movements is heavily dependent on the conditions involved with the eccentric phase, such as rate and magnitude of stretch, and time of movement (7). By separating eccentric and concentric phases of a horizontal jump, the function of the SSC during the eccentric phase of a ballistic movement can be investigated further to determine whether or not changes in eccentric variables influence changes in concentric variables, resulting in enhanced performance.

Currently, only one study has been published in an international peer reviewed journal on this topic (9). Cronin et al. (9) reported handheld loads of 6 kg and 8 kg resulted in significant increases ($p < 0.05$) in jump distance, jump duration, and vertical and horizontal impulse in 16 male

participants. In addition, an optimum relative load for enhancing jump distance was found to be 9.2 ± 3.4 % BM. However, there have been no studies conducted involving women, and no studies that have separated the eccentric and concentric phases of a standing horizontal jump. Therefore, the purpose of this study was to determine the acute effects of handheld load on horizontal jump distance and biomechanics during a single standing horizontal jump in female netball players, and to determine individualised optimum loads relative body mass for enhancing jump distance.

Methods

Experimental Approach to the Problem

In order to investigate the possibility of improved jump performance with handheld load, and determine the optimal load where jump performance is improved in a single standing horizontal jump, 12 female netball players performed standing horizontal jumps while holding load in each hand. Olympic Weightlifting plates (Eleiko, Sweden) were used for handheld loading and the combined loads (i.e. total load for both hand) sequentially involved: baseline (0 kg), 2 kg, 4 kg, 6 kg, 8 kg, and 10 kg. Combined loads were achieved by holding the following plates per hand: 1 kg, 2 kg, 2x 1.5 kg, 2x 2 kg, and 5 kg. All participants jumped off a force plate and jump distance was measured for each loading condition. To determine the optimum load where jump distance was maximised, the relative handheld load (i.e. % BM) was determined for each loading condition of each participant. A fitted 5th order polynomial curve then identified the optimum handheld load and the maximum jump distance.

Participants

Twelve female netball players volunteered to participate in this study (mean age: 20.1 ± 1.8 years; mean height: 176.5 ± 5.5 cm; mean BM: 74.3 ± 8.6 kg). The players were classed as premiere representative players. The average playing experience within the sample was 10.8 ± 3.0 years and playing positions were as follows: five shooter, three mid-court, four defence. All players were free from injury. Written

consent was gained prior to data collection. All procedures carried out in this study were approved by the University ethics committee.

Procedures

All participants were required to attend two familiarisation sessions prior to one formal testing session. Both familiarisation sessions lasted approximately 15 minutes and were five days apart. The jump technique, to be performed during the subsequent testing, was explained and demonstrated to all participants in the first familiarisation session. Participants were instructed to start standing with their feet approximately hip-width apart. Movement was initiated by swinging both arms up above the head. This movement was followed by swinging the arms backwards and down ending behind the body, as the knees simultaneously flexed during the countermovement. Participants were then instructed to swing the arms forward and upwards "to head height" while jumping, keeping their head facing forwards at all times (Figure 3). The participants were further instructed to "jump as far as possible", implying a maximal effort jump. When holding load it needed to feel as if "the weights are pulling your body forwards". Participants were asked to practice this movement prior to the second familiarisation session. In the second session, the jump demonstration and instruction was repeated for the participants who were then required to complete a series of maximum-effort jumps employing this technique. Three jumps at each of the following load conditions: 0 kg, 3 kg and 5 kg (total load), were performed. Instruction and feedback were given throughout this session.

Demographic information (i.e. height, weight, playing years) was collected prior to the testing session. A generalised netball warm up, consisting of jogging, fast dynamic movement (e.g. fast feet, high knees, high skips) and dynamic stretches (lunges, squats, calf pulses) was self-directed by each participant and completed in the lab before testing commenced. Each participant then completed three jumps at each of the following loads: Baseline (0 kg), 2 kg, 4 kg, 6 kg, 8 kg, 10 kg (total). Olympic Weightlifting plates (Eleiko, Sweden) were held for loading at each of the specified loads. Absolute mass, and not percentage of body

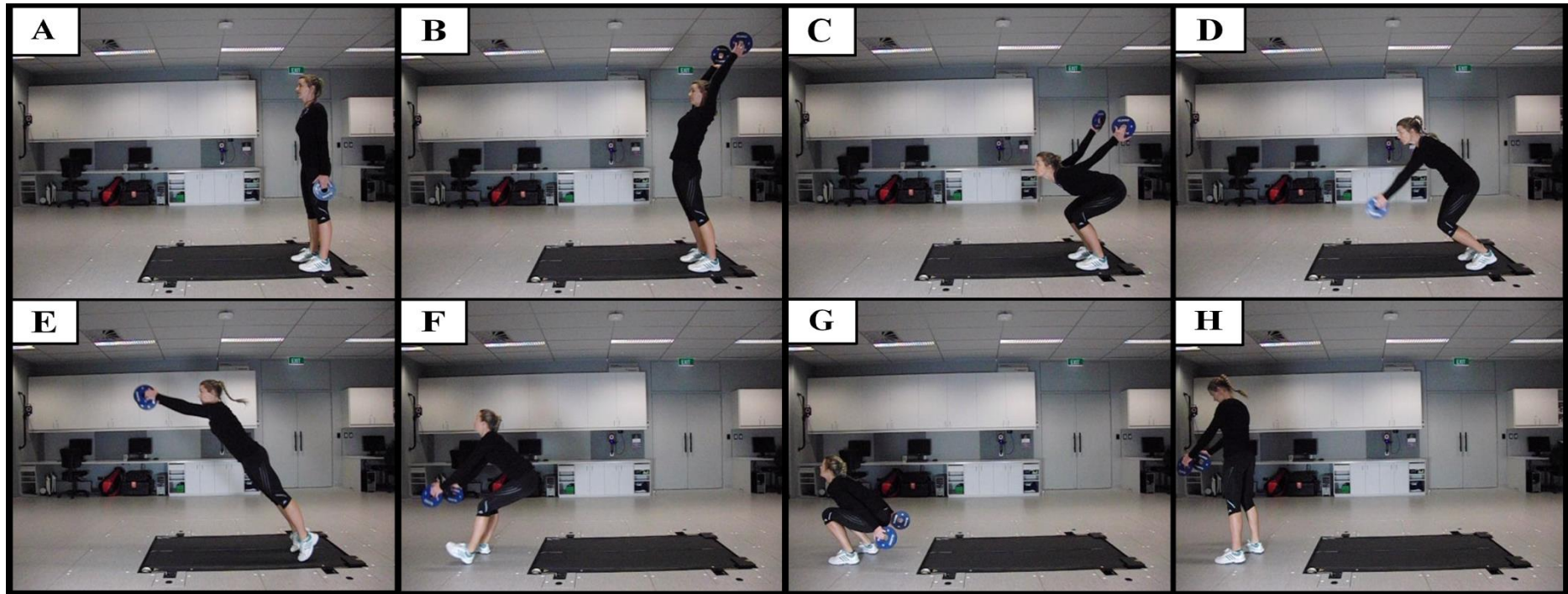


Figure 3. The horizontal jump with handheld load at the start position (A), initial arm-swing phase (B), initial propulsion phase, (C) mid-propulsion phase (D), take-off (E), heel contact (F), landing (G) and end position (H).

mass, was adopted for handheld load prescription in this study due to the limitations and availability of plate loads. The Olympic Weightlifting plates were only available in 0.5 kg increments from 0.5 kg to 2.5 kg, and 5.0 kg increments from 5 kg. Plates, and not dumbbells, were used for an even load distribution and to allow an open grip with the two middle fingers taking the load through the centre hole of the plate; thus reducing tension in the forearms, thought to possibly effect arm swing during pilot testing. Conditions increased sequentially and participants had approximately three to four minutes between each condition. The order of the loaded conditions was not randomised as pilot testing indicated that performing horizontal jumps with handheld load prior to unloaded horizontal jumping could affect the movement pattern of jumping with no handheld load and make the horizontal jump movement unnatural for some participants.

All participants jumped from a still standing, bilateral position off on an instrumented dual belt Bertec treadmill (Model AM6501, Bertec Corp., Columbus, OH, USA). To act as a force plate the treadmill belts were locked, enabling stability under each foot for jumping. Jumps were performed from one side of the treadmill only (left), thus a single reading from the left force plate was used for data analysis. Participants employed the jump technique instructed during the familiarisation session for each of the loading conditions. Vertical and anterior-posterior (i.e. horizontal) ground reaction force (GRF) data was collected from the force plate at a sampling rate of 1000 Hz. A custom designed Labview (National Instruments, Austin, Texas, USA) analysis programme was used to calculate the variables of interest. The initiation of the horizontal jump movement, as shown in Figure 4, was set at the point where the vertical GRF-time curve dropped below the value of one body weight. The point when the vertical GRF-time curve dropped to zero newtons (N), also known as the instant of take-off, defined the end of the jump. All variables of interest from the vertical and horizontal GRF-time curves were recorded between these two time points, termed the ground contact time (30, 31).

In order to separate the eccentric and concentric phases a similar method to that previously used by Meylan et al. (30) was applied. Acceleration-time curves were obtained after dividing vertical GRF by total mass (i.e. body mass of each participant and mass of external loading) at each time point, and then subtracting the acceleration due to gravity. Then, the acceleration-time curve was numerically integrated using the Simpson method to calculate vertical velocity and displacement of the centre of mass (CM) (13, 30). The eccentric and concentric phases were analysed separately, as shown in Figure 4. The start of the concentric phase was identified as the point when velocity of the CM became positive, corresponding to the minimum height of the CM (i.e. bottom position of displacement) (30, 31). Peak and mean GRF, impulse and jump duration (i.e. ground contact time) were calculated for both phases in the vertical and horizontal directions.

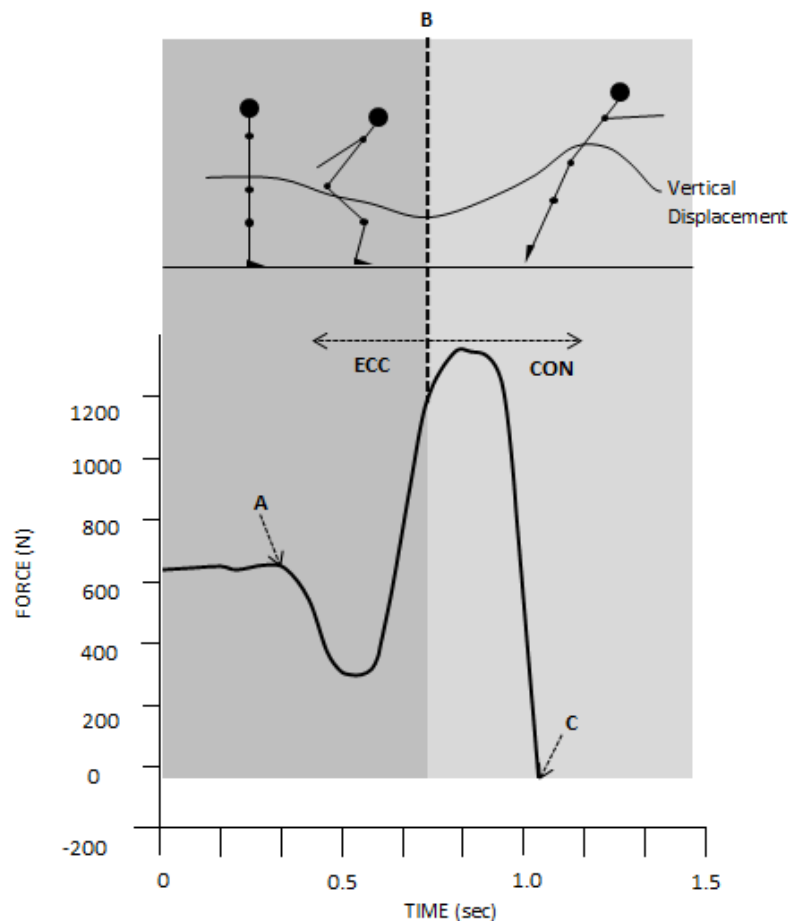


Figure 4. Force-time curve of the horizontal jump during the entire jump sequence of a 70kg participant. A) Start of the countermovement (eccentric phase), B) CM at bottom position, and C) take-off.

As with the take-off, jump landing was bilateral and participants were required to stick their landing enabling the distance to be accurately measured by a measuring tape along the floor. If they fell or stepped (forwards or backwards) the jump was regarded as a “no-jump”, and the jump was repeated until three successful jumps were recorded. Jump distance was measured to the nearest 0.01m between the distal aspect of the great toe at take-off and the heel of the back foot at landing. The plates were kept held in the hands at all times throughout the jump sequence. Additional instruction was provided to the participants during testing when necessary.

To determine the optimum load (relative to BM) for each individual, a 5th order polynomial was applied to the data. Each absolute load of baseline (0kg), 2, 4, 6, 8, and 10 kg was converted to a load relative to BM. The polynomial was then fitted to each participant’s relative handheld load and jump distance. Maximum jump distance was identified from the curve, once the optimum load was determined. The mean of three jumps was used as the final value for each variable.

Statistical Analyses

Means and standard deviations were used to determine measures of centrality and spread of the data. A repeated-measure Analysis of Variance (ANOVA), using SPSS software (Version 20.0 for Windows, SPSS Inc., Chicago IL, USA), was used to compare the dependent variables between each loading condition (baseline, 2 kg, 4 kg, 6 kg, 8 kg and 10 kg). Where necessary, comparisons of the sample’s means were performed using a Fisher’s Least Significant Difference (LSD) post hoc analysis to determine pairwise differences. Statistical significance was accepted at $p < 0.05$. Interpretations of the extent of change in results, expressed as an effect size (ES) was also calculated. The scale of ES’s used in this study was based on Cohen’s ES and was interpreted based on the following: $ES < 0.2$ (trivial), $0.2 < 0.6$ (small), $0.6 < 1.2$ (moderate) and $ES > 1.2$ (large) (12).

Results

As shown in Table 2, horizontal jump distance increased with a handheld load of 4 kg ($ES=0.39$, $p=0.04$). Concentric vertical peak force increased at each load from baseline ($ES=0.25-1.19$, $p<0.05$); however, eccentric vertical peak force only showed a remarkable increase at 10 kg ($ES=0.79$, $p<0.05$). Similar findings were found for vertical mean force. Concentric vertical mean force increased at each load from baseline ($ES=0.50-0.92$, $p<0.05$), except for 2 kg load, compared to eccentric vertical mean force which only showed an increase at 10 kg ($ES=0.83$, $p<0.05$).

An increase was found between eccentric horizontal peak force at 10 kg, compared to baseline ($ES=0.71$, $p<0.05$). Notable increases were also found in concentric horizontal mean force between baseline and both 4 kg ($ES=0.52$, $p<0.05$) and 10 kg loads ($ES=0.61$, $p<0.05$). A similar increase was found in eccentric horizontal mean force at 10kg ($ES=0.61$, $p<0.05$).

The individual optimal loads of each participant can be seen in Table 3. When load was made relative to body mass, the average optimal load was found to be 6.4 ± 4.0 % BM (i.e. 3.2 ± 2.0 % BM per hand). This load significantly increased jump distance by 9.5 ± 6.8 cm ($ES=0.61$). The greatest individual increase was 18.7 cm with an optimal load of 11.7 % BM ($ES=3.58$). One out of the 12 participants did not increase jump distance with handheld load.

Table 2. Standing horizontal jump performance and biomechanics with increasing handheld load (total load)

	Baseline	2 kg	4 kg	6 kg	8 kg	10 kg
Jump distance (cm)	170.7 ±15.3	174.5 ±16.4	176.7 ±15.4*	172.7 ±17.6	171.3 ±16.7	171.5 ±16.1
F _V Peak CON (N)	1476.7 ±153.1	1512.8 ±132.4*	1565.4 ±132.0*	1587.8 ±134.5*	1606.6 ±131.4*	1652.4 ±141.2*
F _V Peak ECC (N)	1169.0 ±189.0	1152.2 ±200.8	1213.1 ±265.5	1271.1 ±239.2	1291.4 ±269.2	1349.7 ±266.3*
F _V Mean CON (N)	1257.9 ±153.5	1299.7 ±138.9	1334.7 ±154.0*	1361.8 ±167.6*	1365.3 ±169.0*	1409.0 ±175.1*
F _V Mean ECC (N)	966.5 ±131.2	954.6 ±132.6	984.6 ±142.9	1014.0 ±114.0	1039.9 ±146.3	1079.7 ±140.2*
F _H Peak CON (N)	590.8 ±69.7	599.6 ±72.2	610.9 ±92.3	607.4 ±98.0	590.7 ±95.9	611.3 ±116.4
F _H Peak ECC (N)	273.5 ±88.2	288.7 ±88.1	314.3 ±94.5	321.9 ±111.3	324.0 ±116.6	348.4 ±121.9*
F _H Mean CON (N)	425.8 ±89.1	449.1 ±81.1	471.5 ±88.2*	477.6 ±104.6	467.3 ±109.5	490.8 ±125.7*
F _H Mean ECC (N)	199.3 ±82.1	215.6 ±78.0	220.4 ±76.6	234.5 ±84.1	238.0 ±92.6	249.0 ±82.1*
Impulse _V CON (N.s)	360.0 ±105.8	353.7 ±81.2	350.4 ±92.0	346.7 ±108.2	361.0 ±149.9	358.4 ±161.0
Impulse _V ECC (N.s)	194.5 ±85.2	165.6 ±58.8	207.0 ±85.2	211.1 ±104.8	215.6 ±101.0	228.7 ±84.3
Impulse _H CON (N.s)	116.8 ±19.1	118.6 ±19.6	119.3 ±20.7	117.1 ±24.8	116.4 ±28.9	114.2 ±27.8
Impulse _H ECC (N.s)	33.6 ±11.7	33.0 ±10.0	40.5 ±11.2	43.3 ±17.7	45.5 ±23.4	49.8 ±25.0
Duration CON (ms)	301.7 ±133.0	283.3 ±89.3	274.1 ±96.5	266.4 ±109.5	279.2 ±154.9	273.1 ±164.0
Duration ECC (ms)	206.0 ±97.3	173.1 ±66.0	213.9 ±97.3	205.8 ±103.3	202.6 ±88.9	206.2 ±67.0

Values are means ±standard deviation

*Significantly different from Baseline (p<0.05)

F= force; H= horizontal; V= vertical; cm=centimetres; N= newtons ; s= seconds; ms=milliseconds, CON=concentric muscle action, ECC=eccentric muscle action

Table 3. Individual results for jump distance with optimum hand held loading relative to body mass.

Participant Number	Optimal Load Total (% BM)	Maximum (max) Jump Distance (cm)	Baseline (BL) Jump Distance (cm)	Absolute Difference (Max-BL) (cm)
1	11.9	183.0	169.0	14.0
2	1.9	162.5	161.1	1.4
3	0.0	172.3	172.3	0.0
4	4.8	170.9	164.3	6.6
5	4.0	171.8	161.9	9.9
6	11.7	172.0	153.3	18.7
7	5.2	163.5	147.3	16.2
8	3.2	191.3	188.6	2.7
9	6.6	196.5	180.3	16.2
10	8.1	214.6	203.6	11.0
11	12.1	189.1	173.7	15.4
12	7.3	174.5	173.1	1.4

Discussion

This was the first study, to our knowledge, to investigate the effects of handheld load on horizontal jump performance in female netball players to determine an optimal load for jump enhancement. Additionally, we have reported GRF's in separate concentric and eccentric phases. The main findings were: 1) significant improvements in jump distance with a handheld load of 4 kg, 2) concentric, but not eccentric, GRF's significantly increased with handheld loading, and 3) the average optimum load (i.e. both hands combined) for enhancing jump distance was 6.4 ± 4.0 % BM (i.e. 3.2 ± 2.0 % BM per hand) for an increased distance of 9.5 ± 6.8 cm. These findings suggest Ancient athletes were likely to have exploited the fundamentals of handheld load to increase jump performance. Previous studies have shown that the use of arm motion (i.e. arm swing), during a vertical or horizontal jump movement, improves jump distance by optimising the position of the body at take-off and increasing take-off velocity (2, 3, 6, 11, 14-16, 19-21, 26, 38). Thus, with the addition of load in the hand, the effect of arm motion is possibly amplified to augment jump performance.

Handheld load was shown to significantly increase jump distance in a standing horizontal jump ($ES=0.39$, $p<0.05$). A handheld load of 4 kg (total load) produced an increase in jump distance from baseline (170.7 ± 15.3 cm to 176.7 ± 15.4 cm, respectively). A similar increase of 6 cm in jump distance was found by Huang et al. (23) with a 2 to 4 kg handheld load; however participants in this study were all male athletes. Another study by Huang et al. (22), involving eight male sprint runners, found a 12 cm increase in jump distance. Although the level of sprint competition of the participants was not reported, a doubled increase in jump distance may indicate that the sample of sprinters had greater development in horizontal force production capability due to the horizontal characteristics of sprinting. Therefore, this may provide support towards the concept of loaded horizontal jumping as a training method to improve horizontal force capabilities in court sports. Similar increases in jump distance with 3 kg and 6 kg total handheld loads were found by Papadopoulos et al. (35). Total jump distance was found to increase by 7 cm and 5 cm, respectively. Participants in this study were thirteen males and two females, however the results were not analysed by gender and therefore it is difficult to compare the results of the female participants to those in the present study. Furthermore, a 9 cm increase in horizontal jump distance with a 4.6 kg load (4 male participants) was reported by Filush (16).

Standing jump performance has been shown to increase to a greater extent with handheld load in other studies (5, 22, 37). Butcher and Bertram (5) reported increases of 16 cm and 25 cm in jump distance with handheld loads of 7.2 kg and 4.6 kg in a study with involving one male and one female. The female participant was lighter (57.3 kg) than the average netball player in the present study (74.3 kg), but no other information was provided to be able to compare results to account for the large difference in results (10 cm difference). Simulation studies have reported much larger increases in jump distance with handheld load compared to no handheld load (1, 32). However, as results are based on computer simulations and not human participants, it is difficult to draw comparisons and conclusions. Despite the many methodological

limitations in current research, findings of this study are in agreement with the literature supporting a handheld load of ~3-8 kg for increasing horizontal jump distance.

An optimal load, where the greatest enhancement of jump distance can be observed, was also identified in this study. Body mass was recorded to enable the reporting of relative loading. The optimal total load found in this study was 6.4 ± 4.0 % BM. Previous studies have reported relative loading or optimal load in the range of ~5-9 % BM (5, 22, 23). An optimal load of 6.25 % BM was reported by Huang et al. (23), and Butcher and Bertram (5) and Huang et al. (22) both reported improvements in jump distance of 6 cm to 25 cm when handheld load was 8 % BM. A slightly higher optimal load of 9.2 % BM, reported by Cronin et al. (9), was found to significantly enhance jump distance by 13.4 cm. However, Table 3 shows a large variance between individual participants and their optimal load. Thus, the implication for training highlights the importance of individualised loads in comparison to using a mean relative load for athletes.

Vertical peak concentric force increased significantly in all loading conditions compared to baseline. In addition, vertical mean concentric force and horizontal mean concentric force both increased significantly at 4 kg and 10 kg conditions. As previously mentioned, arm swing mechanics during a jump movement can significantly improve jump performance (2, 3, 6, 11, 14-16, 19-21, 26, 38). In this instance, the "pull theory" could explain the increase in concentric force production in both the vertical and horizontal GRF's. The pull theory involves the transfer of energy created by the muscles at the shoulder joint to the rest of the body during the propulsive phase of a jump (2). During the end of the propulsive phase of the jump, as the body is preparing for take-off, the arms start to decelerate causing the torque at the shoulder joint to pull the trunk forward (in a horizontal jump) (6). This mechanism causes energy to be transferred from the arms to the rest of the system during the concentric phase of the jump (2, 6, 26). Thus, with increased load at the hands, more work is created at the shoulder joint to enable

the movement of greater load leading to an increase in concentric force production at take-off. Studies reporting on the pull theory have shown work created at the shoulder joint contributed to approximately 33 % of performance enhancement (11, 26). A simulation study by Cheng et al. (6) reported shoulder joint work was responsible for approximately half (52 %) of additional energy caused by arm motion. However, these studies did not analyse concentric GRF's with the use of arm motion.

In addition to the pull theory, an increase in concentric force may be explained by the joint torque augmentation theory. Joint torque augmentation improves jump performance and may explain the significant increase in concentric force production at 4 kg where jump distance is significantly increased (6, 11, 14, 15, 20). Similar to the "pull" mechanism, swinging the arms during the early propulsive phase of a jump generates a downward force at the shoulder which is transferred to the trunk and the rest of the body (2). This downward force slows the shortening of the major lower body muscles when they are in an optimum position to produce force (15). Additionally, a decrease in shortening velocity allows the relevant muscles to produce more force according to the force-velocity relationship (2, 11, 20). A decrease in torques at the hips, knees and ankles during the early propulsive phase of a jump has been shown in previous studies (14, 20). Hip joint torque was found to considerably increase by 47 % by Cheng et al. (6) when arm swing was used during jumping compared to without. However, joint torque augmentation only occurred at the hips and not at the knees and ankles. As a direct result of hip joint torque augmentation, GRF's were found to increase in the end-stage of the propulsive phase of a jump (6, 21).

Measuring both eccentric and concentric GRF's allowed for a further in-depth analysis into the mechanics of the horizontal jump and the effects of handheld load on horizontal jumping. Results showed vertical peak concentric force, vertical mean concentric force, and horizontal mean concentric force increased significantly. However, even though concentric forces significantly increased, there were no accompanying significant

increases in eccentric GRF's. An influence of eccentric muscle activity (i.e. stretch-shorten cycle) on subsequent concentric force production during jumping has been shown in previous studies (8, 29). While previous research has reported the eccentric phase of a jump enhances jump performance from 10 to 15 % (30), findings in this study indicate less of a relationship between the two (i.e. an increase in concentric force does not require an increase in eccentric force) to increase jump distance. Inconsistencies between the results of the current study and previous research could be explained by the differences in jump methods (4, 39). The contributions and resultant effects of the SSC on jump performance could vary between horizontal and vertical jumps (e.g. squat jump for vertical height versus broad jump for horizontal distance).

It has been suggested that sports involving movements which require a longer time to produce force may benefit from loaded horizontal jump training (9). Cronin et al. (9) found both vertical ($ES=0.69-1.22$) and horizontal ($ES=0.70-0.88$) impulse, and jump duration ($ES=1.22-1.83$) increased significantly in all loading conditions; resulting in increased jump distance. As impulse is the product of force and time, it was proposed that increases in impulse and jump duration were the main influential factors in the enhancement of jump performance. Physical movements benefiting from the application of this concept during training are movements which require force production over a longer duration of time (~ 500 ms); such as a change-of-direction, or a standing broad jump. In comparison, movements requiring a shorter duration of force production (<150 ms) may be negatively affected by this method of training (9). Netball involves many movements requiring the production of force over relatively long durations. For example, horizontal jumping has been highlighted as an essential movement in a game of netball (25) as well as being a movement requiring a longer duration of force production (~ 500 ms) (9). However, this paper did not find increases in jump duration or impulse to be statistically significant at any loading condition. This may be due to differences between the participants of the two studies. The study by Cronin et al. (9) involved all male athletic participants, compared to the all-female netball group in the present

study. Differences between male and female participants could include technical and physical capabilities during jumping. Netball players likely have different jump techniques due to training backgrounds, and less upper body strength to utilise handheld load. These differences could also help to explain why the netball players had a lower optimum load for enhancing jump distance ($\sim 6.4\%$ BM vs. $\sim 9.2\%$ BM) in comparison with the male participants in Cronin et al. (9).

Practical Applications

Effective training programmes for performance enhancement are directed by the sporting demands. As previously stated, horizontal or forward jumping alone is a dominant movement in mid-court, netball players. In addition, movement producing horizontal forces for acceleration and short sprints is essential to be able to achieve successful performance. Therefore, as an acute enhancement in horizontal jump performance was achieved with handheld loading, training benefits could occur with handheld load used as a training method. The transference of benefits could prepare players for the specific demands of the sport and in particular their position in that sport. Training prescription can be individually focused by identifying and applying an optimal handheld load in horizontal jumping. The effect of handheld load in horizontal jumping, and its' alterations to arm swing, is highly applicable to strength and conditioners, specialist trainers, and athletes. Future research should consider investigating further biomechanical analysis with individualised handheld loading, and ultimately the chronic adaptations of training, including training prescription.

CHAPTER 4

INFLUENCE OF OPTIMAL HANDHELD LOAD ON JUMP PERFORMANCE AND THE TECHNICAL ABILITY TO PRODUCE FORCE IN FEMALE NETBALL PLAYERS

Abstract

Handheld load has previously been shown to enhance horizontal jump performance. The purpose of this study was to investigate the effects of individualised optimal handheld load on jumping performance and the technical ability to produce force during a single horizontal jump. Maximal effort, single standing, horizontal jumps were performed by 13 netball players. Participants performed the jumps under two loaded conditions: 1) unloaded, and 2) with optimal load in each hand. The optimum load for each athlete was determined in Chapter 3. Jump distance increased from 188.2 ± 16.1 cm to 196.4 ± 13.6 cm. ($p < 0.01$; Effect size [ES]=0.55) with handheld load. Concentric vertical and horizontal ground reaction forces were also found to increase ($p < 0.05$; ES=0.23-0.79) in loaded conditions, as did resultant force (ES=0.69). The ratio of horizontal force to resultant force increased (ES=0.55, $p < 0.05$), suggesting the technical ability to apply force in the correct direction of intended movement, is of equal importance to the magnitude of force applied per se. In regards to joint kinematics, an increase was found in lower body joint angles with handheld load at the ankle, during the static phase of a jump (ES=0.39), and the hip, during the take-off phase (ES=0.48), in the sagittal plane. In conclusion, individualised optimal handheld loading improved single horizontal jump performance in this population of athletes, most likely through increased concentric forces and the technical ability of force application. Therefore, findings, based on the acute improvement of jump distance with handheld load, could have practical implications for the strength and conditioning coach, trainer and athlete. Future research should consider investigating the

chronic adaptations of training with handheld loads in a variety of athletic populations.

Introduction

Horizontal force production in many sports is necessary to achieve successful performance (31, 34). Athletic movements that require substantial horizontal components include, but are not limited to, acceleration, short sprints, and horizontal jumping (28). In addition to various long jump events, court sports such as volleyball, basketball, and netball could benefit from training focused on the improvement of horizontal force production. Previously, handheld load has been shown to significantly improve jump distance, as well as ground reaction forces (GRF) when performing a horizontal jump (see Chapter 3). Several researchers have suggested that performing horizontal jumps with handheld load enhances jump performance (5, 9, 23, 35-37). Thus, horizontal jump training with handheld load could have practical implications for the strength and conditioning coach, trainer and athlete. Based on the acute improvement of jump distance with handheld load, it is possible that repeated horizontal jumping with handheld load during training could result in muscular adaptations and improved force application capability, due to the loading demands placed on the body. Therefore, loaded horizontal jumping could be applied as an assisted jump-training method to improve sports performance.

Arm motion (i.e. arm swing) during a horizontal jump could provide an explanation for the improvements in jump performance and force production with handheld load. The ability to use arm motion during a vertical or horizontal jump has been shown to optimise the position of the body during a jump sequence, consequently improving jump performance (2, 3, 6, 11, 14-16, 19-21, 26, 38). Furthermore, when load is added to the hands during a jump, it is possible that arm motion is augmented to further increase jump distance. Four main theories have been proposed to explain the influence of arm motion during jumping: 1) pull theory, 2) hold back theory, 3) joint augmentation theory, and 4)

take-off theory. The pull theory involves the transference of energy generated at the shoulders and arms to the rest of the body "pulling" the body forward during a horizontal jump (2, 6, 11, 26). Without the ability to swing the arms during a horizontal jump, the jumper must decrease extension of the lower limbs, or "hold back", during the propulsive phase. By doing so the jumper overcomes excessive forward rotation that would otherwise prevent correct landing of the jump (2, 3). The third theory involves decreased torques at the hips, knees and ankles during the early propulsive phase of a jump, which augment in the latter phase of propulsion (14). A downward force from the shoulders through to the trunk during the propulsive phase of a jump slows the shortening velocity of the muscles of the lower body enabling them to produce greater force while in a more optimum position (2, 11, 15, 20). The fourth theory, involving the projectile angle of the body at take-off (TO), has been suggested to increase horizontal jump performance (19, 38). In a sample of long jumpers, the optimal TO angle was determined to be 19-27° (38). As the projection velocity is known to decrease as the projection angle increases in long jumpers, the expected optimum angle for projectile motion of 45° is not optimal (38). Therefore, techniques that could increase the projection angle at TO (above 19-27°) while maintaining TO velocity could be useful.

The observed increases in jump distance with the use of arm motion and optimal handheld load raises the question of whether jump enhancement is caused by the technical ability of an individual to apply force (i.e. jump technique of an individual) or the physical capability of an individual (i.e. the maximum force applied) when elicited by load. The technical ability of force production, or specifically, applying greater horizontal orientation of force onto the supporting ground during the acceleration phase of a sprint, has been shown to be more important than the total amount of force produced (24, 33). During a horizontal jump the acceleration of mass requires the production of horizontal force; however despite the forward movement of the body, force is produced largely in a vertical direction due to gravitational constraints. Though the vertical component is necessary to overcome the acceleration due to gravity, only the

horizontal component of total force is directed forward (33). Therefore, the effectiveness of force application could be defined as the ratio of horizontal force application (RF) to the total force applied to the ground (resultant force). In other terms this could be referred to as the jumpers' force application technique. The concept of RF can be applied to a horizontal jump, quantitatively measuring the jumpers force application technique and their ability to apply force in a more optimal direction.

An optimal load, where the greatest enhancement in jump performance is observed, has been found in numerous studies (5, 9, 16, 22, 23, 35, 36). Current research has found combined optimal handheld loads of ~5 to 9 % of body mass (BM) result in increases in jump distance of ~9 to 15 cm (5, 9, 16, 22, 23, 35, 36). However, these values of optimal load are generalised and based on mean or average values of the sample population; therefore, to our knowledge, there is currently no research investigating individualised handheld loads on horizontal jumping performance. A previous study found an average optimal total load of 6.4 ± 4.0 % BM in a group of 12 netball players; though substantial differences in optimal load results between individual participants were highlighted (see Chapter 3). When individual optimal loads were analysed separately in this study they varied greatly from the average value of the group ranging from 1.9 to 12.1 % BM, with increases in jump distance from 1.4 to 18.7 cm.

Therefore, the purposes of this study were to investigate the effects of individualised optimal handheld load on: 1) single horizontal jump performance in female netball players, 2) the ratio of forces to determine the technical ability of force production, and 3) mechanisms involved in enhanced jump performance.

Methods

Experimental Approach to the Problem

To examine the effects of individualised optimal handheld loads during a horizontal jump, 13 female netball players performed standing single

horizontal jumps while holding a pre-determined, optimal load in each hand. Handheld loading was achieved with the use of Olympic Weightlifting plates (Eleiko, Sweden), and the optimal total loads (i.e. combined load for both hands), relative to body mass, ranged from 1 to 9 kilograms (kg) (1.9 to 12.1 % BM). All optimal loads were compared to baseline (0 kg) values. Plates comprised of 0.5 kg, 1 kg, 1.5 kg, 2 kg, and 2.5 kg, with the combination of relevant plates to construct the correct optimal loads for each participant. All participants jumped off a force plate, and three-dimensional (3D) analysis was used to measure joint angles of the lower body. Jump distance was measured in all jumps.

Participants

Thirteen female netball players volunteered to participate in this study (mean age: 20.6 ± 1.5 years; mean height: 177.0 ± 6.2 cm; mean BM: 75.6 ± 9.2 kg). The players were classed as premiere and/or representative players. The average playing experience within the sample was 11.2 ± 3.1 years, and playing positions were as follows: five shooter, three mid-court, five defence. All players were free from injury. Data collection occurred in-season with players participating in one to three netball games per week. Written consent was gained prior to data collection. All procedures carried out in this study were approved by the University ethics committee.

Procedures

All participants were familiarised with the required jump movement prior to the testing session. Repetitions of the single jump movement (without handheld load) were carried out on two separate occasions. Both sessions lasted 10 to 15 minutes and were seven days apart. Participants performed approximately 12 maximal effort single jumps during each session. Participants were asked to practice the jump in their own time following the last familiarisation session, before the formal testing session. Further familiarisation with optimal load was carried out prior to the commencement of testing in the lab after warm up.

With feet approximately hip-width apart, and head straight and forward, the jump movement was initiated by swinging both arms up above the head then backwards and down to end behind the body in preparation for TO. Once the knees reached peak flexion, the participants were instructed to “throw” their arms forward and upwards, to “approximately head height”, and jump as far forward as possible to achieve a maximal effort jump. When performing the jump with handheld load, the participants were again prompted to “throw the weight forward” for it to “feel as if the weight is pulling the body forward”. Participants were asked to apply maximal horizontal effort to each jump, reducing vertical movement.

Participants individually performed a self-directed, generalised netball warm up. Warm up involved jogging and a mixture of fast and slow dynamic movement (e.g. high knees, butt kicks, lunges, and squats) in the lab before testing commenced. Each participant then went through further familiarisation at 50 % effort with and without their prescribed optimal handheld load. The single jump technique instructed during the familiarisation sessions was employed for the loaded and unloaded jump conditions. Three baseline (0 kg) single jumps were performed, followed by three single jumps with optimal handheld load. Olympic Weightlifting plates (Eleiko, Sweden) were held for the optimal load conditions. Absolute mass was adopted for handheld load prescription in this study due to the limitations and availability of plate loads. The Olympic Weightlifting plates were available in only 0.5 kg increments from 0.5 kg to 2.5 kg, and 5.0 kg increments from 5 kg; therefore pre-determined optimal handheld load was rounded to the nearest 1.0 kg. For example, a participant with a body mass of 78 kg and a relative optimal handheld load of 11.9 % BM, had an optimal handheld load 9.28 kg, rounded to an absolute handheld load of 9 kg. Plates, and not dumbbells, were used for an even load distribution and to allow an open grip with the two middle fingers taking the load through the centre hole of the plate; thus reducing tension in the forearms, thought to possibly effect arm swing during pilot testing. Participants had approximately three minutes rest between each jump condition. The order of the loaded conditions was not

randomised as pilot testing indicated that performing horizontal jumps with handheld load prior to unloaded horizontal jumping could affect the movement pattern of jumping with no handheld load and make the horizontal jump movement unnatural for some participants.

All GRF variables were collected using an instrumented dual belt Bertec treadmill (Model AM6501, Bertec Corp., Columbus, OH, USA). The treadmill belts were locked, enabling the treadmill to act as a force plate, providing stability for participants to jump from a still standing, bilateral position. All single jumps were performed from the left belt of the treadmill, producing a single reading from the left force plate for data analysis. Vertical and anterior-posterior (i.e. horizontal) GRF data was collected from the force plate at a sampling rate of 1000 Hz. A custom designed Labview (National Instruments, Austin, Texas, USA) analysis programme was used to calculate the variables of interest. The initiation of the horizontal jump movement, as shown in Figure 5, was set at the point where the vertical GRF-time curve dropped below the value of one body weight. The point where the vertical GRF-time curve dropped to zero newtons (N), also known as the instant of TO, defined the end of the jump. All variables of interest from the vertical and horizontal GRF-time curves were recorded between these two time points, referred to as the ground contact time (30, 31).

In order to separate the eccentric and concentric phases a similar method to that previously used by Meylan et al. (30) was applied. Acceleration-time curves were obtained after dividing vertical GRF by total mass (i.e. body mass of each participant and mass of external loading) at each time point, and then subtracting the acceleration due to gravity. Then, the acceleration-time curve was numerically integrated using the Simpson method to calculate vertical velocity and displacement of the centre of mass (CM) (13, 30). The eccentric and concentric phases were analysed separately, as shown in Figure 5. The start of the concentric phase was identified as the point when velocity of the CM became positive, corresponding to the minimum height of the CM (i.e. bottom position of displacement) (30, 31). Peak and mean GRF, impulse

and jump duration (i.e. ground contact time) were calculated for both phases in the vertical and horizontal directions. The RF was calculated as the mean ratio of horizontal force to resultant force.

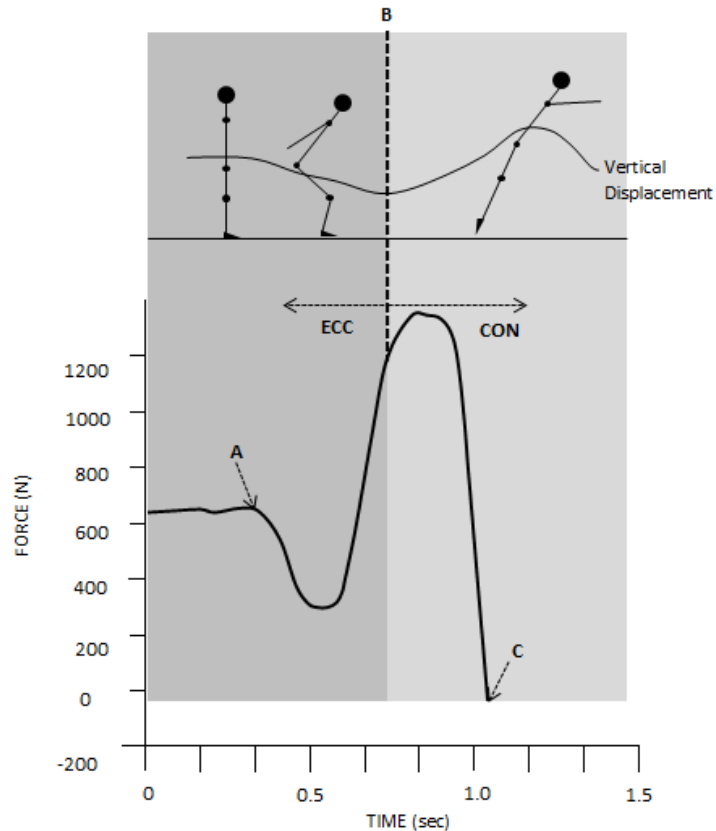


Figure 5. Force-time curve of the horizontal jump during the entire jump sequence of a 70kg participant. A) Start of the countermovement (eccentric phase), B) CM at bottom position, and C) take-off.

The landing of the jump was bilateral and it was necessary for participants to stick each jump landing to enable the researcher to manually measure the distance of each jump accurately with a measuring tape along the floor. Jumps were disregarded, or considered a “no-jump” if participants fell or stepped forwards or backwards. Testing continued until three successful jumps were recorded for each jump condition. Jump distance was measured to the nearest 0.01m between the distal aspect of the great toe at TO and the heel of the back foot at landing. The plates were kept held in the hands at all times throughout the jump sequences.

Joint angles of the lower body were analysed with the use of 3D software (Vicon Nexus 1.8.4, Vicon Motion Systems LTD., Oxford, UK). Joint angles included the hip, ankle, and knee joints. Reflective markers were placed on five locations of the body for 3D analysis: Acromiale, greater trochanter, lateral epicondyle of the femur, lateral malleolus, and the base of the fifth metatarsal. Placement of the reflective markers was carried out by a qualified International Society for the Advancement of Kinanthropometry (ISAK) Level 2 anthropometrist. Movement was captured through a nine-camera set-up and a 3D model was created by connecting the five joint markers in order, in the sagittal plane only (Figure 6). Joint angle analysis was obtained by collecting joint angles during either peak flexion or extension at the different phases of the jump: static, bottom (end of the eccentric phase), TO (triple extension of all three joints) and landing (Figure 6-A, B, C, D, respectively) for each trial. Actual joint angles were calculated from raw joint angle data (180° -Raw $^\circ$) as shown in Figure 7.

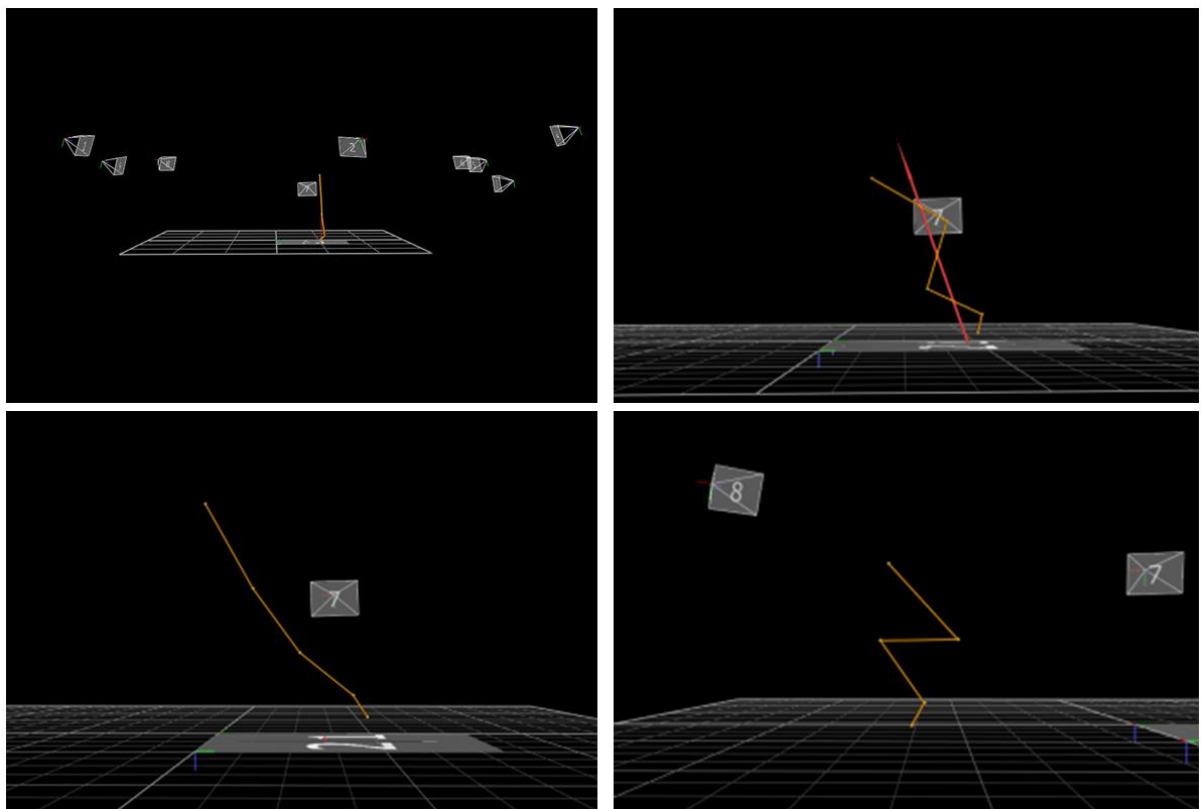


Figure 6. Set-up and phases of the jump sequence during 3D Analysis: A) Static position and visual of camera set-up, B) Bottom, C) Take-off, and D) Landing.

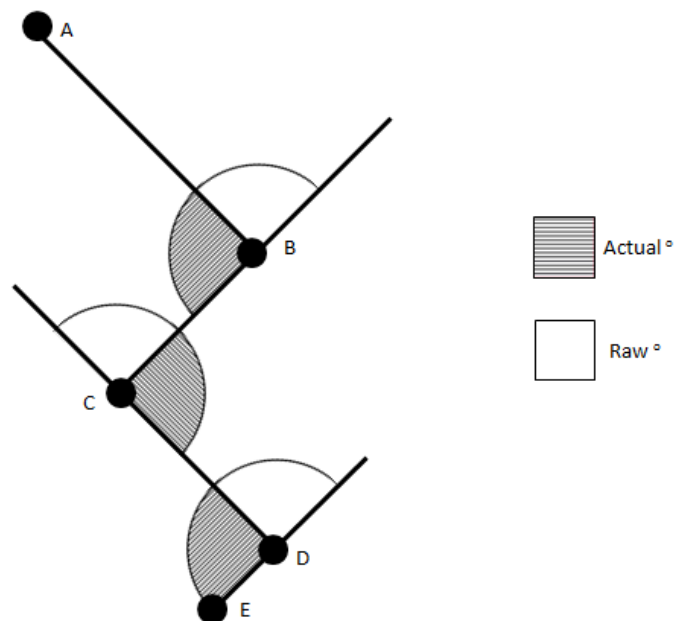


Figure 7. Actual and Raw joint angles of the hip, knee and ankle taken from A) acromiale, B) greater trochanter, C) lateral epicondyle, D) lateral malleolus, and E) the base of the fifth metatarsal

Statistical Analyses

Means and standard deviations were used to determine measures of centrality and spread of the data. A Paired Samples T-Test, using SPSS software (Version 20.0 for Windows, SPSS Inc., Chicago IL, USA), was used to compare the dependent variables between baseline and optimal loading conditions. Statistical significance was set at $p < 0.05$. Interpretations of the extent of change in results, expressed as an effect size (ES) was also calculated. The scale of ES's used in this study was based on Cohen's ES and was interpreted based on the following: $ES < 0.2$ (trivial), $0.2 < 0.6$ (small), $0.6 < 1.2$ (moderate) and $ES > 1.2$ (large) (12).

Results

As shown in Table 4, the average horizontal jump distance increased from 188.2 ± 16.1 cm to 196.4 ± 13.6 cm ($p = 0.00$; $ES = 0.55$) when performing a single horizontal jump with an individual optimal handheld load. Significant increases were found in vertical peak and vertical mean

concentric forces ($p=0.00$; $ES=0.43$ and $p=0.01$; $ES=0.72$, respectively). Horizontal peak and mean eccentric forces were found to increase with a moderate magnitude ($p=0.02$; $ES=0.93-1.03$), as was horizontal mean concentric force ($p=0.02$; $ES=0.79$). Additionally, RF was found to increase from 29.1 ± 3.5 cm to 31.3 ± 4.5 ($p=0.04$; $ES=0.55$).

Table 4. Single standing horizontal jump performance and biomechanics with optimal load

Jump Variable	Baseline	Optimal Load	Effect Size
Jump distance (cm)	188.2 \pm 16.1	196.4 \pm 13.6*	0.55
F _V Peak CON (N)	1551.1 \pm 205.5	1637.1 \pm 196.7*	0.43
F _V Peak ECC (N)	1204.5 \pm 217.8	1346.3 \pm 201.7	0.68
F _V Mean CON (N)	1310.3 \pm 150.7	1422.5 \pm 161.1*	0.72
F _V Mean ECC (N)	990.5 \pm 169.9	1045.9 \pm 110.7	0.39
F _H Peak CON (N)	650.9 \pm 87.0	670.2 \pm 82.9	0.23
F _H Peak ECC (N)	311.2 \pm 65.5	394.3 \pm 112.7*	0.93
F _H Mean CON (N)	484.4 \pm 52.6	545.4 \pm 100.9*	0.79
F _H Mean ECC (N)	211.3 \pm 46.8	276.0 \pm 78.7*	1.03
Impulse _V CON (N.s)	329.5 \pm 93.6	325.8 \pm 135.6	0.03
Impulse _V ECC (N.s)	219.7 \pm 113.9	206.4 \pm 106.1	0.12
Impulse _H CON (N.s)	123.8 \pm 29.7	118.4 \pm 29.6	0.18
Impulse _H ECC (N.s)	42.1 \pm 17.4	53.6 \pm 22.5	0.58
Duration CON (ms)	256.3 \pm 75.7	236.9 \pm 116.7	0.20
Duration ECC (ms)	223.8 \pm 123.6	198.0 \pm 103.6	0.23
Ratio of Force Application (%)	29.1 \pm 3.5	31.3 \pm 4.5*	0.55
Resultant Force	1202.6 \pm 146.8	1302.1 \pm 143.7*	0.69

Values are means \pm standard deviation

*Significantly different from baseline ($p<0.05$)

F=force; V=vertical; H= horizontal; cm=centimetres; N=newtons;

s=seconds; ms=milliseconds; CON=concentric muscle action;

ECC=eccentric muscle action

Peak sagittal plane angles of the lower body during the single jump can be seen in Table 5. The angle of the ankle joint was found to significantly increase from baseline values during the static phase ($p=0.05$; $ES=0.39$)

of a single horizontal jump. In the TO position, the hip also significantly increased ($p=0.01$; $ES=0.48$) when handheld load was applied to the single jump sequence.

Table 5. Peak flexion and extension of the hip, knee and ankle joints during a single standing horizontal jump

Jump Phase	Joint Angle (°)	Baseline	Optimal Load	Effect Size
Static	Hip	175.1 ± 3.3	174.6 ± 3.1	0.16
	Knee	174.7 ± 1.9	174.4 ± 1.7	0.17
	Ankle	113.6 ± 3.3	114.9 ± 3.3 *	0.39
Bottom	Hip	71.2 ± 17.0	72.8 ± 18.9	0.09
	Knee	115.7 ± 13.6	113.1 ± 15.7	0.18
	Ankle	90.1 ± 8.2	89.7 ± 7.2	0.05
Take-off	Hip	171.2 ± 3.4	172.7 ± 2.9 *	0.48
	Knee	167.4 ± 6.7	166.2 ± 7.2	0.17
	Ankle	156.9 ± 4.0	157.9 ± 4.9	0.22
Landing	Hip	48.3 ± 10.7	50.9 ± 14.2	0.21
	Knee	63.8 ± 12.1	59.0 ± 14.3	0.36
	Ankle	96.0 ± 5.3	96.0 ± 7.8	0.00

Values are means ± standard deviation

*Significantly different from baseline ($p<0.05$)

°=degrees

Discussion

This study investigated the effects of individualised optimal handheld load during a standing single horizontal jump in female netball players. Jump performance, GRF (separated into eccentric and concentric phases), resultant force, RF, and peak joint angles throughout a jump sequence were analysed. The main findings were: 1) significant improvement in jump distance with optimal handheld load, 2) vertical peak and mean concentric forces significantly increased with handheld load, 3) significant increase in horizontal mean forces (both eccentric and concentric), and 4) significant increases in resultant force and RF.

Optimal handheld load was found to significantly increase horizontal jump distance from 188.2 ± 16.1 cm to 196.4 ± 13.6 cm ($p=0.00$; $ES=0.55$) in this study. This result showed a similar enhancement in jump distance compared to Chapter 3, which predicted an enhancement of 9.5 ± 6.8 cm with optimum handheld loading. The enhancement was derived from polynomial curve fitting of individual jump distance-load curves. Thus, the method of predicting optimum relative loading for enhancing jump distance based on polynomial curve fittings appears to be sound. The increase in jump distance is similar, but slightly higher than results in other recent studies (23, 35); however, it is still much lower when compared to studies involving male participants. A study of 12 male sprint runners was found to increase jump distance with handheld load by 12 cm (22). A similar increase was found by Cronin et al. (9) who found jump distance to significantly increase by 13.4 cm in 16 team-sportsmen, with an optimum handheld load of 9.2 % BM. Furthermore, the study by Filush (16) reported an increase of 9 cm in horizontal jump distance in 4 male participants. In the current study, the female participants may have lacked sufficient upper body strength to be able to swing the load back and forth in a continuous movement; thus hindering the performance of the jump in comparison with studies involving male participants.

As previously mentioned, arm swing theories can be used to explain the objective enhancements in jump performance (5, 16, 22, 23, 26, 36). Both vertical peak and mean concentric GRF's significantly increased ($p=0.00-0.01$; $ES=0.43-0.72$) with handheld load during a single horizontal jump. Horizontal concentric and eccentric GRF's also significantly increased ($p=0.02$; $ES=0.79-1.03$). Although GRF's have not been studied with the use of arm swing motion, studies investigating the pull theory have shown that increased shoulder joint work was responsible for enhanced jump performance (6, 11, 26). Additionally, decreases in torques at the hip, knee, and ankle joints during the early-stage of the propulsive phase of a jump have been shown in previous studies (14, 20). Furthermore, torque augmentation at the hip was found to increase by 47 % at the end-stage of the propulsive phase of a jump

when arm motion was used, in comparison to jumping without arm motion. Thus, the “pull” and “joint torque augmentation” theories could both help to explain the mechanical changes to the body during the preparation and TO phases, resulting in improved jump performance in the current study.

When load is held in the hand during a horizontal jump, there is likely to be a greater transference of energy from the shoulder joint to the rest of the body as the shoulders and arms are working harder to move the increased load. Once the body reaches the propulsive phase of the jump, ready for TO, the arms start to decelerate causing the increased torque at the shoulder joint to “pull” the body forward to a greater extent than during an unloaded jump. Handheld load results in an increased pull from the upper body enabling the movement of increased load. In turn, this causes increased concentric and eccentric forces at TO in both the vertical and horizontal directions during a jump sequence. Additionally, the increased downwards force from the shoulders and upper extremities, when jumping with handheld load, slows the shortening velocity of the lower body muscles putting them in a better position to produce force and consequently increase jump distance.

The RF significantly increased when participants performed a horizontal jump with optimal handheld load ($p=0.04$; $ES=0.55$). The concept of the technical ability of force application refers to the individuals’ technical ability to apply force in the correct direction to improve performance (i.e. apply force in the horizontal direction in a horizontal jump). During the propulsive phase of a horizontal jump, an individual may adopt different strategies of force application for a given resultant force. Such strategies may therefore result in different horizontal force values depending on the applied direction of the force (33). Therefore, a significant increase in resultant force ($p=0.02$; $ES=0.69$) and an increase in RF, may have contributed to the significant increase in horizontal jump distance. A recent study by Kawamori et al. (24) found a significantly greater mean RF when a weighted towing sled (30 % BM) was applied to the acceleration phase of a sprint, compared to a control group. A second

study involving sprint performance investigated the role of RF and concluded that the runners' technical ability to apply force to the ground appeared to be more important than the resultant force, or physical ability, during a sprint (33). When applying the same concept to the findings of the current study, practical applications could include standing horizontal jumping with handheld load into training (assisted-jump approach) to help develop RF in athletic movements requiring horizontal force production (9, 24, 33). The result, if applied over time, may cause a chronic adaptation transferring to improved ability to produce horizontal force during ground contact in various sporting situations (24).

Although the joint angles at the ankle and hip were found to significantly increase during the static and TO phases of the horizontal jump with handheld load (ES=0.39 and ES=0.48, respectively), the added load in each hand did not seem to elicit expected changes in flexion and extension of the joint angles in the sagittal plane throughout the jump sequence. Furthermore, with no changes in joint angles, the take-off angle theory was not likely to explain the increase in jump performance. Instead, the improvement of jump performance is most likely due to the increase in concentric GRF's through the pull and joint torque augmentation theories and RF, as previously discussed.

Practical Applications

The findings in this study have not only shown that increases in total force applied to the supporting ground during a horizontal jump movement can improve jump performance, but the technical ability to orient force application in the horizontal direction enhances jump distance. Therefore, when loaded horizontal jumping is applied in training, the development of correct force application could help improve the physical and technical ability to produce horizontal forces during many sporting activities. In many court sports, specifically mid-court netball players who are generally constantly moving forward, technical ability to apply force in the required (horizontal) direction is essential in

many movements; for example, interceptions across court, acceleration and short sprints. For females we recommend performance of single jump movements with optimal handheld load. Further research should look at training studies to investigate chronic adaptations of horizontal jumping with optimal handheld load.

CHAPTER 5

DISCUSSION AND CONCLUSION

Preface

This chapter is the synthesis of the thesis outlining the acute effects of handheld load on horizontal jumping biomechanics and performance in female athletes. The aim of this chapter is to present the practical implications of these findings, in context with the existing literature, to enhance scientific knowledge and biomechanical understanding of the effects of handheld load in female netball players. The chapter ends with a conclusion of the thesis as a whole.

Discussion

The review of existing literature provided supporting rationale for further investigation into the effects of handheld load on horizontal jumping. There were many methodological issues in current literature, including low participant numbers, homogeneous participants, simulation studies, inadequate familiarization and limited reporting of reliability. Additionally all of the reviewed studies have used predominantly male participants. During the time of this thesis, one international peer-reviewed journal article was published on this topic; however, this study still involved all male participants. All other literature was sourced from conference proceedings, a university publication and a master's thesis. Although there were many limitations to the existing literature, positive findings provided sufficient reason for further investigation on this topic, particularly in female athletes.

Horizontal force output is necessary to perform many sporting movements required for successful performance in court sports. In court sports (e.g. basketball, volleyball) vertical jumping is perceived to dominate successful performance. However, these sports generally

involve movements that have strong horizontal components such as acceleration, short sprints and horizontal jumping; thus, the ability to generate horizontal momentum, in addition to vertical force, is just as important to achieve successful performance (34). Therefore, based on the acute enhancement of jump distance with handheld load, when loaded horizontal jumping is repeatedly applied in training, muscular adaptations and improved technical application of force could occur due to the demands placed on the body, improving horizontal force production. Horizontal jumping could be applied as an assisted-jump training method.

As a popular female court sport, involving movements demanding horizontal force production, netball was seen as an appropriate sport to investigate this concept. It is a sport in particular that could benefit from this possible new method of training. There is very limited research into netball performance, and up until this thesis there has been no studies investigating the effects of handheld loading on horizontal jumping in the sport of netball or female athletes.

Effects of Handheld Load on Horizontal Jump Biomechanics and Performance

Optimal handheld load augments the biomechanics of horizontal jumping to enhance the performance of a horizontal jump. Horizontal jump distance, vertical and horizontal concentric ground reaction forces (GRF), and the ratio of force application (RF) all significantly increased when load was held in each hand during a single standing horizontal jump.

Jump distance

Jump distance was found to increase in both studies with handheld load. The improvements in jump distance were similar between studies and were congruent with existing literature. The total jump distance was much higher in the second study when individualised optimal handheld load was applied. Some studies have found greater increases in jump distance; however these studies involved either all male participants

(highlighting gender differences), and/or involved a multiple jump sequence (i.e. 5-fold jump), and/or were computer simulation studies (1, 9, 16, 22, 27).

Ground Reaction Forces & Arm Swing Motion

Increases in vertical and horizontal force, predominantly in the concentric phase, during the propulsive phase of a horizontal jump, were found in both studies. Arm swing motion, a common underlying mechanism applied across the three papers in this thesis, helps to explain the improvements in jump performance with handheld load. Many studies have found jump performance to decline with restricted arm motion when jumping (2, 3, 6, 11, 26). These findings have promoted theories of arm motion (i.e. arm swing) while jumping; including the pull theory, hold back theory, and joint torque augmentation theory. The two theories that could be accountable for the increase in GRF's are the pull theory and the joint torque augmentation theory (2, 6, 11, 15, 15, 26).

Arm swing creates work at the shoulder joint which is then transferred to the rest of the body during the propulsive phase of a jump. It also causes torques at the hips, knees and ankles to decrease in the early propulsive phase and increase in the latter propulsive phase, just before take-off, with an increase in force. Additionally, the downwards force initiated at the shoulders places the muscles of the lower body in a more optimal position to produce greater force through a decrease in shortening velocities of the muscles. Therefore, with greater load in the hand, more energy is created at the shoulder and upper body and passed on to the rest of the system, resulting in greater reaction forces from the supporting ground.

Ratio of Force Application

With a significant increase in the resultant force, RF is also significantly increased with optimal handheld load. The technical ability of force application in the horizontal direction has been shown to be an influencing factor in the improvement of acceleration and sprint performance (24, 33). It has now also been shown to be a mechanism in

the improvement of horizontal jump performance in female athletes, augmented with the use of handheld load. Therefore, training with handheld can improve technical ability of correct force application to enhance performance, rather than the amount of force as such.

Jump Duration

Sporting movements requiring a longer time to produce force may benefit from loaded horizontal jump training. As impulse is the product of force and time, impulse and jump duration are influential variables in the enhancement of jump performance (9). Therefore, physical movements benefiting from the application of this concept during training are movements which require force production over a longer duration of time (~500ms) (9). Court sports involve these types of movements, including change-of-direction and horizontal jumps. In comparison, movements requiring a shorter duration of force production (<150ms) may be negatively affected by including horizontal jumps with handheld load in training (9). Netball, as a court sport, involves many movements requiring the production of force over relatively long durations (25). However, jump duration or impulse was not found to enhance jump distance from baseline conditions with handheld load in the studies of this thesis. Therefore, arm swing motion and RF best explain the underlying mechanics of the enhancement in horizontal jump performance in this female athlete population

Thesis Limitations and Delimitations

The studies presented in this thesis may have been limited by methodological constraints, and it is important to be aware of the following limitations when interpreting the results.

1. Participant numbers were generally lower than would be ideal, potentially compromising statistical power. It should be noted that the participants used in this study were all from the same netball squad, and the majority of the participants were used in both

studies. Data collection for each study was conducted during two different times of the season (pre-season and in-season) due to squad commitments and availability, possibly compromising data with changes in the training status of the individual. In addition, the spread of the playing positions of the group was not equal. Some playing positions (mid-court) require more horizontal movement on court than others (end-goal), therefore players more trained in mid-court positions could have naturally achieved better results due to their training status.

2. The nature of the movement with handheld load was difficult for some of the participants to perform. The horizontal jump with handheld load requires upper body strength, and some participants did not have sufficient strength. Despite familiarisation of the jump movement, participants still found it challenging.
3. The range of handheld load conditions was limited due to the range of Olympic Weightlifting plates available. Plates only came in absolute loads and therefore optimal load conditions (% body mass) were needed to be rounded to the nearest whole 1.0 kg.
4. Every effort was made to ensure the correct placement of markers for 3D analysis; however, there is the chance the marker placement in each of the testing sessions was slightly different, introducing greater variability into the data, and making the test less sensitive to actual changes. To minimise this potential source of error, on both testing occasions, the markers were secured by the same experienced ISAK Level 2 anthropometrist.
5. The decision not to randomise the order of loaded conditions during each study was informed by pilot testing. It was indicated that performing horizontal jumps before unloaded jumps could affect the movement pattern of a subsequent unloaded jump. However, as the increase in load was sequential there could have

been an issue of potentiation between lighter and heavier loading conditions.

6. The work performed in this study consisted of bilateral jumping only. In many sports situations, jumps are performed in a unilateral modality. Therefore, this limitation could be considered for future research and sport application.

Future Research

The acute changes in horizontal jump performance highlight the need for further research in this area. Future research should consist of training studies to investigate chronic adaptations to horizontal jumping with optimal handheld load. Information from such training studies could determine physical and performance changes when loaded horizontal jumping is repeatedly applied over time. Additionally, training protocols and appropriate handheld loading for a variety of populations need to be prescribed dependant on more research. Furthermore, given the scarcity of literature on the performance enhancement of netballers, the need for future research for the performance enhancement of this athletic population is warranted.

Conclusion

This thesis consists of a series of studies investigating the effects of handheld load on single standing horizontal jumping in female netball players. Until recently, the great feats of ancient Olympic athletes were questionable. Now, handheld load has been shown to improve horizontal jump performance. Encouraging evidence has been provided to suggest loaded horizontal jumping be implemented as a training tool to assist in the production and enhancement of horizontal force production and application. With further research appropriate training protocols can be determined and implemented for court sports, such as netball.

Practical Recommendations

Findings in this thesis have provided practical applications for the modality of loaded horizontal jump training in female athletes, in particular netball players. Trainers, strength and conditioners, specialist coaches and athletes can use this method of training with the aim of enhancing horizontal force production for performance enhancement. Athletes can find their optimal handheld load by completing the protocol of jumping with handheld load at increasing loaded conditions, or a simple spreadsheet can be created to calculate individualised optimal handheld loads relative to the body mass of individual athletes, which was identified as a mean of 6.4 % of body mass in this study.

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APPENDIX 1

AUT ETHICS APPROVAL



AUTEC
SECRETARIAT

10 July 2013

Matt Brughelli
Faculty of Health and Environmental Sciences

Dear Matt

Re Ethics Application: **13/162 The effects of handheld loading on horizontal jumping biomechanics and performance.**

Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 10 July 2016.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 10 July 2016;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 10 July 2016 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Chole McKenzie chloe-mckenzie@hotmail.co.nz

APPENDIX 2

PARTICIPANT INFORMATION SHEET

Participant Information Sheet



Date Information Sheet Produced: 29th May 2013

PROJECT TITLE

The effects of handheld loading on horizontal jumping biomechanics and performance

INTRODUCTION

My name is Chloe McKenzie. I am a student completing my Master's degree in Sport and Exercise Science at the AUT University, Auckland. As part of my qualification I am required to carry out a research project and I would like to invite you to take part in my study.

I have been playing netball for over 10 years and am interested in determining how handheld load can affect the performance and biomechanics of horizontal jumping in netball players. I propose to do this by: 1) testing players to investigate the optimal load where jump performance (measured by distance) is improved in a single standing long jump, 2) performing a biomechanical analysis of the effects of handheld load during a horizontal jump in female netball players; and 3) testing the inter-session reliability on jump biomechanics and performance.

There is very little evidence in the scientific literature regarding female athletes and horizontal jumping with handheld load. Therefore, I hope this study will assist in the advancement of training methods and performance in netball, as well as give you some useful and/or interesting information for your own netball training.

INVITATION TO PARTICIPATE

You are invited to take part in the above mentioned research project. Your participation in this research is voluntary. Together, you and your whanau should decide whether or not you would like to be involved. You don't have to be involved, it won't affect your role in your team or club and you can stop being involved in the study at any time.

Your consent to participate in this research will be indicated by your signing and dating of a consent form. Signing the consent form indicates that you have freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of the study is to determine the effects of handheld loading on horizontal jumping biomechanics and performance in female netball players.

This study is being conducted as part of a master's degree thesis. The results of this study will be submitted to peer-reviewed journals.

HOW WAS I CHOSEN TO BE ASKED TO PARTICIPATE IN THE STUDY?

You have been identified and invited to take part in this study because you are part of the North Harbour Netball Centre, playing in either a Premiere or Elite Development grade.

WHAT HAPPENS IN THE STUDY?

We will ask you to complete an initial familiarisation session at your netball club so you get used to jumping with handheld load. We will then require you to come to the AUT Millennium Campus to complete a testing session which will take approximately 1-2 hours.

During the testing session you will be asked to:

Have surface electrodes placed on certain muscles (quadriceps, gluteus maximus, calf muscle and shin) of your dominant leg.

Have surface reflectors placed on various joints of your body and be videoed with a 3D camera system.

Perform the following laboratory tests;

- A single standing horizontal long jump holding various loads (increasing loads: No weight (NW), 2kg, 3kg, 4kg, 5kg and 6kg in each hand).
- A five-fold horizontal long jump (five jumps in a row) with your identified optimum handheld load.

WHAT ARE THE DISCOMFORTS AND RISKS?

You will experience the discomforts and risks that normally occur from participating in netball training and matches.

WHAT COMPENSATION IS AVAILABLE FOR INJURY OR NEGLIGENCE?

In the unlikely event of a physical injury as a result of your participation in this study, you may be covered by ACC under the Injury Prevention, Rehabilitation, and Compensation Act 2001. ACC cover is not automatic, and your case will need to be assessed by ACC according to the provisions of the Injury Prevention, Rehabilitation, and Compensation Act 2001. If your claim is accepted by ACC, you still might not get any compensation. This depends on a number of factors, such as whether you are an earner or non-earner. ACC usually provides only partial reimbursement of costs and expenses, and there may be no lump sum compensation payable. There is no cover for mental injury unless it is a

result of physical injury. If you have ACC cover, generally this will affect your right to sue the investigators. If you have any questions about ACC, contact your nearest ACC office or the investigator. You are also advised to check whether participation in this study would affect any indemnity cover you have or are considering, such as medical insurance, life insurance and superannuation.

WHAT ARE THE BENEFITS?

Information gained from this research has potential to help shape training strategies and performance of value to athletes, clinicians, physical conditioners and coaches. You will have the option of receiving an individualised one page report on your optimum handheld load which enhances your horizontal jumping performance.

HOW IS MY PRIVACY PROTECTED?

The data from the project will be coded and held anonymously in secure storage under the responsibility of the principal investigator of the study in accordance with the requirements of the New Zealand Privacy Act (1993).

All reference to participants will be by code number only in terms of the research thesis and publications. Identification information will be stored on a separate file and computer from that containing the actual data.

Video footage (3D) will be used for data collection and analysis for this research only. Videos will correspond with the participant's coded number, not name. This too will be held in secure storage.

Only the investigators will have access to computerised data.

WHAT ARE THE COSTS OF PARTICIPATING?

There is no monetary cost to you to be involved in this research, the only cost is time. The testing will be conducted at the AUT Millennium campus and will take approximately 1 to 2 hours.

OPPORTUNITY TO CONSIDER INVITATION

Please take the necessary time you need to consider the invitation to participate in this research.

It is reiterated that your participation in this research is completely voluntary.

If you require further information about the research topic please feel free to contact Chloe McKenzie or Matt Brughelli (details are at the bottom of this information sheet).

You may withdraw from the study at any time without there being any adverse consequences of any kind.

You may ask for a copy of your results at any time.

HOW DO I JOIN THE STUDY?

If you are interested in participating in this research please feel free to contact Annie Sadlier at Netball North Harbour who will subsequently contact Chloe McKenzie. Although feel free to contact Chloe directly (details are at the bottom of this information sheet).

PARTICIPANT CONCERNS

If you have any questions please feel free to contact Chloe McKenzie or Matt Brughelli. Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor – Matt Brughelli.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTC, Dr Rosemary Godbold, rosemary.godbold@aut.ac.nz or phone 921 9999 ext 6902.

Researcher Contact Details:

Chloe McKenzie, School of Sport and Recreation, AUT University. Email: chloe-mckenzie@hotmail.co.nz or phone +64 21 277 0673.

Project Supervisor Contact Details

Primary Supervisor: Dr Matt Brughelli, Sports Performance Research Institute New Zealand, School of Sport and Recreation, AUT University. Email: mbrughelli@aut.ac.nz or phone +64 9 921 9999 ext .7025

Additional Supervisor: Dr. Chris Whatman, Faculty of Health and Environmental Sciences, School of Sport and Recreation, AUT University. Email: chris.whatman@aut.ac.nz or phone +64 9 921 9999 ext. 7037

Thank you for considering participating in this research.

Approved by the Auckland University of Technology Ethics Committee on 10/07/2013. AUTC Reference number 13/162

APPENDIX 3

PARTICIPANT CONSENT FORM

Consent to Participation in Research

Player



Title of Project: **The effects of handheld loading on horizontal jumping biomechanics and performance**

Project Supervisor: **Dr Matt Brughelli**

Researcher: **Chloe McKenzie**

- I have read and understood the information provided about this research project (Information Sheet dated 29th May 2013) designed to measure the effects of handheld loading on horizontal jumping.
- I have had an opportunity to ask questions and to have them answered.
- I understand that taking part in the study is entirely my choice and that I may withdraw any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all relevant information will be destroyed.
- I permit the researcher to use the data from testing that is part of this project exclusively for research or educational purposes
- I understand that any information I give during this study will be confidential and my name will not be recorded on any collected data at any time.
- I agree to participate in the research.
- I wish to receive a copy of the report from the research: tick one: Yes ☐ No ☐

Player's signature: Parents Signature

.....

Player's Name: Parents Name

.....

Date: Date:

.....

Project Supervisor Contact Details:

Dr Matt Brughelli,
Sports Performance Research Institute New Zealand,
School of Sport and Recreation,
Auckland University of Technology.

Private Bag 92006
Auckland 1020
64 9 921 9999 ext .7025
mbrughelli@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee **10/07/2013. AUTEK Reference number 13/162**