Martial arts techniques to reduce fall severity

Brenda Groen

The work presented in this thesis is part of the research programme of the Institue for Fundamental and Clinical Human Movement Sciences (IFKB) and was carried out at the Sint Maartenskliniek Nijmegen, The Netherlands. Financial support was provided by the Sint Maartenskliniek Nijmegen and POM Nijmegen BV.

The publication of this thesis was financially supported by the Radboud University Nijmegen Medical Centre (Department of Rehabilitation), Institute for Fundamental and Clinical Human Movement Sciences (IFKB), POM Nijmegen BV, Anna Fonds and Stichting OrthoResearch.

Design and lay-out: In Zicht Grafisch Ontwerp, www.promotie-inzicht.nl
Printed: Quickprint

ISBN 978-90-9025651-1

Martial arts techniques to reduce fall severity

Een wetenschappelijke proeve op het gebied van
de Medische Wetenschappen

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. mr. S.C.J.J. Kortmann,
volgens het besluit van het college van decanen
in het openbaar te verdedigen op maandag 25 oktober 2010
om 15:30 uur precies

door

Brenda Edith Groen
geboren op 26 november 1974
te De Lier

Promotor

Prof. dr. J.E.J. Duysens

Copromotor

Mw. dr. V.G.M. Weerdesteyn

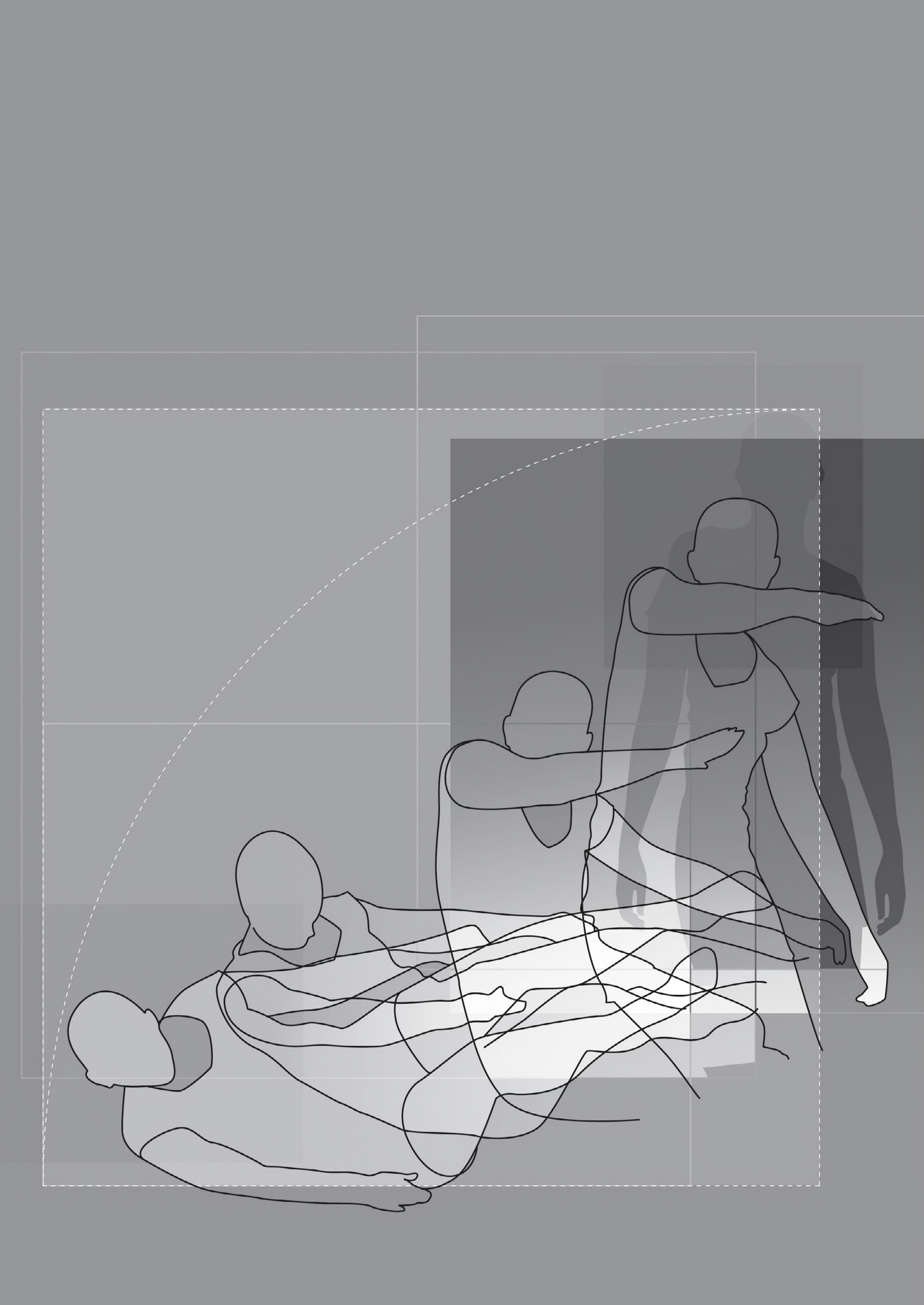
Manuscriptcommissie

Prof. dr. B.R. Bloem

Prof. dr. J.H. van Dieën (VU Amsterdam)

Prof. dr. ir. N.J.J. Verdonschot

Contents



1

Chapter

General introduction

Hip fractures among the elderly are a major health problem. These fractures are associated with high mortality and morbidity rates (Roche et al., 2005). Most hip fractures are caused by falls (Cumming and Klineberg, 1994). There is some evidence that fall prevention programmes are effective in reducing fall-related injuries (Robertson et al., 2002), suggesting that hip fractures may be prevented by reducing the risk of falling. Hip fractures may also be prevented by limiting the severity and the consequences of the falls. This thesis focuses on limiting fall severity by means of using martial arts (MA) fall techniques. Its main purpose is to explore the potential usefulness of MA fall training for hip fracture prevention in the elderly.

This general introduction starts by describing the epidemiology of hip fractures, followed by an overview of interventions focusing on hip fracture prevention. In addition, the characteristics of the MA fall techniques and the effects of these techniques on fall severity will be described in more detail. The general introduction concludes with the aims and outline of this thesis.

Epidemiology of hip fractures

About 90% of all hip fractures are due to falls (Cumming and Klineberg, 1994). Falls with the highest risk for hip fracture are sideways falls and falls with direct impact on the greater trochanter of the proximal femur (Nevitt and Cummings, 1993; Wei et al., 2001).

Epidemiological studies, based on demographic trends, predicted that the yearly number of hip fractures in the world will rise from 1.26-1.66 million in 1991 to at least 4.65 million by 2050 (Cooper et al., 1992; Gullberg et al., 1997). The incidence of hip fractures varies among the different countries of the world. The highest incidence rates were found in (Northern) Europe and North America (Cooper et al., 1992; Gullberg et al., 1997; Kanis et al., 2002).

The majority of hip fractures occur in women (70-80%) (Cooper et al., 1992; Gullberg et al., 1997; Haleem et al., 2008; Brauer et al., 2009). The hip fracture rate increases exponentially with age (Cooper et al., 1992; Gullberg et al., 1997; Brauer et al., 2009; Kanis et al., 2002). The estimated life-time risk of a hip fracture at the age of 50 years ranges from 1% to 28.5% in women and 1.8% to 13.1% in men depending on geographical area (Kanis et al., 2002).

Mortality after a hip fracture is high, being 9.6% at one month (Roche et al., 2005), 11-23% at six months (Haleem et al., 2008), and 22-33% at one year post

injury (Roche et al., 2005; Haleem et al., 2008). Parallel to the fracture rate, the mortality rate after hip fracture increases with age (Brauer et al., 2009). After adjusting for age and previous hospitalization, the mortality risk increases threefold during the first six month after a hip fracture and remains substantially increased for at least six years post fracture (Farahmand et al., 2005).

In addition, hip fractures are associated with high morbidity rates. The most common post-operative complications are chest infection (9%) and heart failure (5%)(Roche et al., 2005). Many survivors experience functional loss after hip fracture: they are unable to walk independently, have difficulties with at least one essential activity of daily living and/or are restricted in other activities, such as driving and grocery shopping. Hip fractures are therefore a common cause of loss for independence or institutionalization (Cooper, 1997).

Consequently, the related financial burden is high. In the Netherlands, for example, the mean direct medical costs are 14,000 Euros for each older individual with a hip fracture (Consument en Veiligheid, 2005). Furthermore, the total healthcare costs for patients with hip fractures were 391.6 million Euros in 2005, or 0.6% of the total cost of Dutch healthcare (Poos et al., 2008).

Relevant clinical risk factors for hip fractures are femoral neck bone mineral density (BMD), age, sex, low body mass index, a prior fragility fracture, a parental history of hip fracture, long-time use of oral glucocorticoids, rheumatoid arthritis as well as other causes of secondary osteoporosis, currently smoking, and an alcohol consumption of three or more units daily (Kanis et al., 2008). These clinical risk factors have been used in models to predict the ten-year probability of hip fracture in men and women (Kanis et al., 2008). A comparative study showed no better predictions in the ten-year risk of hip fracture in woman using complex models, which included all the above mentioned clinical risk factors for hip fractures, than simple models based only on age and BMD or only on age and fracture history (Ensrud et al., 2009). Therefore, one may conclude that low BMD, high age, fracture history and being female are the most important clinical risk factors.

Hip fracture prevention

Individuals with osteoporosis (low BMD, T-score ≤ -2.5) have a high risk for hip fractures because of their reduced bone strength. Consequently in clinical practice, hip fracture prevention has traditionally focused on treating osteoporosis,

predominantly by prescribing bisphosphonates. The efficacy of bisphosphonates is extensively documented in the literature. Cochrane reviews reported that treatment with alendronate (Wells et al., 2008b) or risedronate (Wells et al., 2008a) for secondary prevention results in a statistically significant and clinically relevant reduction in hip fracture risk in postmenopausal woman with osteoporosis. For primary prevention, no statistically significant reduction in hip fracture risk was found whether alendronate (Wells et al., 2008b) or risedronate (Wells et al., 2008a) was used. For etidronate, no statistically significant reduction in hip fracture risk was found whether for primary or secondary prevention (Wells et al., 2008c). In addition, a Cochrane review on the effect of vitamin D revealed that vitamin D alone is unlikely to be effective in preventing hip fractures. However, frail, older individuals living in institutional care facilities may sustain fewer hip fractures if vitamin D with calcium is given (Avenell et al., 2009).

Since the majority of hip fractures are caused by falls, it is to be expected that fall prevention in general would also reduce the number of hip fractures. An abundance of interventions to prevent falls in older individuals have been developed and evaluated. A recent Cochrane review on the effects of these interventions for older individuals living in the community (Gillespie et al., 2009) demonstrated that exercise programmes, including Tai Chi, reduce the rate of falls and the number of fallers (or risk of falling) if comprised of two or more of the following components: strength, balance, flexibility, and endurance. These exercise programmes are effective whether they are delivered in groups or given on individual basis. Multifactorial interventions (i.e. multi-component interventions based on individual assessement) are effective in reducing the rate of falls but not in reducing the number of fallers. Overall, home safety interventions did not reduce falls, but there is limited evidence that they may be effective in reducing falls for individuals with a higher risk of falling. In addition, vitamin D does not appear to be effective in reducing falls in general, but may reduce falls in individuals with low vitamin D levels. There is only limited evidence that other interventions, such as medication interventions, are effective in reducing falls or the number of fallers (Gillespie et al., 2009). From the pooled data on fractures, there is some evidence that exercise programmes reduce the fracture risk for all kinds of fractures (Gillespie et al., 2009). This suggests that hip fractures may be prevented by preventing falls. However, whether fall prevention interventions indeed reduce the number of hip fractures remains to be demonstrated.

Hip fractures may also be prevented by the use of hip protectors. Hip protectors have been designed to shunt the energy of a fall away toward the soft tissues around the hip and/or to absorb part of the energy of the fall. In vitro experiments have shown that the best hip protectors can attenuate the impact forces by as much as 65-85% (Kannus et al., 1999; Robinovitch et al., 1995a). However, clinical trials to evaluate the preventive effects for hip fractures have shown conflicting results. Recent reviews of randomized clinical trials concluded that there is accumulating evidence which indicates that hip protectors are ineffective in preventing hip fractures in older individuals living in the community. Furthermore, the potential benefits in reducing hip fractures in older individuals living in institutional care is uncertain and requires further confirmation (Sawka et al., 2005; Parker et al., 2006). These disappointing results may in part be due to the poor compliance in wearing hip protectors in everyday life. A systematic review reported that the primary acceptance of hip protectors ranged from 37% to 72% (median 68%) and that the compliance varied between 20% and 92% (median 56%). The most frequently mentioned determinants for non-compliance were: lack of comfort (too tight/poor fit); the extra effort (and time) needed to wear the device; urinary incontinence; and physical difficulties/illness (van Schoor et al., 2002). In addition, a hip protector may not be correctly positioned to optimally attenuate the hip impact force during a fall (Minns et al., 2007). The conflicting results may also result from differences in the research designs of the clinical trials used to study hip protectors. Furthermore, the absence of testing standards has made it difficult for manufactures to optimize hip protectors and for clinical researchers to select the best hip protectors to use in clinical trials (Robinovitch et al., 2009). On response, the International Protector Research Group has published a consensus statement with recommendations for testing the biomechanical performance of hip protectors (Robinovitch et al., 2009) and for conducting future clinical trials with hip protectors (Cameron et al., 2010).

Alternatively, older individuals may be taught how to fall safely (DeGoede et al., 2003). A fall, in particular a sideways fall from a standing height, is dangerous and can result in a hip fracture even in young adults (Kannus et al., 2006). Nevertheless, hip fractures rarely occur in young individuals. Hip fractures are even rare among athletes who regularly fall onto hard surfaces, for example during martial arts or free running. Based on biomechanical models it has been estimated that any fall from standing height with a direct, lateral impact on the greater

trochanter would fracture the elderly hip (Robinovitch et al., 1991). However, hip fractures only occur in 1-2% of the falls in the elderly (Tinetti et al., 1988). Hsiao and Rovinovitch (1998), therefore, suggested that highly effective movement strategies exist which prevent injuries such as hip fractures. Various potential strategies to reduce fall severity during sideways falls have been studied in young adults, including natural fall arrest strategies (Hsiao and Robinovitch, 1998), forward or backward rotation (Robinovitch et al., 2003), relaxing the body (Sabick et al., 1999; van den Kroonenberg et al., 1996), and MA fall techniques (Sabick et al., 1999).

Martial arts fall techniques

Judokas fall on the floor all the time without injuring themselves. Therefore, it seems obvious that the MA fall techniques used by these athletes do effectively reduce fall severity and, thereby, fall injuries. The three most important characteristics of MA fall techniques are to change the fall into a rolling motion by curving and rotating the trunk, to protect the head by neck flexion, and to the use the arm to break the fall (Figure 1.1). However, to date, few studies have evaluated the effects of MA fall techniques on fall severity.

In one of the first studies on this subject, Sabick and co-workers (1999) found that in experienced members of aikido clubs, MA fall techniques reduced the impact forces on the hip and shoulder by 12% and 16%, respectively, as compared to a broomstick strategy during a volitional sideways fall from a kneeling position. It was suggested that hand impact, which occurred after hip impact, could play a role in the reduction of hip impact force (Sabick et al., 1999), but this has not been unequivocally proven. In fact, knowledge about the working mechanisms and effects of MA fall techniques is still limited. To be effective in preventing hip fractures in older individuals, MA fall techniques have to be trainable in that age group. Recently, an MA fall training was introduced as an element of the Nijmegen Falls Prevention Program for healthy, elderly persons (Weerdesteyn et al., 2006). It was observed that participants were able to learn the basics of MA fall techniques within five sessions. During the training sessions, they were able to perform the techniques with increasing fluency and confidence. Some participants even reported that in daily life they had been able to use these techniques during a fall. However, the trainability of MA fall techniques and the effectiveness of MA fall training in older individuals had not been quantified.

Figure 1.1 Photo series of martial arts fall techniques from a kneeling position. Martial arts fall techniques during (a) a sideways, (b) a forward, and (c) a backward fall.

Outline of this thesis

The main purpose of this thesis is to explore the potential usefulness of MA fall training for hip fracture prevention in the elderly. The main purpose comprises four aims. The first aim is to study the effect of MA fall techniques on fall severity and to detect experience-related differences. The second aim is to gain knowledge about the working mechanisms by which MA fall techniques reduce the impact on the hip during a sideways fall. The third aim is to determine the trainability of MA fall techniques in young adults and older individuals. The fourth aim is to investigate the safety of the MA fall training for persons with osteoporosis, as these individuals may benefit the most from such training because of their high risk for (hip) fractures. A series of fall experiments has been conducted and will be described in the following chapters.

In Chapter 2, the effects and the proposed working mechanisms of MA fall techniques during a volitional sideways fall from kneeling height are reported for a group of experienced judokas. To determine the reduction of the impact forces on the hip, the MA fall techniques were compared with a natural fall arrest strategy in which the outstretched arm was used to block the fall. To study the effect of arm use on hip impact force during MA falls, these were performed with and without the use of the arm. In addition to hip impact force, hip impact velocity and trunk orientation were measured.

Chapter 3 starts with an overview of movement strategies that may be effective in reducing fall severity during a sideways fall. In vivo studies that evaluate fall severity for different fall strategies often use impact velocity instead of impact force to measure fall severity. The question is addressed whether the impact velocity is indeed a valid predictor of impact force and can be used to evaluate differences in fall severity between different fall strategies.

Chapter 4 reports, whether a reduction in hip impact forces can be shown in young subjects (without prior MA fall experience) after a brief training in MA fall techniques. The same experimental set-up as in Chapter 2 was used. In addition, the EMG patterns from trunk, neck and shoulder muscles during the sideways falls of the experienced judokas and those of the young subjects (after the brief training) were compared to identify potential experience-related differences that occur during the execution of the MA techniques.

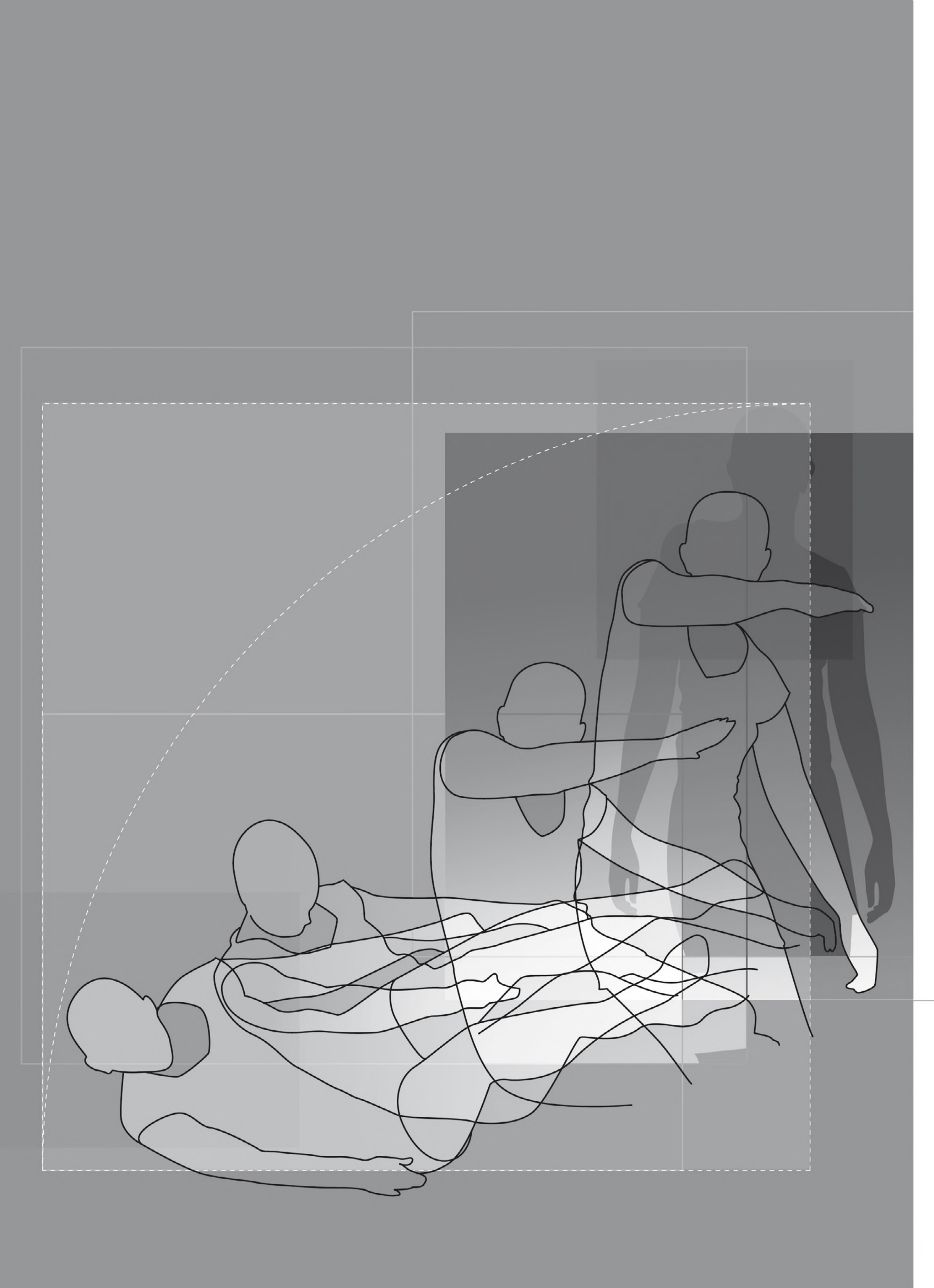
Chapter 5 focuses on the neuromuscular control of the MA fall technique and a natural fall arrest strategy during volitional sideways falls. Again experienced

judokas and young subjects (after a brief training) were compared. The times to initiate and to adequately execute a fall strategy after the onset of a sideways fall were measured. In this fall experiment either an MA fall technique or a natural fall arrest strategy was executed according to an auditory cue given at different delays after the onset of the fall. Success rates, reaction times and EMG patterns from trunk, neck and shoulder muscles were measured to determine the effects of cue delay and fall strategy.

Chapter 6 addresses the question whether older individuals are able to learn MA fall techniques and, if so, whether a better fall performance after an MA fall training does result in a reduction of hip impact forces during a volitional sideways fall. The MA fall performance of older individuals before and after a five-session MA fall training was compared. In addition to fall performance, data on hip impact force, hip impact velocity, fall duration, and fear of falling before and after training were compared.

Chapter 7 reports an experiment to determine whether MA training would be safe for persons with osteoporosis. Hip impact forces were measured in young adults while they performed all the exercises included in the fall training. Using these data it was possible to infer which exercises were safe for persons with osteoporosis by using two stringent safety criteria based on femoral fracture load data, available in the literature, and data on the protective effects of a hip protector.

Finally, in Chapter 8, the main findings and conclusions of this thesis are summarized and further discussed.



2

Chapter

Martial arts fall techniques decrease the impact forces at the hip during sideways falling

Based on
B.E. Groen, V. Weerdesteyn, and J. Duysens
Journal of Biomechanics 40(2):458-462, 2007

Introduction

A hip fracture is a serious consequence of falls in elderly people. About 90% of hip fractures are caused by falls (Cumming and Klineberg, 1994). In particular falls to the side and those with impact on the hip have an increased risk for hip fractures. Interventions that reduce the fall severity of these more dangerous falls are expected to decrease the risk of fractures (Greenspan et al., 1994; Nevitt and Cummings, 1993).

Experimental fall studies have shown that to avoid hip impact during a sideways fall, young subjects use their hands and rotate the trunk (Hsiao and Robinovitch, 1998). For elderly, using the hands is not without risk, as hand impact increases the risk for wrist fractures (Nevitt and Cummings, 1993). Relaxing the body during descent could reduce the impact velocity (van den Kroonenberg et al., 1996), but not the hip impact force (Sabick et al., 1999). In contrast, a martial arts (MA) fall technique has been shown to reduce the hip impact force as compared to 'normal' tensed falls (Sabick et al., 1999). Knowledge about the working mechanisms and the potential benefits for elderly to learn the MA fall techniques is limited, but is needed since MA fall techniques are being successfully used in programmes to prevent falls in elderly (Weerdesteyn et al., 2006). The high impact force at the hand that is used to break the MA fall has raised concerns (DeGoede et al., 2003). It was suggested that hand impact would play a role in the reduction of hip impact force (Sabick et al., 1999), however it has not been proven. Hence, experiments are needed to determine if hand impact is essential to reduce hip impact force.

According to simple impact models, hip impact force is determined by hip impact velocity, the effective mass of that part of the body that is moving prior to impact, and the overall stiffness of the soft tissue overlying the hip (van den Kroonenberg et al., 1995). The effective mass is dependent on trunk orientation at impact in such a way that the more vertical the trunk, the larger the effective mass. Hence, other factors that may play a role in the reduction of hip impact by the MA technique are impact velocity and trunk orientation.

The purpose of this study was to get insight into the mechanisms by which MA fall techniques would reduce hip impact force during sideways falls. The hypothesis was that the presence of hand impact, a decreased impact velocity and a more horizontal trunk orientation would provide an explanation.

In addition, the time curves of the different fall techniques were examined to detect temporal differences and to investigate if changes were attributable to certain kinematic or kinetic events.

Methods

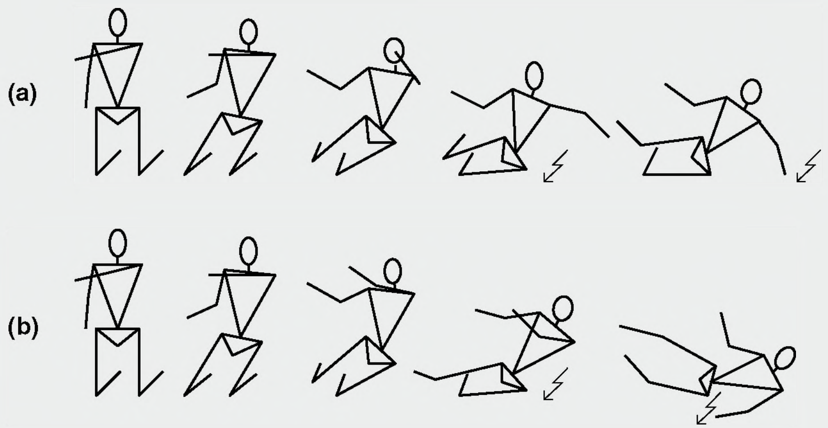
Six experienced judokas participated (age: 24.2 ± 3.8 years, weight: 65.8 ± 19.6 kg, experience: 13.0 ± 6.8 years) and signed informed consent prior to participation. The protocol was approved by the Ethical Board of the region Arnhem-Nijmegen.

Forces were measured with a force plate (Kistler, size 0.6 m x 0.4 m) at 2400 Hz. The 3-D positions of reflective markers were simultaneously registered with a 6-camera motion analysis system (Primas) at 100 Hz. Markers were placed on the left shoulder, wrist, and greater trochanter (GT), and a marker frame with three markers was attached to the left femur.

Three different fall techniques were studied: the block with arm (Block) or control, the MA with arm (MA-a), and the MA no arm (MA-na) technique. The Block technique is based on a natural equilibrium reaction of elderly in which they use compensatory trunk movements and react with their arms by stretching into the direction of the impending fall (Allum et al., 2002). The subjects were instructed to fall sideways on the hip and to use the outstretched arm to block the fall (Figure 2.1a). The MA-a technique is derived from judo. The fall is changed into a rolling movement, which allows for an optimal distribution of impact applied to any site along the contact path. The arm is used to break the fall (Figure 2.1b). The MA-na technique is similar to the MA-a technique, but the subjects were instructed to hold the left arm above the ground.

Data collection started with a reference measurement to define the position of the GT with respect to the marker frame and to determine the reference GT to shoulder angle (for definition, see below). The position of the GT during the falls was calculated based on the position and orientation of the marker frame using the method described by Söderkvist and Wedin (Söderkvist and Wedin, 1993). Then the GT marker was removed. The testing protocol was similar to that used by Sabick et al. (1999). The subjects were kneeling on a padded surface next to the force plate with the left arm in front of them. The falls were voluntarily initiated

Figure 2.1 Stick figures of sideways falls using the control and martial arts technique (frontal view). (a) Block with arm or control technique. The subjects were instructed to fall sideways on the hip and to use the arm to block the fall. (b) Martial arts with arm technique. The fall is changed into a rolling movement while the arm is used to break the fall. Impact is indicated by a broken arrow (↯).

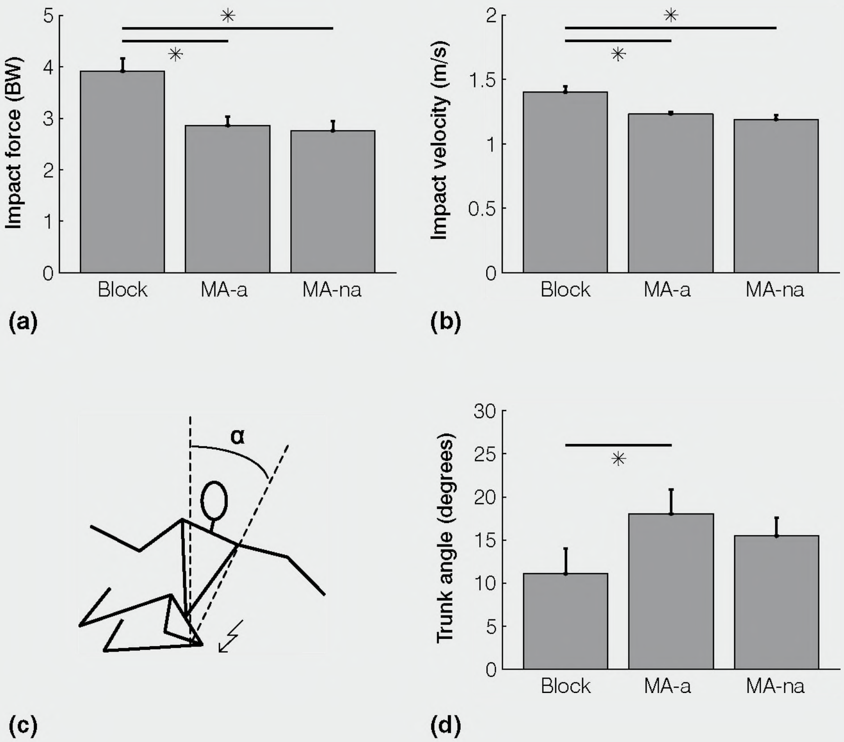


and fall initiation was detected visually by the experimenter. The subjects then received a short vocal instruction (single syllable word) which technique they had to perform. All instructions were given by the same experimenter to avoid systematic differences between trials and subjects. The experimenter controlled visually if the impact was on the force plate. Two series of 15 falls were performed. One series consisted of 5 Block falls and 10 MA-a falls. In the other series the MA-a falls were replaced by MA-na falls. Falls were performed in random order within each series. The series were also performed in random order.

The instant of impact was defined as the instant at which the vertical force first exceeded 10 N. As hand impact was always later than hip impact, hip impact force was defined as the first peak force in vertical direction. Hip impact force was normalized to body weight (BW). Velocity was computed by numerical differentiation of position data and subsequently low-pass filtered with a

fourth-order Butterworth filter with a cut-off frequency of 10 Hz. Hip impact velocity was defined as the vertical velocity of the GT just before impact. Trunk angle (α) was defined by the angle between the line connecting the GT and shoulder marker and the vertical at hip impact, subtracted by the angle in the reference measurement (Figure 2.2c).

Figure 2.2 Mean values ± SEM (N = 6) of the impact data. The mean of the (a) hip impact force (normalized for body weight (BW)), (b) hip impact velocity in (m/s), and (d) trunk angle (°) for the block with arm technique (Block), the martial art technique with the use of the arm to break the fall (MA-a) and the martial art technique without the use of the arm (MA-na). (c) Trunk angle was defined by the angle between the line connecting the GT and shoulder marker and the vertical at hip impact (α) subtracted by the angle in the reference measurement. Impact is indicated by a broken arrow (⚡). Asterisks (*) indicate statistically significant differences (exact p < 0.05).

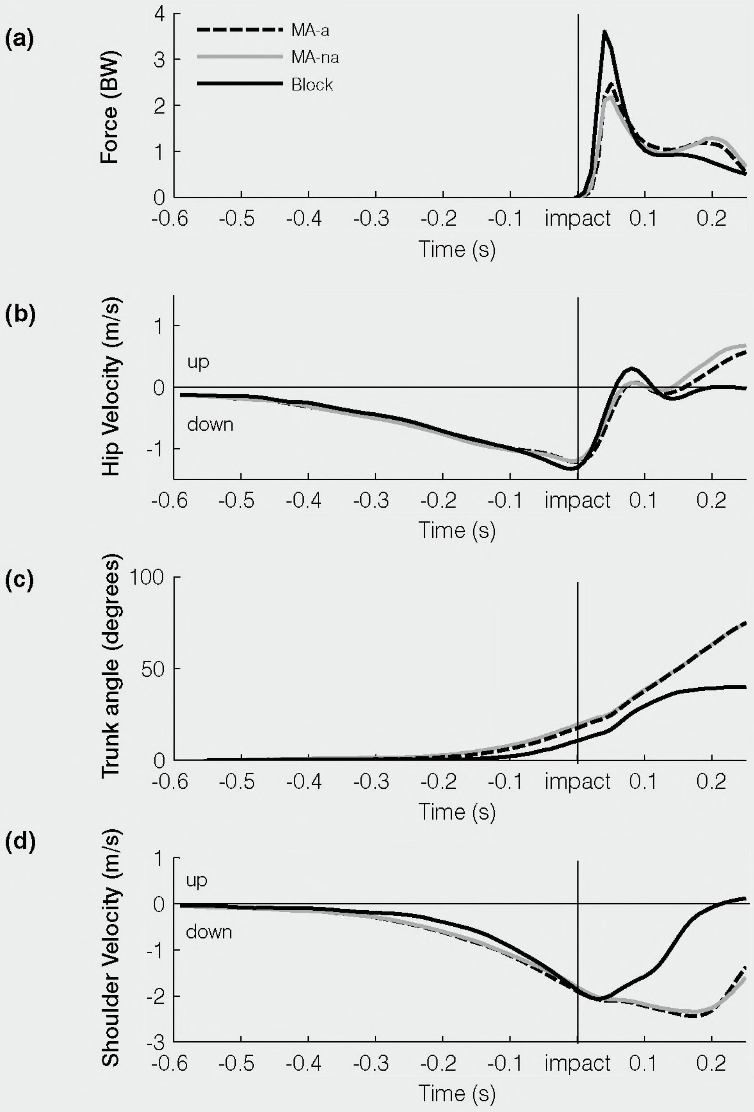


Data were averaged for each subject and for each technique. Because of the small number of subjects, non-parametric statistics were used. Differences between the techniques were examined with a non-parametric analysis of variance for repeated measurements (Friedman). Post-hoc, two-tailed Wilcoxon signed-ranks tests for matched pairs were used to detect directional effects. An exact p-value < 0.05 was considered statistically significant. In addition, the time curves of the impact force, hip vertical velocity, trunk angle, and shoulder vertical velocity of the three fall techniques were examined.

Results

The largest mean hip impact forces and velocities and the most vertical trunk orientations were found for the Block falls (Figure 2.2). The Friedman test revealed a main effect of technique on hip impact force ($Fr = 9.333$; $p = 0.006$), impact velocity ($Fr = 10.333$; $p = 0.002$), and trunk angle ($Fr = 8.333$; $p = 0.012$). Post-hoc comparisons showed that the MA-a and the MA-na technique significantly (both $p = 0.031$) reduced the hip impact force by 27.0% and 29.5%, respectively. The impact velocity was significantly lower in both the MA-a (Δ0.17 m/s; $p = 0.031$) and MA-na (Δ0.21 m/s; $p = 0.031$) falls compared to the Block falls. Further, a significantly less vertical trunk orientation was found in the MA-a (7.0^{o}; $p = 0.031$), but not for the MA-na falls (4.5^{o}; $p = 0.063$) compared to the Block falls. No significant differences between the MA-fall techniques were observed ($p > 0.05$). Figure 2.3 shows the time curves of the impact force, hip vertical velocity, trunk angle, and shoulder vertical velocity of the three fall techniques of one of the subjects. Note that the difference in hip vertical velocity between the Block and MA falls started just prior to hip impact. After hip impact, trunk angle, and shoulder vertical velocity increased in the MA falls.

Figure 2.3 Time curves of the (a) impact force (BW), (b) hip vertical velocity (m/s), (c) trunk angle (^{o}), and (d) shoulder vertical velocity (m/s) of the three fall techniques of one of the subjects. Note that the difference in hip velocity between the Block and MA falls started prior to hip impact. After hip impact, trunk angle, and shoulder vertical velocity increased in the MA falls. Impact is indicated by the vertical line.



Discussion

The results showed that the MA-a and MA-na techniques reduced the hip impact force in sideways falls from kneeling height by 27.0% and 29.5%, respectively. In comparison, Sabick et al. (1999) found a reduction of 12% as compared to their 'normal' tensed condition without hand impact. They suggested that hand impact would be responsible for this reduction. In contrast, our study showed that hand impact is not an essential element of the MA technique in the reduction of hip impact force since no significant differences were found between the MA techniques with or without arm involvement. Hence, hand impact in the MA technique was not essential in protecting the hip, but this does not imply that hand impact had no benefits at all. Hand impact might play an essential role in protecting the head and shoulder. However, this could not be tested in the present study.

In conjunction with decreased hip impact force, hip impact velocity was significantly reduced in the MA falls. As shown in Figure 2.3, differences in hip impact velocity between the Block and MA falls started prior to hip impact. Analysis of the time curves of the GT and shoulder marker (velocities) could not reveal a clear explanation for the change in impact velocity. Since trunk rotation is important in the preparation for landing in the MA falls, changes in hip velocities might coincide with the initiation of trunk rotation, but further research is needed on this issue.

The trunk orientation was less vertical in the MA falls than in the Block falls, but the difference was significant only for the MA-a falls. It indicates that trunk orientation might be of less importance than impact velocity for the MA techniques to reduce hip impact force. Theoretically, the effects of trunk orientation are not clear either. According to simple impact models a less vertical trunk orientation would result in a lower effective mass and thereby reduce the impact force (van den Kroonenberg et al., 1995). However, others predicted that a less vertical trunk orientation would increase the exchange of potential energy to kinetic energy during a fall and increase the impact velocity (Sandler and Robinovitch, 2001). The increase in impact velocity would increase the impact force and thereby counterbalance the effects of a lower effective mass.

Another feature of the MA fall techniques that may play an important role in the reduction of hip impact force is the rolling movement after impact. Because of

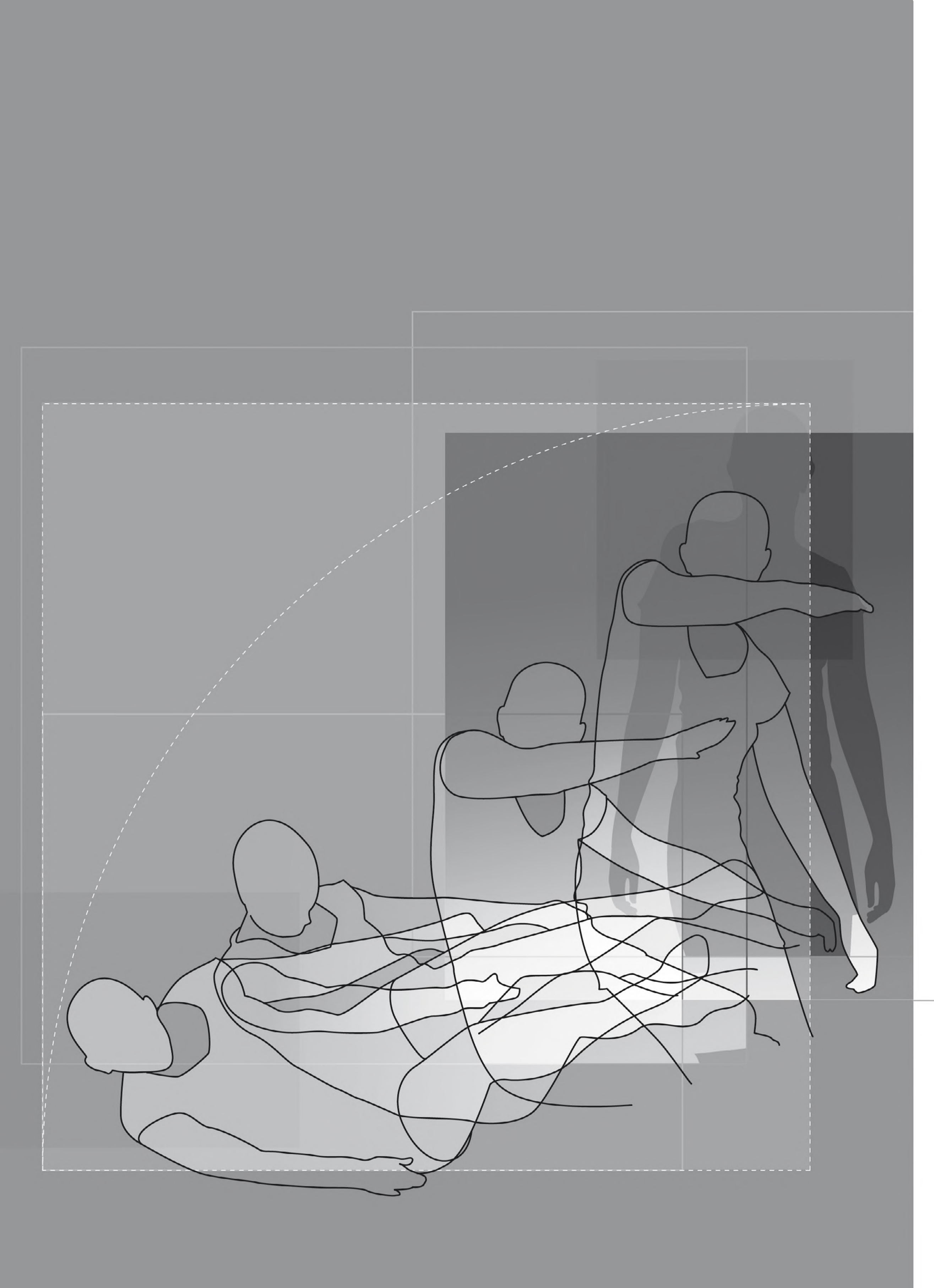
this rolling movement the kinetic energy of the upper body segments after impact is expected to be higher in MA falls than in Block falls, which could lead to reduced energy absorption and, consequently, lower forces at impact. The amount of kinetic energy is determined by the mass (which is a constant in a within-subject comparison) and velocity of the moving segments. Hence, in the present study the larger shoulder velocity in the MA falls after impact (Figure 2.3), indicative of increased kinetic energy, provides support for the proposed role of rolling in the reduction of hip impact force.

The falls performed in the present study differ in some aspects from most falls in daily life. For safety reasons, the falls were performed from kneeling height and not from standing height. The principles of the MA techniques, however, are the same for both fall heights. Therefore, it is expected that the working mechanisms of the MA techniques in falls from kneeling are similar to those in falls from standing. The absolute increase in impact forces due to the increase in fall height, however, can be expected to be relatively small, because in falls from standing height there are additional impact reducing mechanisms, such as squatting during descent (Robinovitch et al., 2004). In addition, the falls in the present study were self-initiated while most falls in daily life are unexpected. Although it will decrease the absolute impact values (Robinovitch et al., 2004), self-initiated falls are useful to study the effects and underlying mechanisms of different fall techniques. Whether such techniques can be used to reduce hip impact force in falls in the elderly remains a question for further research, preferably involving elderly. Experiences with these techniques within the Nijmegen Falls Prevention Program (Weerdesteyn et al., 2006) were promising. Elderly could learn these techniques within five training sessions and some participants reported that they had used these techniques in falls in daily life.

In summary, the MA fall techniques reduced the hip impact force by more than 25%, which was associated with a lower impact velocity and less vertical trunk orientation. Rolling after impact, which is characteristic for MA falls, is likely to contribute to the reduction of impact forces, as well. Hand impact was not an essential element of the MA technique in the reduction of hip impact force. These findings provided support for the use of MA fall techniques in fall prevention programmes for elderly.

Acknowledgements

This study was supported by the POM, Nijmegen, the Organization for Healthcare Research in the Netherlands (ZonMW), and an EU grant (Eurokinesis, QLK6-CT-2002-00151).



3

Chapter

The relation between hip impact velocity and hip impact force differs between sideways fall techniques

Based on

B.E. Groen, V. Weerdesteyn, and J. Duysens

Journal of Electromyography and Kinesiology 18(2):228-234, 2008

Introduction

Hip fractures are a major health problem in the elderly. Epidemiological studies predicted that the number of hip fractures in the world would have risen to at least 4.5 million by the year 2050 (Cooper et al., 1992; Gullberg et al., 1997). The related financial burden is high. The mean direct medical costs in the Netherlands are 14,000 Euros for each older individual with a hip fracture (Consument en Veiligheid, 2005). In addition, hip fractures are related to high mortality and morbidity rates. About 90% of the hip fractures are caused by falls (Cumming and Klineberg, 1994). Hence, hip fracture risk can be reduced, either by preventing the fall or by limiting the severity of the fall.

In falls, fracture risk is dependent on both the severity of the impact and the capacity of the bones to resist the impact applied. Hence, fracture risk can be defined by the ratio of forces at impact divided by the load necessary to cause a fracture (DeGoede et al., 2003; Hayes et al., 1996). In vitro studies have shown that the fracture load of the femur is dependent on for example the direction of impact (Pinilla et al., 1996), loading rate (Courtney et al., 1994) and bone mineral density of the femur (Courtney et al., 1995). In agreement with these in vitro studies, clinical studies have shown that bone mineral density and fall direction are important risk factors for hip fractures (Greenspan et al., 1994). Falls with most risk for hip fractures are those to the side with direct impact on the greater trochanter of the proximal femur (Nevitt and Cummings, 1993). In contrast, little is known about strategies that reduce fall severity. The fundamental variable for fall severity is impact force. For safety reasons, however, direct impact force measurements are often not possible and instead kinematic data are used to compare differences in severity between fall techniques (Robinovitch et al., 2003; van den Kroonenberg et al., 1996). In the present study the focus will be on how these indirect variables of fall severity relate to impact force in different fall techniques.

It has been estimated that the impact force of any fall from standing height with impact on the greater trochanter is sufficient to fracture the elderly hip (Courtney et al., 1994; Nankaku et al., 2005; Robinovitch et al., 1991). In a fall from standing, hip impact occurs about 0.7 s after the onset of a perturbation (Hsiao and Robinovitch, 1998). Hence, there is only a short time available to react and apply a fall technique. Hip fractures rarely occur among young individuals, even

among athletes who regularly fall onto hard surfaces, and even in elderly such fractures occur only in 1-2% of falls in elderly (Tinetti et al., 1988). Therefore, Hsiao and Robinovitch (1998) hypothesized that highly effective movement strategies exist for preventing injury during a fall. To study such fall strategies and to evaluate how falls can be avoided, Hsiao and Robinovitch (1998) measured the natural reactions to an unexpected translational movement of the underground covered with a mattress. Young subjects started in a standing position and were instructed to try to prevent themselves from falling. After lateral-directed perturbations that would cause sideways falls, subjects were able to avoid a fall in 72% of the trials. During falls with impact of the trunk or pelvis, the average downward impact velocity of the pelvis was 2.55 ± 0.85 m/s. During sideways falls, subjects showed large trunk rotations about an inferior-superior axis in forward direction during descent. They used their outstretched hands to avoid impact to the lateral aspect of the hip. Avoidance of hip impact might be useful to decrease the risk of hip fractures, since it has been shown that falling on or near the hip increases the risk of hip fracture by thirtyfold (odds ratio 32.5) (Nevitt and Cummings, 1993). By changing a sideways fall into a forward fall the use of the outstretched arms is essential to protect the head and trunk for impacting the ground. However, this is a risk by itself, since it has been shown that using the hands will increase the risk to wrist fractures by twentyfold in older individuals (odds ratio 20.4) (Nevitt and Cummings, 1993). Furthermore, it is questionable whether older individuals have enough arm muscle strength to prevent head and trunk impact (DeGoede et al., 2003).

In addition to forward rotation, Robinovitch et al. (2003) studied also backward rotation as a technique to avoid hip impact during a sideways fall. Rotating backward may be beneficial, since impacting the ground with outstretched hands is not needed and landing on the buttocks may result in more energy absorption by soft tissues. During the experiment, young female adults performed sideways falls from standing position onto a mattress. Falls were initiated by release of a tether that supported the subjects at a 15^{o} lean angle from the vertical. Prior to tether release, the subjects were instructed to rotate forward during descent to land on the outstretched hands or to rotate backward during descent to land on the buttocks. The results showed that the average time interval between tether release and hip impact was larger during forward rotation (1135 ± 128 ms versus 993 ± 102 ms). This might be due to hand and knee impact prior to pelvis impact

during falls with forward rotation. Backward rotation was as effective as forward rotation to avoid hip impact as measured with the amount of axial rotation. However, impact velocity was larger in falls with a backward rotation (2.95 ± 0.25 m/s) as compared to falls with a forward rotation (2.45 ± 0.77 m/s) technique. In addition, whole-body kinetic energy at impact was larger in the falls with backward rotation as well (2.38 ± 70 J versus 156 ± 90 J). These results indicate an increased impact severity during falls with backward rotation as compared to falls with forward rotation to avoid hip impact. Since falls without trunk rotation were not included in the study of Robinovitch et al (2003), it remains unclear whether forward and backward rotation led to different impact velocity as compared to sideways falls with no rotation.

In daily life, falls are in most cases unexpected and fall strategies can rarely be planned before fall initiation. Therefore, Feldman and Robinovitch (2004) conducted an experiment in which the instruction to rotate backward or forward was given at various instants (300 ms, 200 ms, 100 ms and 0 ms) both before and after release. Subjects were able to follow the instruction as long as the instruction was given within 200 ms after release. In falls with instructions given with long delays (200 ms and 300 ms) after release, subjects performed more rotation in the backward rotation technique as compared to the forward rotation technique.

In addition to fall direction, relaxing the body is considered to be an important strategy to reduce fall severity. Based on the results of pelvis release experiments Robinovitch et al. (1991) predicted a decrease in peak impact force from 8600 N to 5600 N by relaxing the muscles as compared to activating the muscles during a sideways fall. To simulate sideways falls, young subjects were released from different preload force levels from zero height with their hip onto a force plate. Force characteristics were used to measure the effective stiffness and damping of the body, which were used to predict peak forces in falls from non-zero height.

In agreement with the results of the pelvis release experiments, Nankaku et al. (2005) observed a positive correlation between the activity of the quadriceps muscle (as index of relaxation) and the impact force in voluntarily sideways falls from standing height. During the experiments young adults fell voluntarily onto a force plate covered with a mattress. The subjects were instructed to avoid protective movements such as stepping, knee bending and landing on their arms. The mean vertical impact force was 2251.6 ± 442.4 N in lateral falls and

2497.7 ± 457.0 N in posterolateral falls. The mean vertical impact velocities were in lateral and posterolateral falls (1.99 ± 0.32 m/s versus 2.25 ± 0.35 m/s).

Studies that evaluated the effect of relaxing the body during real falls were less clear about the reducing effect on fall severity. In support of the results of Robinovitch et al. (1991), van den Kroonenberg et al. (1996) found a lower vertical impact velocity for the relaxed falls (3.09 ± 0.41 m/s) than for the natural muscle active falls (3.31 ± 0.43 m/s), which suggests a lower impact force in the relaxed falls. However, they also observed a reduction in trunk angle at impact (corresponding to a more vertical trunk) during the relaxed falls (21.8 ± 10.4^{o}) as compared to the muscle active falls (13.6 ± 11.2^{o}). A more vertical trunk orientation is associated with a larger effective mass and subsequently to an increased impact force. This latter effect may reduce or even negate the expected reduction in impact force by the reduced impact velocity in muscle-relaxed falls.
However, Sabick et al (1999) found no significant differences in impact force between relaxed and 'normal' tensed falls during falls from kneeling height, although the impact forces tended to be lower during the relaxed falls. In the latter study, young adults with experience in martial arts started in kneeling position next to a padded force plate and received the construction which technique they had to perform after voluntarily initiation of the fall. No hands were used to block the fall in both the tensed and relaxed falls. The resultant hip impact forces (normalized for body weight) were 2.69 ± 0.68 BW and 2.76 ± 0.83 BW during the relaxed falls and tensed falls, respectively.

In the same study Sabick et al. (1999) have shown that martial arts fall techniques (MA) could reduce the hip impact force as compared to the 'normal' tensed falls (2.44 ± 0.70 BW versus 2.76 ± 0.83 BW, force normalized for bodyweight). In MA, a fall is changed into a rolling movement, which allows for an optimal distribution of the impact applied to any site along the contact path. In MA falls the arm was used to break the fall by slapping onto the ground (after hip impact) resulting in high impact forces at the wrist.

Recently, the reducing effect of the MA techniques on fall severity has been confirmed in a study in our laboratory (Groen et al., 2007). Young subjects with experience in judo performed sideways falls from kneeling height unto an unpadded force plate. In a similar experimental set-up as used by Sabick et al. (1999) we observed a reduction in impact force by about 27.0% in the MA falls with use of the arm to break the fall as compared to 'natural' falls in which the arm

was used to block the fall (Block). Vertical impact velocity was reduced by 12% and the trunk was 7° more horizontally oriented at the instant of hip impact. In addition, no differences were found between an MA fall with or without use of the arm, suggesting that hand impact played no essential role in protection of the hip in the MA technique.

In summary, several strategies to reduce fall severity during sideways falls have been studied, including rotating backward and forward (Robinovitch et al., 2003), relaxing the body (Sabick et al., 1999; van den Kroonenberg et al., 1996), and MA fall techniques (Sabick et al., 1999; Groen et al., 2007). All fall techniques have been evaluated in young adults. Further research is needed to determine whether such techniques can be used to reduce fall severity and subsequently hip fractures in older individuals. In the studies mentioned many differences existed in experimental set-up, for example, differences in fall height (standing or kneeling), in fall initiation (tether release, moving the ground surface or voluntarily) and underground (mattress or floor). Because of these differences, it is often difficult to compare the reduction in impact severity of fall techniques between studies. In addition, different kinematic variables for fall severity have been used, in particular vertical impact velocity.

The rationale for the use of impact velocity to determine fall severity is based on simple impact models. In these models, the body is represented as an undamped single-degree-of-freedom mass-spring system with a linear spring constant. The spring constant accounts for soft tissue overlying the hip and the stiffness of the body, including the action of the muscles (van den Kroonenberg et al., 1995). It is assumed that all of the kinetic energy of the body is transformed into the strain energy of the spring. In such model, impact velocity is proportional to impact force. The effects of damping and energy lost to friction are neglected. Furthermore, is assumed that the effective mass of the part of the body that is moving prior to impact remains constant during impact. If these models are used to compare different fall techniques based on differences in impact velocity it is assumed that the effective mass is similar in these techniques. However, in falls in vivo it is has not been studied yet if all these assumptions sufficiently apply and if not, how this would affect fall severity estimates as based on impact velocity.

In a previous study (Groen et al., 2007), a larger reduction in vertical hip impact force (27-30%) was found than in vertical hip impact velocity (12-15%) for MA falls as compared to Block falls. This indicates that differences in impact

velocity are not necessarily similar to differences in impact force. It was suggested that the reduced hip impact force in the MA fall techniques resulted from a smaller amount of energy absorption as a result of rolling on after impact that is characteristic of MA falls. In MA falls a smaller amount of kinetic energy is transformed into the strain energy. This indicates that the relationship between impact velocity and impact force might be different for various fall techniques due to differences in energy absorption, which might affect the predicted fall severity as based on impact velocity.

The purpose of this study is to assess the relationship between hip impact velocity and hip impact force in order to determine whether differences in hip impact force between different fall techniques can be predicted by impact velocity.

Methods

Five experienced female judokas (age: 23.8 ± 4.1 years, weight: 59.4 ± 5.9 kg and fall experience 11.8 ± 6.8 years) participated in this study. The protocol was approved by the Ethical Board of the region Arnhem-Nijmegen and all participants signed informed consent prior to participation.

Participants performed three sideways fall techniques from kneeling height onto an unpadded force plate, namely, the 'natural' Block (Figure 3.1a) and two MA techniques. In the MA-a falls the arm is used to break the fall (Figure 3.1b), and in the MA-na falls the arm was held above the ground. The testing procedures were similar to those described previously in more detail (Groen et al., 2007). After voluntary initiation of the fall to the left, participants received an instruction, about which technique they had to perform. A total of 10 falls for each technique were performed. One participant (one of the authors, VW) performed the total protocol on four more occasions. In addition, she volunteered for five additional series of 10 voluntary falls from standing height using the MA technique with the use of the arm to break the fall (MA-s).

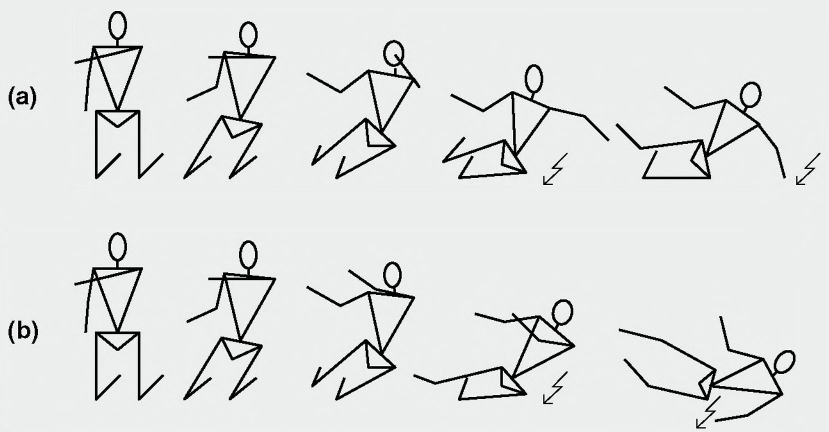
Force (Kistler, 2400 Hz) and kinematic data (Primas, 100 Hz) were measured to determine the peak hip impact force (normalized for bodyweight) and the hip impact velocity (one frame before impact) (Groen et al., 2007). In agreement with most other studies in which fall techniques were evaluated for reduction on fall

severity, force and kinematic data were analysed in vertical direction only.

Analysis of variance (ANOVA) was used to determine whether hip impact force and hip impact velocity were affected by fall technique. Post-hoc, *t*-tests with Bonferroni corrections were used to determine between which fall techniques the differences existed.

A linear regression model was used to determine the relationship between hip impact force (dependent variable) and hip impact velocity (independent variable) for each fall technique for both the group of judokas and the single judoka. In addition, the effect of fall technique (reflected by differences in intercept) and the interaction between fall technique and impact velocity (reflected by differences in slope) were determined by including dummy variables for technique and technique multiplied with impact velocity in SPSS. For the linear regression models, the criterion to entry and staying in the model for regressors was set at $p = 0.05$ and $p = 0.1$, respectively. The level of significance was set at $p = 0.05$ for all tests.

Figure 3.1 Stick figures showing the falls from kneeling height (frontal view) using the (a) Block with arm technique (Block). (b) MA technique with the use of the arm to break the fall (MA-a). Impact is indicated by a broken arrow (Reprinted from Groen et al. (2007), with permission from Elsevier).



Results

For the group of judokas, only one fall had to be discarded due to technical problems. Table 3.1 presents the average hip impact force (normalized for body weight) and hip impact velocity for each technique. The average hip impact force was in the hip impact velocity were on average 30% and 12% lower in the MA falls than in the Block falls. No significant differences were found between the two MA techniques from kneeling height. In further analysis MA-a and MA-na falls from kneeling height were combined and referred to as MA technique from kneeling height.

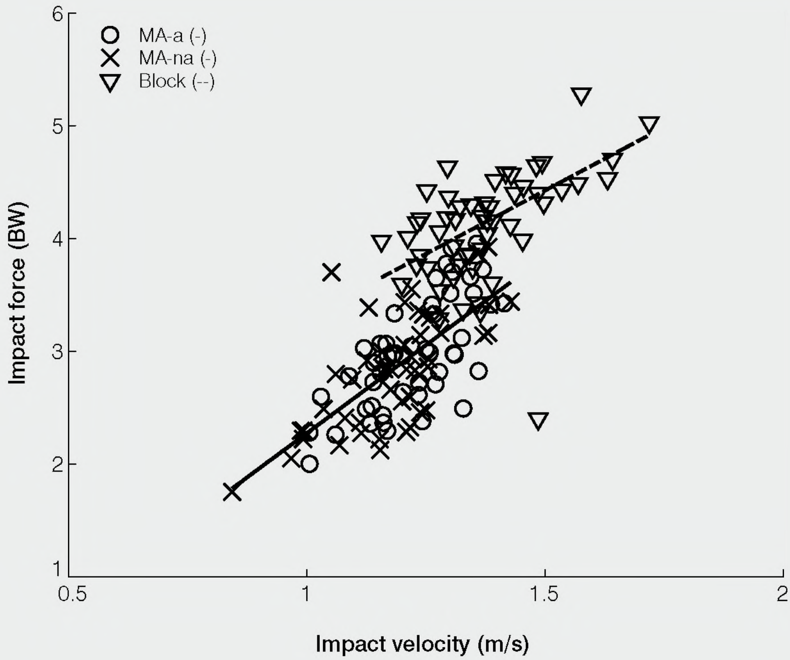
Figure 3.2 shows the relationship of the hip impact force and hip impact velocity for each fall technique. In falls with comparable velocities, impact forces in Block falls were larger than in MA falls from kneeling height. Impact velocity could explain 40% and 50% of the variance in impact force within the Block technique and MA technique from kneeling height, respectively ($p < 0.001$) (Table 3.2). The linear regression model of the Block and MA technique from kneeling height together showed a linear relation between impact velocity and impact force ($p < 0.001$, beta = 0.580), which was dependent on technique ($p = 0.006$, beta = 1.21). No interaction was observed between technique and impact velocity ($p = 0.91$, beta = 0.77).

Table 3.1 Mean (SD) hip impact force (normalized for bodyweight (BW)) and hip impact velocity (m/s) for each technique.

Fall technique	Group judokas		Single judoka	
	Force (BW)	Velocity (m/s)	Force (BW)	Velocity (m/s)
Block	4.14 (0.43)[a]	1.37 (0.12)[a]	4.30 (0.49)[a]	1.39 (0.09)[a]
MA-na	2.83 (0.51)	1.18 (0.12)	2.59 (0.34)	1.28 (0.10)
MA-a	2.97 (0.48)	1.22 (0.10)	2.47 (0.33)	1.26 (0.11)
MA-s	-	-	4.45 (0.73)[a]	2.30 (0.19)[a,b]

[a]= significantly different from MA technique from kneeling height (MA-a and MA-na).
[b]= significantly different from Block technique.

Figure 3.2 Impact force (normalized for body weight) plotted as a function of impact velocity (m/s) for falls of the group of judokas. Each fall is represented by one symbol.



3

Table 3.2 Linear relationship between hip impact velocity and hip impact force for each fall technique.

Fall technique	Group judokas		Single judoka	
	r^2	*p*-value	r^2	*p*-value
Block	0.395	<0.001	0.196	0.001
MA-a & na	0.493	<0.001	0.468	<0.001
MA-s	-	-	0.247	<0.001

r^2=explained variance of hip impact force by hip impact velocity.

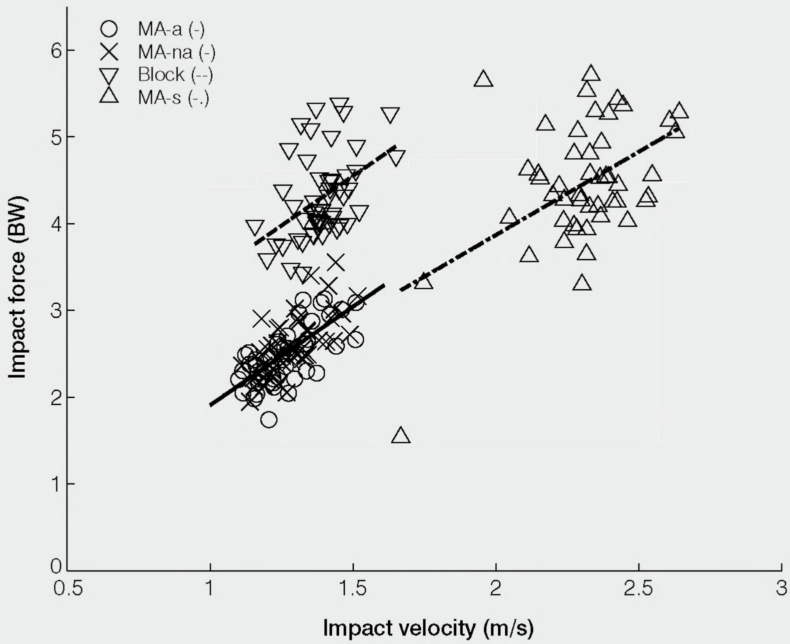
One of the authors volunteered for the extended protocol, including a series of MA falls from standing height (MA-s). Table 3.1 presents the average hip impact force and hip impact velocity for each technique for this single subject. On average hip impact force and hip impact velocity in the MA falls from kneeling height were about 42% and 9% lower than in the Block falls. For the MA-s falls hip impact force was comparable to the hip impact force of the Block falls from kneeling height, whereas hip impact velocity in the MA-s falls was higher. As previously found in the group of judokas, no significant differences were found between the MA techniques from kneeling height.

Figure 3.3 shows the relationship of the hip impact force and hip impact velocity for each technique for the single subject. It is evident that for a given range of impact velocities there clearly were higher impact forces in the Block falls than in the MA falls from kneeling height (MA-a and MA-na). In general, Figure 3.3 mirrors the data of the group of judokas (Figure 3.2). Impact velocity could explain 20-47% of the variance in the hip impact force within the techniques ($p < 0.001$) (Table 3.2). The linear regression model of the Block and MA technique from kneeling height together showed a linear relation between impact velocity and impact force ($p < 0.001$, beta = 0.28). The effect of technique bordered significance ($p = 0.068$, beta = 0.68) and no significant interaction effect was found ($p = 0.975$, beta = -0.14). No effect of technique was likely to be due to the low explained variance (20%) in the Block technique. In addition, the linear regression model for the MA technique from kneeling height was not different from the model for the MA technique from standing height (MA-s) ($p = 0.666$ and $p = 0.502$ for intercept and slope, respectively).

Discussion

The purpose of the study was to assess the relationship between hip impact velocity and hip impact force in order to determine whether differences in hip impact force between fall techniques can be predicted by hip impact velocity. Based on simple impact models it is assumed that impact velocity is proportional to impact force. The results of the present study showed that hip impact velocity and hip impact force were significantly, linearly related within each fall technique (Block, MA from kneeling and standing height). The strength of the relationship

Figure 3.3 Impact force (normalized for body weight) plotted as a function of impact velocity (m/s) for falls of the single judoka. Each fall is represented by one symbol.



was low to moderate (explained variance 20-50%), meaning that hip impact velocity may only be used to make an approximate prediction of hip impact force.

Furthermore, the relationship between hip impact velocity and hip impact force depended heavily on the fall technique used. In falls with comparable impact velocities, the impact forces in the Block falls were larger than those in the MA falls from kneeling height. In addition, the data of the single judoka showed that in falls with comparable impact forces, the impact velocities were much larger in MA falls from standing height than in Block falls. This means that differences in hip impact velocity do not always reflect differences in hip impact force between different fall techniques. In other words, hip impact velocity is not always a valid predictor of differences in hip impact force between techniques. The finding of

lower impact forces in falls with similar impact velocities for the MA technique supports the hypothesized effects of rolling on after impact in MA falls as a mechanism to reduce the hip impact force (Groen et al., 2007). Rolling on means a higher kinetic energy of the body after impact, which might result in a smaller amount of kinetic energy transformed into strain energy. Consequently the impact force might be lower than predicted by impact velocity prior to impact. Given the importance of kinetic energy after impact in the reduction of impact forces, combining impact velocity with energy estimates before and after impact might provide a more valid algorithm to determine fall severity, when direct impact force measurements are not possible. In the present study, the number of reflective markers was too small to estimate the amount of kinetic energy of the whole body during falling. In addition to the kinetic energy of the body after impact, other factors, such as body configuration at impact, soft tissue characteristics (van den Kroonenberg et al., 1995), damping and bodyweight might affect the relationship between hip impact velocity and hip impact force as well.

Interestingly, the linear regression model for the MA technique from standing height seemed not to be different from the model for the MA technique from kneeling height in the single subject. This supports the assumption that the principles and working mechanisms of MA falls are similar for falls from standing and kneeling height (Groen et al., 2007). This is important since experiments with falls from kneeling height are validated in this way and are increasingly important for the evaluation of fall severity in both young and elderly subjects.

A limitation of the study was the small number of experienced female judokas included in this study. With a larger number of judokas, the relationship between hip impact velocity and hip impact force might have been stronger due to increased power and probably larger ranges in impact velocity and force.

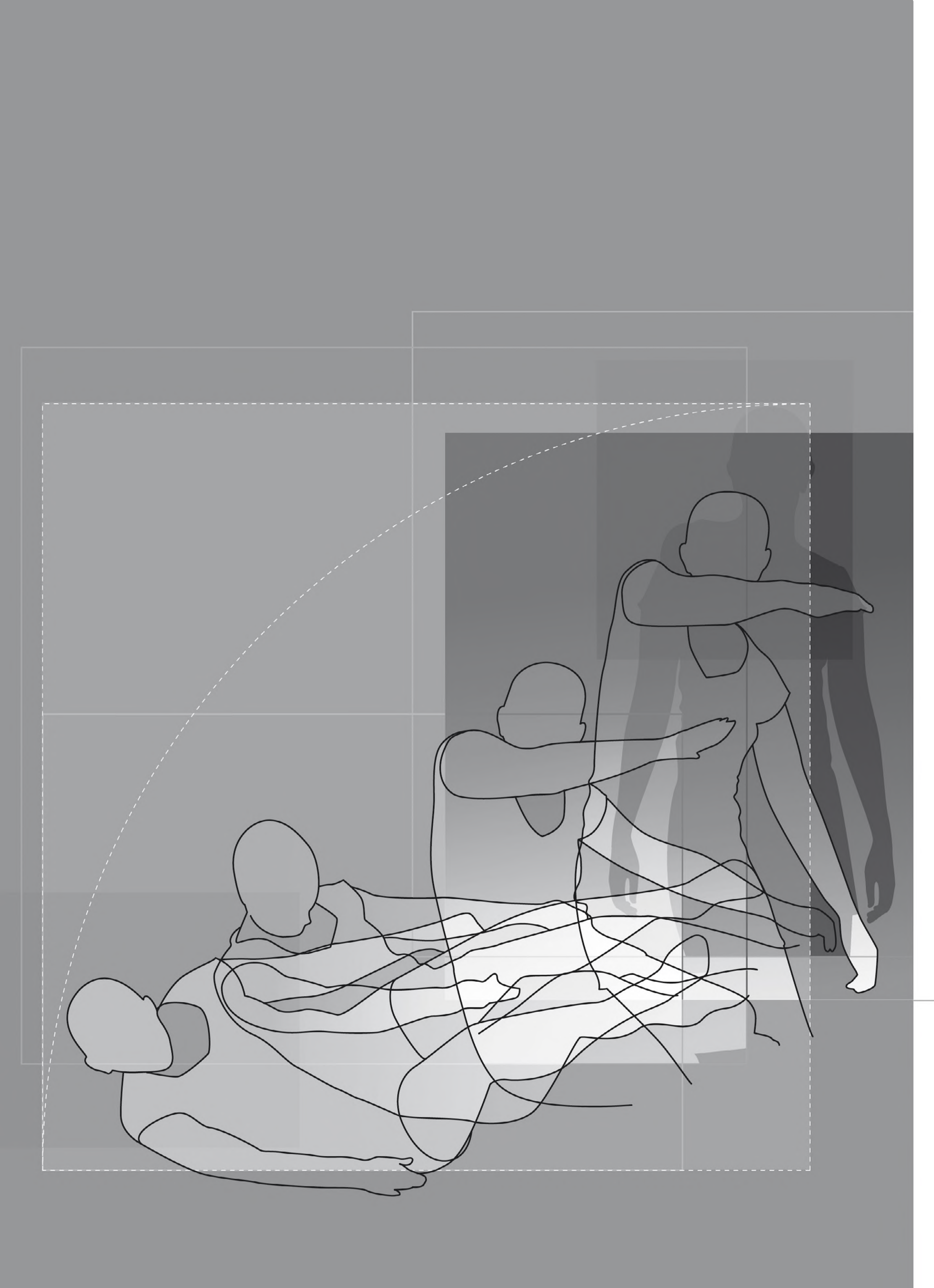
A second limitation was that the falls in the present study were self-initiated, while most falls in daily life are unexpected. Although this factor probably reduced the absolute impact values (Robinovitch et al., 2004), and although it might even affect the relationship between impact velocity and impact force within techniques, it is expected that differences between the techniques will remain since underlying mechanism of different fall techniques is similar in unexpected falls and self-initiated falls.

In conclusion, hip impact velocity can be used to make an approximate prediction of hip impact force within fall techniques. However, to determine

differences between techniques it is not always a valid predictor. When direct impact force measurements are not possible, methods combining impact velocity with energy estimates before and after impact are likely to be more valid.

Acknowledgements

This study was supported by the POM, Nijmegen and the Organization for Healthcare Research in the Netherlands (ZonMW)



4

Chapter

Martial arts fall techniques reduce hip impact forces in naïve subjects after a brief period of training

Based on

V. Weerdesteyn, B.E. Groen, R. van Swigchem, and J.Duysens

Journal of Electromyography and Kinesiology 18(2):235-242, 2008

Introduction

Hip fractures in the elderly are among the most serious consequences of falls. Mortality after a hip fracture is 5-10% within the first month (Roche et al., 2005) and even about 30% within a year (Roche et al., 2005; Keene et al., 1993). Furthermore, hip fractures are a common cause of loss of independence or institutionalization. As a result, hip fractures constitute a major burden on health care systems in developed countries, both clinically and financially. Within the next decades, this burden is expected to become much larger, given the aging of the population and the exponential increase of hip fracture incidence with age (Gallagher et al., 1980).

About 90% of hip fractures are caused by falls (Cumming and Klineberg, 1994) and both sideways fall direction (Greenspan et al., 1994) and an impact site at or near the hip (Nevitt and Cummings, 1993) are major determinants of hip fracture risk. A reduction of the number of hip fractures can be assumed the logical result of a reduction of fall incidents in general. Previous research has convincingly shown that exercise programmes can reduce fall incidence rates by up to 50% (Weerdesteyn et al., 2006; Gillespie et al., 2003; Province et al., 1995). However, a considerable number of falls and consequent hip fractures remain even after such an intervention. Hence, it is expected to be beneficial if interventions would not only aim at a reduction of fall incidence, but also of fall severity. In this respect, the use of hip protectors has been suggested to absorb the impact energy or shunt it away from the hip, but compliance is poor and even their efficacy in fracture risk reduction is not unequivocally proven yet (Parker et al., 2005).

Alternatively, the practice of fall techniques, in order to achieve the safest possible landing after loss of balance, may possibly contribute to a further reduction of fall-related hip fractures. Which fall techniques would be both effective and suitable for elderly is still a matter of debate. It has been shown that using the arm to block the impending fall results in a threefold reduction of the likelihood of hip fractures (Nevitt and Cummings, 1993). When the elbow is not held straight, but slightly flexed at impact, followed by eccentric triceps activity, this fall arrest strategy could go without sacrificing the wrist (DeGoede and Ashton-Miller, 2002). However, in the elderly an age-related reduction in triceps strength will significantly reduce their ability to use their arms for safe fall arrest (DeGoede and Ashton-Miller,

2003). Secondly, the arm is likely to be too late for hip protection in the elderly. Even in young subjects, experimental fall data show mixed results with respect to the sequence of arm and hip impacts (Hsiao and Robinovitch, 1998; van den Kroonenberg et al., 1996). In older subjects the probability of a late hand impact further increases, as the time to move their hands into a position for breaking a fall was considerably longer than in the young (Robinovitch et al., 2005). The observation in epidemiological studies that the incidence of wrist fractures in the elderly remains at a relatively constant level with increasing age (Owen et al., 1982), whereas the incidence of hip fractures increases exponentially (Gallagher et al., 1980) also provides support for the ineffectiveness of the use of an outstretched arm in protecting the hip in the elderly.

A more promising landing strategy appears to be the martial arts (MA) way of falling, as this technique has been shown to significantly reduce hip impact forces in falls to the side in experienced martial artists (Groen et al., 2007; Sabick et al., 1999). The main feature of MA fall techniques is rolling on after impact, as opposed to the rather abrupt landing in the 'natural' fall arrest strategy. MA techniques reduced hip impact forces by 27.0-29.5%, in conjunction with a 12-15% decrease in impact velocity. In addition, larger upper body velocities in MA falls after hip impact, indicative of less energy dissipation at the instant of impact, provided support for the role of rolling in the reduction of hip impact force.

Recently, MA fall techniques have been introduced in a fall prevention exercise programme (Weerdesteyn et al., 2006). Elderly could learn these techniques within five 45-min training sessions and some participants reported that they had used the technique in a fall in daily life. However, even though the techniques are easy to learn and seem to be executed correctly after a short training, it is not known yet whether extensive training is required in order to benefit from these techniques in terms of impact force reduction. The present study was conducted to investigate whether a reduction in hip impact forces could be demonstrated in naïve young subjects after a brief training in MA fall techniques. It was hypothesized that a reduction of at least 10% could be achieved in hip impact forces. The anticipated reduction, however, was expected to be less than in very experienced martial artists (judokas; (Groen et al., 2007)). Furthermore, it was hypothesized that the experienced judokas and the briefly trained subjects would show some basic differences in the execution of the MA fall technique, thereby explaining the anticipated superiority of the technique as applied by the judokas.

In order to identify such potential experience-related differences in the execution of the MA technique, an additional study was conducted in which EMG patterns of selected trunk, neck, and shoulder muscles were compared between experienced fallers and young subjects (without prior experience) after a brief training session.

Methods

Fall experiments were conducted in a group of healthy, young women, with and without experience in martial arts fall techniques. Prior to the experiments, participants without judo experience were administered a 30-min training session in which they practiced sideways MA fall techniques on a safety mat (4 cm polyurethane foam, Agglorex®, Lommel, Belgium). A sideways MA fall technique is characterized by trunk lateral flexion and rotation and shoulder protraction in order to enable rolling on after impact. This allows for an optimal distribution of impact applied to any site along the contact path. Furthermore, in contrast to the 'natural' way of falling, in MA techniques the arm is not used to block the impending fall, but can be slapped on the ground after hip and trunk impact. The final fall height during training was from a kneeling position. None of the participants suffered from any neurological or musculoskeletal disorders that could affect their performance and/or behaviour in this study. The Ethical Board of the region Arnhem-Nijmegen approved the protocol and participants gave informed consent to participate.

Part 1

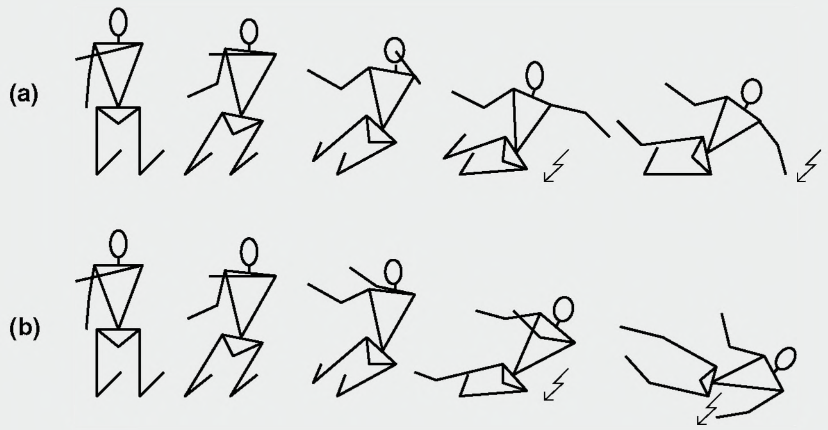
Participants

Ten young women (age 28.3 ± 6.6 years, weight 65.0 ± 6.6 kg) without any prior experience in martial arts fall techniques participated in this experiment.

Experimental procedure

In this experiment, MA techniques with and without the use of the arm (MA-a and MA-na, respectively) were compared with the commonly observed way of falling, in which the outstretched arm is used to block the impending fall (Block technique)

Figure 4.1 Stick figures showing the falls from kneeling height (frontal view) using the (a) Block with arm technique (Block), and (b) MA technique with the use of the arm to break the fall (MA-a). Impact is indicated by a broken arrow. Figure 4.1 is reprinted from Groen BE, Weerdesteyn V, Duysens J. Martial arts fall techniques decrease the impact forces at the hip during sideways falling. J Biomech 2007; 40:458-62, Copyright (2007), with permission from Elsevier Science.



(Figure 4.1). The MA-na technique is similar to the MA-a technique, except that the left arm was held above the ground. Participants were kneeling on a padded surface next to a force plate (unpadded surface, 60 cm x 40 cm, Kistler) with the left arm in front of them (90^{o} of shoulder anteflexion). They were instructed to start falling to the left. Once the experimenter had visually detected fall initiation, a verbal (single syllable) cue was given as to which technique the participant had to perform. Instructions were given by the same experimenter in order to avoid systematic differences between trials and subjects. The experimenter also controlled visually whether the position of hip impact was on the force plate. Analogous to our previous study in experienced fallers (Groen et al., 2007), two series of 15 falls were performed. One series consisted of 5 Block falls and 10 MA-a falls. In the other series, MA-a falls were replaced by the MA-na fall. Within each series, the falls were performed in random order. In addition, the order of the series was also randomized.

Forces were measured by the force plate at a sample rate of 2400 Hz. Fall kinematics were obtained by means of a 6-camera 3-D Motion analysis system (Primas) at a sample rate of 100 Hz and recordings were synchronized with force plate data. Reflective markers were placed on the wrist and the greater trochanter (GT), and a rigid marker frame with three markers was attached to the left femur. In a reference measurement, the position of the GT marker with respect to the marker frame was recorded and subsequently removed before the fall trials.

Analysis and statistics

The instant of impact was defined as the instant at which the vertical force exceeded 10 N. As in both Block and MA-a techniques the hand always impacted later than the hip, hip impact force was defined as the first peak force in the vertical direction and was normalized with respect to body weight (BW).

In order to determine hip impact velocity, the position of the GT during falls was calculated based on the position and orientation of the femur marker frame using the method described by Söderkvist and Wedin (1983). Hip impact velocity was computed by numerical differentiation of these virtual GT position data. Data were low-pass filtered with a fourth-order Butterworth filter with a cut-off frequency of 10 Hz. Hip impact velocity was defined as the vertical velocity of the GT just prior to impact.

Differences in impact forces and velocities between techniques were examined by means of analyses of variance for repeated measures with post-hoc contrasts. The alpha level was set at 0.05.

Part 2

Participants

A total of 14 healthy, young women (aged 21-35) participated in this experiment. Five participants were experienced judokas (EXP group, 19-25 years of experience) and nine were inexperienced at any fall technique (INEXP group), except that they had been administered the 30-min training session in MA fall techniques.

Experimental procedure

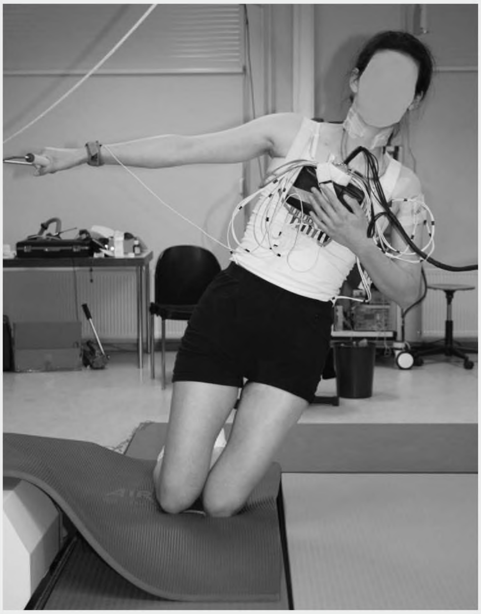
The participants were kneeling on a judo mat (size 2.2 m by 2.7 m, 4 cm polyurethane foam, Agglorex®, Lommel, Belgium). They held on to a grip with the right arm, such that the lateral inclination of the trunk and upper legs was 22°, relative to the vertical (Figure 4.2). The participant received a vocal command to release the grip, resulting in a fall to the left. The moment of release was detected by a load switch, placed in series with the grip. Six practice trials of each fall technique (Block and MA-a) were performed to familiarize with the experimental procedure. Subsequently, two series of trials were recorded, one with 12 Block falls and one with 12 MA falls. The order of the series was randomized. Before the start of a series, participants were instructed which technique they had to perform.

Electromyographic recordings (EMG) were obtained from the left m. trapezius (TR), m. deltoideus pars posterior (DP), m. deltoideus pars anterior (DA), m. pectoralis (PE) and bilaterally from the m. obliquus abdominus (OA) and m. sternocleidomastoideus (SC), using self-adhesive electrodes (Ag/AgCl) (Conmed Neotrode®) placed approximately 2 cm apart and longitudinally on the belly of the muscle. EMG signals were preamplified and analogue band-pass filtered (10-500 Hz). EMG data were sampled synchronously with the data from the load switch at 2400 Hz and stored on a microcomputer.

Analysis and statistics

EMG signals were first processed by bidirectional high-pass filtering (fourth-order Butterworth filter; 15 Hz) to remove motion artefacts. To remove electrocardiographic (ECG) interference from EMG records of PE, and for some participants of OA as well, the ECG component of the signal was isolated by low-pass filtering (50 Hz) and then subtracted from the EMG signal. Subsequently, records of all muscles were Hilbert transformed, full wave rectified, and bidirectionally low-pass

Figure 4.2 Experimental set-up for the EMG data collection. EMG electrodes were positioned on eight shoulder, neck, and trunk muscles. Participants held on to a grip with the right arm such that the lateral inclination of the trunk and upper legs was 22°. The left hand loosely touched the preamplifier, which was mounted to the trunk. After release participants fell to the left side and landed on the mat.



filtered (fourth-order Butterworth filter; 25 Hz) to acquire an adequate 'linear envelope' of the signal. For each muscle, the mean baseline EMG activity and its standard deviation prior to release was calculated over 20 trials and used as control activity. EMG signals after release were normalized with respect to the control activity. For each participant, each muscle, and each technique, mean normalized EMG amplitudes were computed for seven bins of 50 ms following release.

Multivariate analyses of variance (MANOVA) for repeated measures were used for statistical analysis. Group (EXP or INEXP) was used as a between-subjects factor. Within-subjects factors were fall technique (Block or MA), bins of EMG activity (seven bins following release), and side (left or right, for OA and SC only). The alpha level was set at 0.05.

Results

Part 1

Hip impact forces and velocities were compared between fall techniques (MA-a, MA-na, and Block), as learned by previously inexperienced subjects after a 30-min training session. Analysis yielded a significant main effect of technique on hip impact force ($F(2,8) = 10.35$, $p = 0.006$). Post-hoc contrasts revealed that, compared to Block falls, MA-a and MA-na techniques reduced hip impact force by 16.7% ($p = 0.001$) and 15.5% ($p = 0.006$), respectively (Figure 4.3a). In every participant, the average impact force in MA-a falls was smaller than in Block falls, while in MA-na falls, this was true for nine participants. Analysis also yielded a significant main effect of technique on impact velocities ($F(2,8) = 7.62$, $p = 0.014$). In both the MA-a and MA-na technique, impact velocity was, on average, 6.7% lower than in Block falls ($p = 0.003$ and $p = 0.038$, respectively)(Figure 4.3b). There were no significant differences between both MA falls.

Figure 4.3 Means and SE of hip impact forces and impact velocities for the Block and the martial arts (MA) fall techniques. Significant differences are indicated by the asterisks.

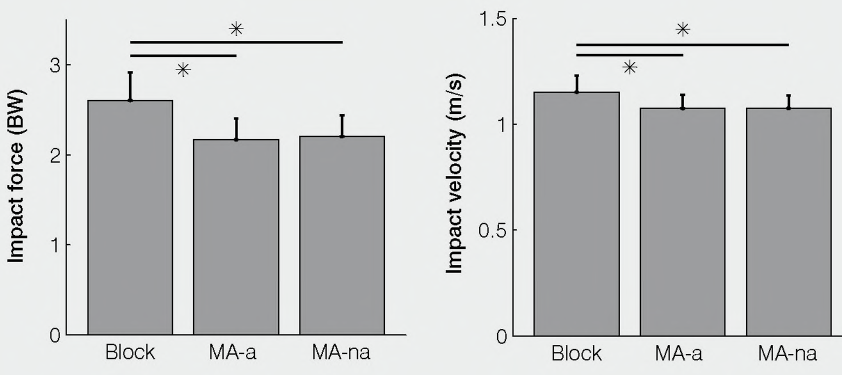
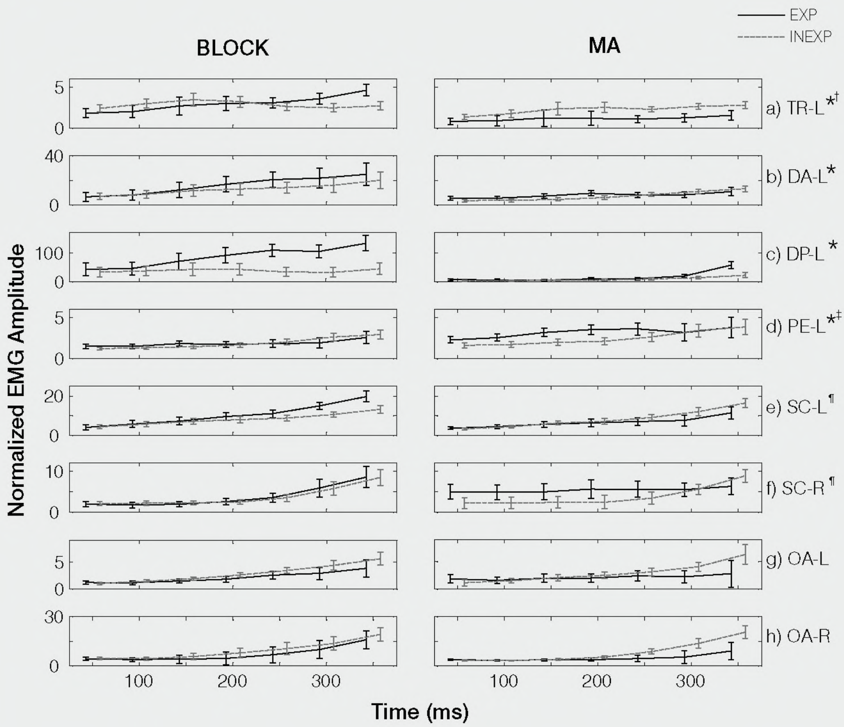


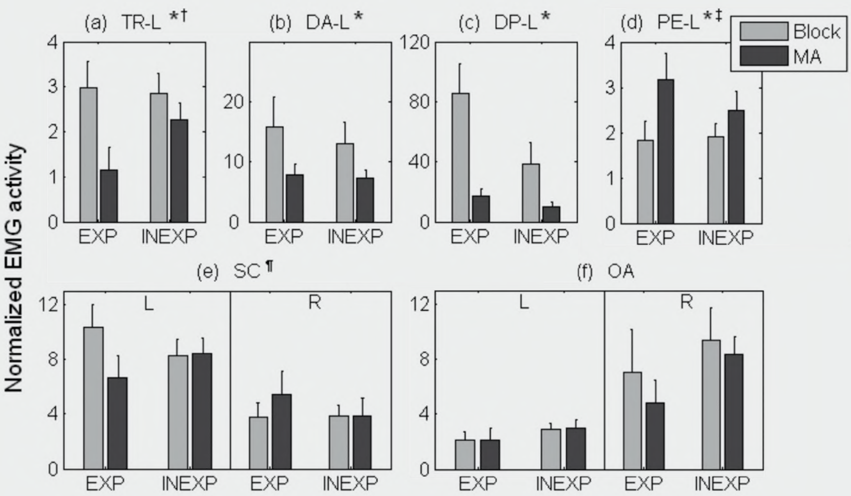
Figure 4.4 Means ± SE for the seven 50-ms bins following release in Block and martial arts (MA) falls in the experienced (EXP) and inexperienced (INEXP) group. Activation patterns are shown for the left m. trapezius (TR-L), m. deltoideus pars posterior (DP-L), m. deltoideus pars anterior (DA-L), m. pectoralis (PE-L) and bilateral m. obliquus abdominus (OA-L and OA-R) and m. sternocleidomastoideus (SC-L and SC-R). * Main effect of technique, $p < 0.05$. † technique x group interaction, $p < 0.01$. ‡ technique x group x bin interaction, $p < 0.01$. ¶ technique x group x side interaction, $p < 0.05$.



Part 2

EMG patterns of eight selected shoulder and trunk muscles were collected in two types of fall techniques (MA-a and Block) and in two groups of participants with and without experience in MA fall techniques (EXP and INEXP). The average EMG patterns of the two techniques in the two groups are shown in Figure 4.4. In general, the most pronounced differences in EMG patterns between techniques

Figure 4.5 Overall normalized EMG amplitudes in the experienced (EXP) and inexperienced (INEXP) group in Block and martial arts (MA) falls. Means ± SE are shown for the left m. trapezius (TR-L), m. deltoideus pars posterior (DP-L), m. deltoideus pars anterior (DA-L), m. pectoralis (PE-L) and bilateral m. obliquus abdominus (OA-L and OA-R) and m. sternocleidomastoideus (SC-L and SC-R). * Main effect of technique, $p < 0.05$. † technique x group interaction, $p < 0.01$. ‡ technique x group x bin interaction, $p < 0.01$. ¶ technique x group x side interaction, $p < 0.05$.



were present in the shoulder muscles. Analysis yielded main effects of technique in TR, DA, DP, and PE ($F(1,12) = 31.37$, $p < 0.001$; $F(1,12) = 5.69$, $p = 0.034$; $F(1,12) = 17.34$, $p = 0.001$; $F(1,12) = 13.56$, $p = 0.003$, respectively), indicating that these muscles were differentially activated in the techniques studied (Figure 4.4a-d and 4.5a-d). In both groups, TR, DA, and DP amplitudes in Block falls were higher than in MA falls, whereas in PE higher amplitudes were observed in MA falls. No significant main effects of technique were found in bilateral SC and OA.

With respect to experience-related differences, analysis yielded a significant group x technique interaction in TR ($F(1,12) = 9.58$, $p = 0.009$). The EXP group had 61.2% lower TR amplitudes in MA falls compared to Block falls, whereas the INEXP group showed a decrease of only 21.0% (Figure 4.4a and 4.5a). Analysis

also revealed a significant group x technique x bin interaction in PE ($F(6,7) = 8.68$, $p = 0.006$). The EXP group increased PE activity during the first 250 ms of the MA fall to a larger extent than did the INEXP group (81.0% and 31.2% more than in Block falls, respectively, Figure 4.4d). Furthermore, a significant group x technique x side interaction was found in SC ($F(1,12) = 4.82$, $p = 0.048$). The INEXP had similar EMG amplitudes in both techniques and similar EMG patterns in left and right SC. In contrast, the EXP group showed a clear differentiation of SC activation both between techniques and between the left and right side. Amplitudes of the left SC were lower in MA than in Block falls, while the reverse was observed for the right SC (Figure 4.4e-f and 4.5e). Finally, no significant experience-related differences could be demonstrated in DA, DP, and bilateral OA.

Discussion

The main result of the present study was that after a 30-min training MA fall techniques could reduce hip impact force in sideways falls in subjects without any prior fall experience. These results support the idea that such short training periods are effective and potentially useful although long-term effects have still to be investigated. The finding that MA fall techniques substantially reduced hip impact forces is in agreement with previous studies on MA fall techniques (Sabick et al., 1999; Groen et al., 2007). The observed reduction of 16% is comparable to the 12% reduction in experienced fallers as reported by Sabick et al. (1999), but in that study MA falls were compared to 'tensed' falls without use of the arm. In the study of Groen et al. (2007), in which exactly the same experimental protocol was used as in the present study, MA techniques were found to reduce hip impact forces by 27.0-29.5% in experienced fallers. In addition, in the present study impact velocities in MA falls were reduced by ~7% as compared to Block falls. In the study of Groen et al. (2007) impact velocities showed larger reductions (12-15%). Hence, the present results, in conjunction with the general pattern of larger reductions of impact forces than velocities, mirror those previously obtained from experienced judokas, except that the amount of reduction in forces and velocities was nearly twice as large in the previous study (Groen et al., 2007). The finding that there were no differences between MA fall techniques with and without the use of the arm was consistent with previous results as well (Groen et

al., 2007). This shows once more that the use of the arm in MA falls does not contribute to the hip impact force reduction, probably because arm impact occurs considerably later than hip impact. In contrast, the arm slap is expected to be important in the protection of the upper body and the head.

The proposed mechanism by which MA fall techniques are effective in reducing hip impact forces is the smaller amount of energy dissipation at impact as a result of rolling (Groen et al., 2007), which is the main feature of MA falls. However, the observation that hip impact velocities are reduced in MA falls indicates that actions during the fall, supposedly related to trunk rotation in preparation of rolling (Groen et al., 2007), also play a role. The relative contribution of these preparatory actions to the rolling movement and the resulting impact force reduction have not been quantified yet. However, the presently reported smaller reductions in impact velocities in inexperienced fallers clearly indicate that experience-related differences in these preparatory actions are important with respect to impact force reductions.

In order to identify the nature of experience-related differences on the neuromuscular level, MA and Block fall EMG data were collected from both experienced and inexperienced fallers. Both groups showed activation patterns consistent with the combination of trunk lateral flexion and rotation that characterizes the MA fall, as both groups showed TR, PE, and OA activation above control levels. However, the results confirmed the anticipated presence of experience-related differences in the execution of the MA fall technique. Compared to experienced fallers, more pronounced TR activation was observed in the inexperienced group, in conjunction with less pronounced PE activation. PE is a mainly active in trunk rotation (Kumar et al., 2003), whereas it is conceivable that TR is more involved in the muscle activation pattern contributing to trunk lateral flexion. The differential effects of experience indicate that inexperienced fallers probably focused more on trunk lateral flexion, whereas experienced fallers showed more pronounced activity subserving trunk rotation. This may have resulted in a better trunk curvature for the rolling movement after hip impact, allowing a more optimal distribution of impact forces along the contact path. Further analysis of trunk kinematics and impact forces could provide further insight into this issue.

Interestingly, experience-related differences were also observed with respect to SC activation patterns. The inexperienced fallers showed similar SC activity in

both techniques, indicative of an indifferent head stabilization by means of co-activation of bilateral SC. In contrast, the experienced fallers showed a clear differentiation between left and right SC, with the right SC being more and the left SC being less active than in inexperienced fallers in MA falls. Although this difference is not expected to contribute to a reduction of hip impact of forces, it highlights another aspect of skilled performance of MA fall techniques with possible implications for upper body impacts.

A limitation of the study was the small sample size of the group of experienced fallers. More subtle experience-related differences might have been detected had a larger number of judokas participated. However, the finding that significant and functionally relevant differences with respect to activation of TR, PE, and SC could be demonstrated even with such a small sample size clearly indicates that these aspects of the MA fall technique should be given more specific attention during training.

A second limitation was that, for safety reasons, falls were performed from kneeling height. Although this does not represent the typical fall from daily life, which is usually from a standing position, the principles of the MA fall techniques and the proposed working mechanisms are expected to be similar in falls from standing and kneeling height. Preliminary evidence for a similar impact reducing effect of MA falls from standing height was provided by the case study by Groen et al. (2008). It was shown that MA falls from standing height yielded similar impact forces as Block falls from kneeling height, but with considerably higher impact velocities. The absolute increase of impact forces may be less than expected on the basis of increased fall heights, because other impact reducing mechanisms, such as squatting during descent (Robinovitch et al., 2004), are coming into play. However, this is not expected to influence the relative impact reduction of the MA fall technique with respect to a 'natural' fall arrest strategy in sideways direction, because this squatting strategy would be applicable to both MA techniques and 'natural' fall arrest strategies from standing height.

A third limitation was that only short-term training effects were investigated. In a previous study on a 10-min intervention to reduce hand impact forces in forward falls (by landing with flexed elbows with subsequent eccentric triceps activity for deceleration), both short and long-term effects have been investigated (Lo et al., 2003). A substantial reduction could be demonstrated immediately after training, but the effects were significantly reduced after three weeks. Preliminary

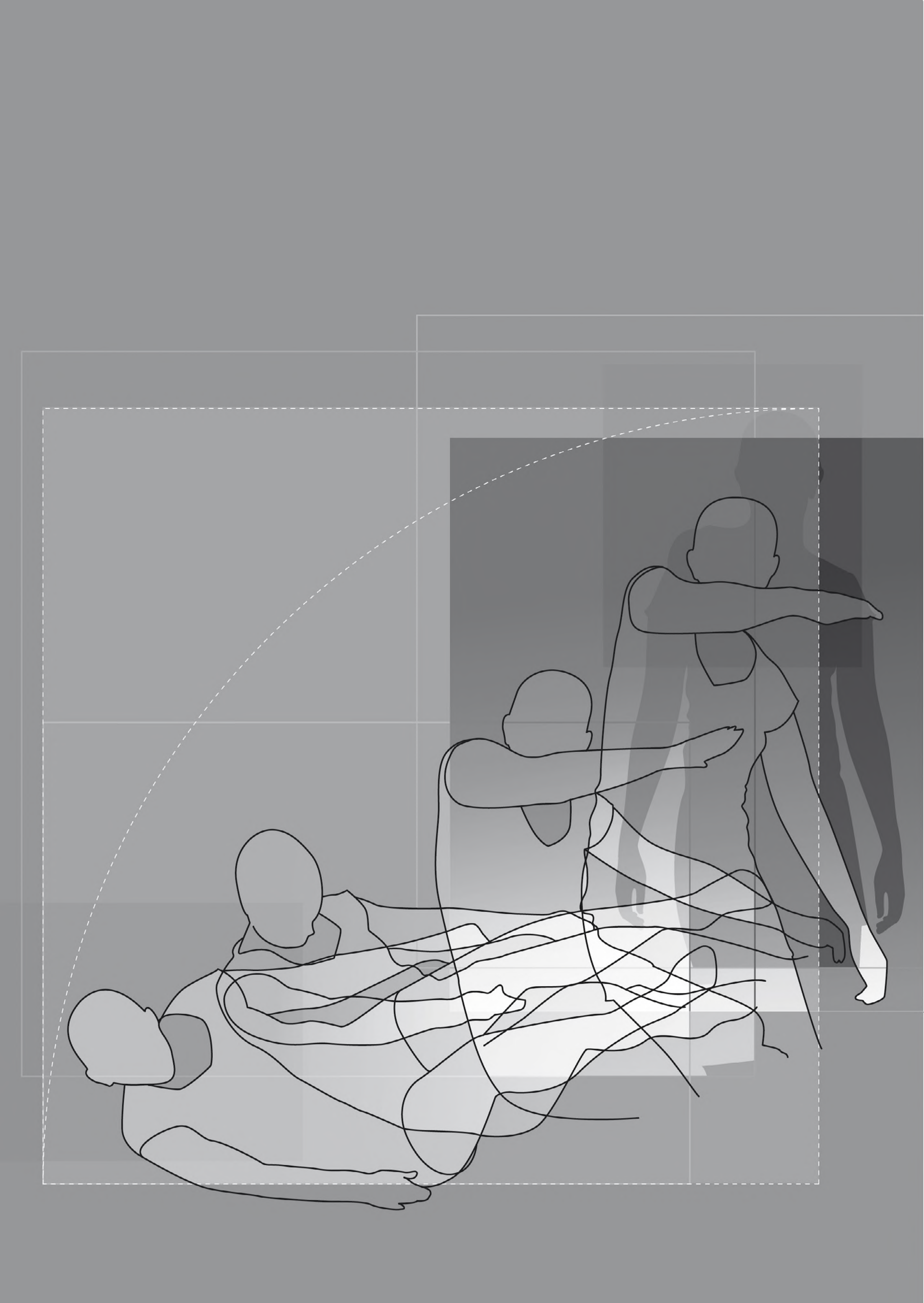
support for better retention of MA fall skills has been provided by some of our inexperienced subjects. When they were asked to do an MA fall a few weeks after training, they all showed a correct performance (as based on observation). However, further research is needed to evaluate the retention of MA fall skills after training.

The observation that young women without prior experience in MA techniques could reduce hip impact forces after a 30-min training shows that the technique is effective and easy to learn. However, the observation that they reduced impact forces to a lesser extent than did experienced judokas indicates that more training is required in order to fully benefit from the protective effects. These results provide important support for the addition of fall techniques to fall preventive interventions for the elderly, in order to reduce hip fracture risk not only by a decrease in the number of falls but also by reducing fall severity. Even though the present results were obtained in a group of young women, similar results would have been expected in young males and in the elderly after the MA falls training as incorporated in the Nijmegen Falls Prevention Program (Weerdesteyn et al., 2006). In this exercise programme, the elderly participants could also learn and correctly execute these techniques within five sessions. In addition, the EMG results suggest that the efficacy of MA falls training may be further enhanced by more specific attention to the component of trunk rotation. In conclusion, MA falls training constitutes a promising method to reduce fall severity, but further research on the acquisition and retention of fall skills in the elderly and the utilization of the acquired techniques in falls in daily life should be conducted to provide conclusive evidence for its benefits in the prevention of fall-related fractures.

Acknowledgements

Financial support was provided by a grant from the Organization for Healthcare Research in the Netherlands (ZonMW)(VW and JD), POM Nijmegen (BG) and the G.J. van Ingen Schenau Promising Young Scientists Award (RS).

4



5

Chapter

The effects of time pressure and experience on the performance of fall techniques during a fall

Based on

R. van Swigchem, B.E. Groen, V. Weerdesteyn, and J. Duysens

Journal of Electromyography and Kinesiology 19: 521-531, 2009

Introduction

Falling is the leading cause of injury-related death in adulthood (Kannus et al., 2000). It is therefore essential to understand the motor control of falls. How do humans react during a fall and how much can they change their behaviour prior to hitting the surface? This type of questions has been studied using falls from standing or from kneeling height. For falls from standing height most studies use a paradigm of tether release (Do and Roby-Brami, 1991; Do et al., 1990; DeGoede and Ashton-Miller, 2002; Lo et al., 2003; Robinovitch et al., 2003) but some use a functional reach test (Ahmed and Ashton-Miller, 2007) or voluntary initiated falls (van den Kroonenberg et al., 1996). It was shown that voluntary modification of a fall is possible and that a proper fall arrest strategy can affect peak impact at contact (DeGoede and Ashton-Miller, 2002; Robinovitch et al., 2003). A similar conclusion was reached from studies using falls from a kneeling position (Sabick et al., 1999; Groen et al., 2007). Sideways falls are the most intensively investigated because hip fracture risk is increased when falling sideways (Parkkari et al., 1999), especially when the hip is impacted (Kannus et al., 2006; Schwartz et al., 1998). Therefore, strategies to prevent fall-related hip fractures should not only target at decreasing the frequency of fall incidents, but also at the severity of these falls to the side.

Several fall strategies to reduce fall severity of sideways falls have been studied including martial arts (MA) fall techniques (Sabick et al., 1999; Groen et al., 2007). MA fall techniques (derived from judo) could reduce hip impact forces in sideways falls by 12-27% in experienced martial artists (Groen et al., 2007; Sabick et al., 1999). Recently, it has been shown that a 30-min training in MA fall techniques was sufficient to reduce hip impact forces by 15% in young adults without prior experience in MA (Weerdesteyn et al., 2008). In these studies a verbal cue was given after initiation of the fall, indicating which fall technique had to be performed. Hence, the resulting differences in impact forces showed that it was possible to initiate and thus change fall strategies after the start of a fall. Similarly, Feldman and Robinovitch (2004) conducted an experiment in which either forward or backward axial body rotations were visually cued at various instants both before and after fall initiation. It was found that a critical time window of 200 ms existed following the start of a fall, within which the movement to arrest the fall should be initiated in order to be effective. However, because fall durations were not reported, it remains unclear how much time was left after this critical

time window, to initiate and successfully execute the requested technique.

To our knowledge, no previous study has been performed to determine how voluntary movements during a fall are controlled at the neuromuscular level, in terms of reaction times and muscle activation patterns. Therefore, it is also unknown whether the characteristics of neuromuscular control would be susceptible to time pressure. In a previous study, muscle activity in automated reactions, like stepping to regain balance, was found to increase with increasing time pressure (Thelen et al., 2000). In addition, (Wang et al., 2006) found that in self-paced stepping, EMG amplitudes were significantly larger and showed higher rates of change during very quick steps compared to comfortably paced steps. Therefore, it may be expected that muscle activation amplitudes increase in fall strategies, in order to generate a more vigorous action when there is only a short time until landing.

Furthermore, although a previous study has shown that MA techniques can be used to reduce hip impact forces after a short training (Weerdesteyn et al., 2008), it is still unknown whether the performance, in terms of EMG characteristics, equals that of experienced fallers. For several sports it has been shown that detailed analyses of given movements can distinguish between experienced athletes and novices (Zehr et al., 1997; Harmenberg et al., 1991). Such analyses can give insight into the differences in motor planning (Yiou and Do, 2001). Furthermore, knowledge of experience-related differences in the neuromuscular control of fall techniques could help to set specific targets to optimize the benefits of training.

The aim of the present study was to examine the neuromuscular control of fall techniques during a sideways fall. Two research questions were determined. The first question was how much time it takes to initiate and to adequately perform such techniques. Secondly, we aimed to determine whether years of experience in fall techniques would have an effect on performance, in terms of success rates and EMG characteristics. To answer these questions the following experiment was conducted. In a choice reaction task to an auditory cue, one of two fall techniques had to be performed during a fall. One technique was a natural fall arrest strategy with an outstretched arm into the direction of the fall; the other technique was an MA fall, which is characterized by rolling on over the trunk after impact. The cue was given at different delays after the start of the fall. The successfulness on the task was assessed by two independent observers. Muscle activation patterns of the two techniques were determined, as well as

reaction times to the cue. Reaction time was defined by the instant at which muscle activation patterns started to differ between techniques. Finally, muscle activation patterns of experienced and inexperienced fallers were compared in order to evaluate the effect of extensive training on timing, amplitude and patterning of EMG responses.

Methods

Participants

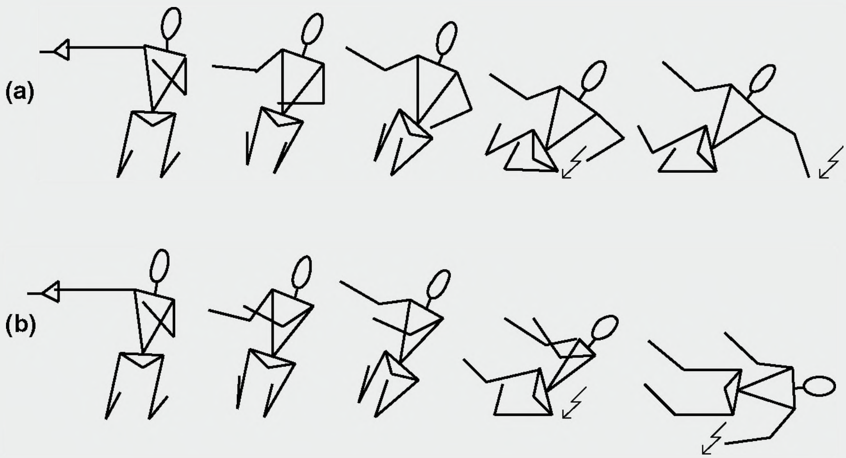
A total of fourteen healthy, young women (aged 21-35) participated; five participants were seasoned judokas (experienced group, 19-25 years of judo experience) and nine were inexperienced in any fall technique (inexperienced group). None of the participants suffered from any neurological or musculoskeletal disorder that could affect their performance and/or behaviour in this study. The Ethical Board of the region Arnhem-Nijmegen approved the protocol and participants gave informed consent to participate.

Experimental set-up and protocol

The experimental set-up consisted of a 2.2 m by 2.7 m platform, covered with judo mats (4 cm polyurethane foam, Agglorex®, Lommel, Belgium). The participants were kneeling on the platform. They held on to a grip with the extended right arm, such that the lateral inclination of the trunk and upper legs was 21°, relative to the vertical (see Figure 5.1).

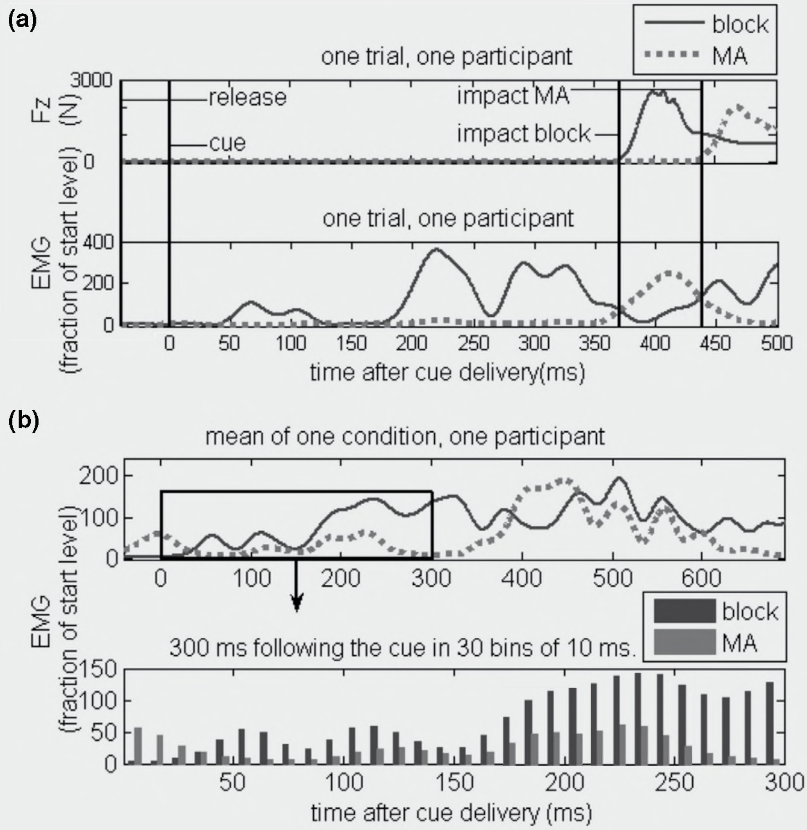
The participants received a vocal command to release the grip. The moment of release was detected by a load switch, placed in series with the grip. After release, participants started falling to the left and during the fall they received one of two auditory cues, one at a low pitch (500 Hz) or one at a high pitch (3000 Hz). The low pitch cue indicated that a natural fall arrest strategy was required, characterized by stretching out the left arm into the direction of the impending fall in combination with trunk lateral flexion in opposite direction (Allum et al., 2002; Groen et al., 2007). This technique, in which the fall was blocked with the arm, will be referred to as the Block technique (Figure 5.1a). The high pitch cue indicated that a martial arts fall technique (MA), derived from judo was required. This technique is characterized by trunk lateral flexion in combination with trunk

Figure 5.1 Schematic representation of fall techniques. In the starting position subjects held on to a grip with the extended right arm: (a) Block fall technique (b) MA fall technique. Impact is indicated by a broken arrow.



rotation and shoulder protraction in order to enable rolling on after impact (Groen et al., 2007) (Weerdesteyn et al., 2008)(Figure 5.1b). The auditory cue was delivered at three delays after release, 1 ms, 40 ms or 80 ms, yielding six experimental conditions (two techniques at three delays). To familiarize to the task, each participant performed 20 practice trials. During the experiment, the participants performed five trials of each of the six conditions, randomly divided over one series of 30 trials. Finally, one catch trial without auditory cue was included at the end of the protocol. Two independent observers judged during the experiment whether the required technique had been performed successfully. They agreed in 100% of cases. Successful execution of a Block fall was defined as consecutively impacting the hip and the left hand or elbow without rolling on after impacting the left arm. Execution of the MA fall was successful when the subject rolled on after hip impact and the left arm was either not impacted or slapped on the mat after hip impact. Electromyographic recordings (EMG) were obtained from the left trapezius (TR), deltoideus pars posterior (DP), deltoideus pars anterior (DA), pectoralis (PE) and from the left and right obliquus abdominus (OA) and sternocleidomastoideus (SC) muscles, using self-adhesive electrodes

Figure 5.2 Graph (a) shows an example of one participant for the 40 ms delay condition, during one trial of the MA and one trial of the Block technique. The upper part of the graph shows the vertical force (Fz) and the lower part shows the normalized EMG amplitude of one exemplary muscle, the left deltoideus pars posterior (DP-left). All EMG data were normalized with respect to the mean level of activity during the starting position. Graph (b) shows the method of EMG data processing on two EMG records of DP-left. The mean of the MA and of the Block technique in the 40 ms delay condition are shown for one participant. The lower graph shows these records divided into 30 bins of 10 ms following the cue. Note that the EMG amplitudes of the MA and Block technique start to diverge at about 190 ms.



(Ag/AgCl) (Conmed Neotrode®) placed approximately 2 cm apart and longitudinally on the belly of the muscle. EMG signals were pre-amplified and analog band-pass filtered (10-500 Hz). EMG data were sampled synchronously with the load switch at 2400 Hz and stored on a microcomputer.

Data analysis

For each participant and each condition, success rates were determined, as defined by the percentage of correctly performed trials. EMG signals were first processed by bidirectional high-pass filtering (fourth-order Butterworth filter; 15 Hz) to remove motion artefacts. To remove electrocardiographic (ECG) interference from EMG records of PE, and for some participants of OA as well, the ECG frequencies were isolated by low-pass filtering (50 Hz) and then subtracted from the signal. Subsequently, records of all the muscles were Hilbert transformed, full wave rectified, and bidirectionally low-pass filtered (fourth-order Butterworth filter; 25 Hz) to acquire an adequate 'linear envelope' of the signal. The mean reference EMG activity was computed over 20 trials during 1 s of quiet hanging before fall initiation for each participant and for each muscle. EMG signals in response to the auditory cue were normalized with respect to this reference activity.

An example of normalized EMG signals of one muscle, during one trial of each technique is provided in Figure 5.2a. For each participant, each muscle, and each condition, mean normalized EMG amplitudes were computed for 30 bins of 10 ms following the cue. Figure 5.2b illustrates how mean normalized EMG amplitudes were calculated for an MA condition and a Block condition. The overall mean fall duration was 405 ms. Given the maximum cue delay of 80 ms, the 30 bins following the cue include EMG activity during the fall, prior to impact.

To control whether subjects postponed fall arrest-related muscle activation until the cue, EMG amplitudes were also computed in the 150 ms period (15 bins of 10 ms) following release of the grip. In this period, cue-related activation was not expected for any of the cue delays, assuming that 150 ms is the minimum time limit in choice reaction tasks (Carson et al., 1995).

Statistical analysis

Multivariate analyses of variance (MANOVA) for repeated measures were used for statistical analysis of success rates and EMGs of the eight muscles. Group (experienced or inexperienced) was used as a between-subjects factor.

Within-subjects factors were fall technique (Block or MA), delay condition (1 ms, 40 ms, and 80 ms), and bins of EMG activity. With respect to the latter factor, 30 bins following cue were included in the analysis of the cue-related (and thus technique specific) effects. In the analysis of release-related EMG activity, 15 bins following release were included. Post-hoc deviation contrasts were determined to differentiate between the delay conditions. To detect the first bin after the cue in which significant differences in EMG activity between the techniques occurred (point of divergence), post-hoc reverse Helmert contrasts were used. An additional criterion for the determination of this point of divergence was that the difference between the techniques had to remain significantly different for four subsequent bins. This criterion was defined as a significant main effect of technique in an additional MANOVA for the four bins following the point of divergence. To analyse the strategies used to arrest the fall in the catch trial, a binomial test was applied. The alpha level was set at 0.05 for all tests.

Results

Success rates

Participants successfully performed the requested technique in 85% of the falls. Table 5.1 shows the means and standard deviations of fall technique success rates of all participants for each condition.

Success rates did not differ between the experienced and inexperienced fallers (main effect of group, $F(1, 12) = 0.643$, $p = 0.438$, $\eta_p^2 = 0.051$), nor between the Block and MA technique (main effect of technique, $F(1, 12) = .188$, $p = 0.673$, $\eta_p^2 = 0.015$). Success rates were significantly affected by the cue delay (main effect of delay, $F(2, 12) = 6.983$, $p = 0.004$, $\eta_p^2 = 0.368$). Post-hoc contrasts revealed that participants were more successful in trials with cue delays of 1 ms and 40 ms than in trials with cue delays of 80 ms ($p = 0.003$, $\eta_p^2 = 0.529$ and $p = 0.034$, $\eta_p^2 = 0.322$ respectively). Experience in MA techniques did not affect the success rates in the six experimental conditions, as indicated by the absence of significant interactions between technique and group and between group and delay (all p-values > 0.129).

During the catch trial, when no cue was given, three (= 60%) of the experienced and three (= 33.3%) of the inexperienced fallers used the Block technique,

Table 5.1 Means (SD) of success rates for the 3 cue delays in MA and Block.

	Block falls			MA falls		
Cue delay (ms)	1	40	80	1	40	80
Experienced (n = 5)	80 (14)	87 (14)	67 (16)	96 (9)	93 (10)	71 (22)
Inexperienced (n = 9)	91 (11)	84 (22)	91 (15)	93 (14)	86 (15)	72 (23)

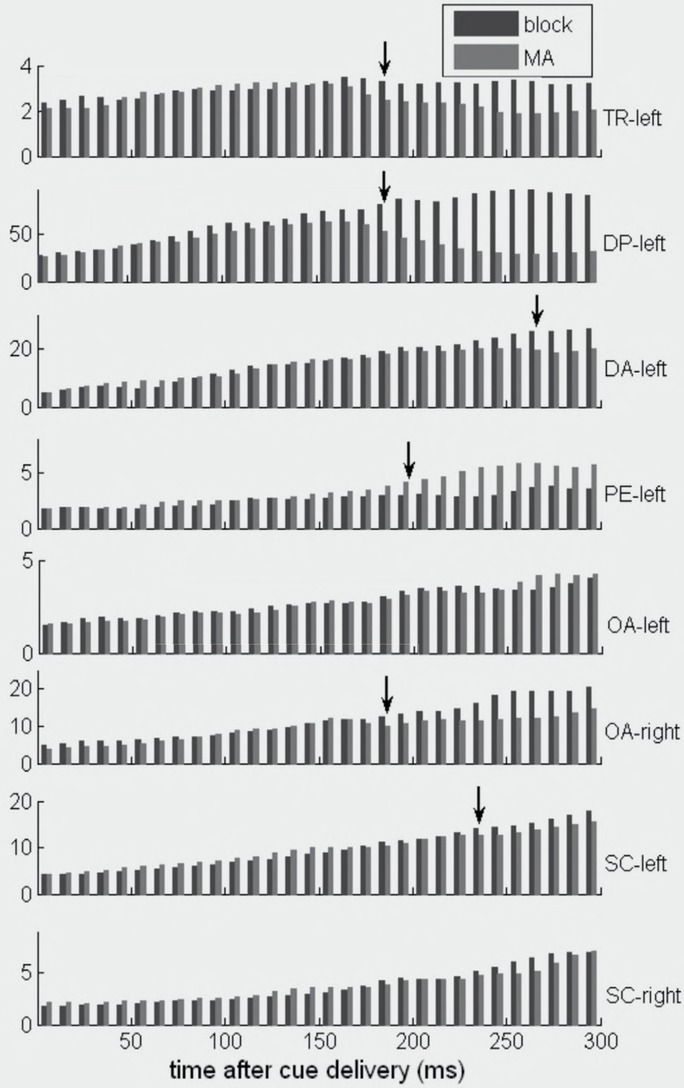
whereas one (= 20%) of the experienced and three (= 33.3%) of the inexperienced fallers used the MA technique. A fall arrest that could not be labelled as Block or MA was made by one (= 20%) of the experienced and three (= 33.3%) of the inexperienced fallers. The groups were not significantly different in their choice for MA or for Block technique (p = 0.754).

Effects of technique

Differences in EMG amplitudes between techniques could be observed in all the muscles. In general, the amplitudes during 300 ms following the cue were higher in Block than in MA falls. In addition, shoulder muscles demonstrated more pronounced differences in EMG amplitudes between the techniques than the abdominal and sternocleidomastoideus muscles. The EMG amplitudes for the two techniques, averaged over all subjects, are presented in Figure 5.3.

Analysis revealed technique-specific differences in EMG amplitudes, as indicated by significant interactions between technique and bin in all the muscles, ($F(29, 348) = 1.547$–11.598, all p-values < 0.038). For six muscles (all except OA-left and SC-right) post-hoc contrasts revealed a significant point of divergence, indicating that EMG amplitudes started to diverge between techniques and remained significantly different for at least four bins. For TR, DP, and OA-right the point of divergence was observed in bin 19 (180-190 ms, $p = 0.043$, $\eta_p^2 = 0.300$; $p = 0.012$, $\eta_p^2 = 0.423$; and $p = 0.028$, $\eta_p^2 = 0.341$, respectively). For PE, EMG amplitudes started to diverge in bin 20 (190-200 ms, $p = 0.038$, $\eta_p^2 = 0.313$), for SC-left in bin 24 (230-240 ms, $p = 0.038$, $\eta_p^2 = 0.312$), and for DA in bin 27 (260-270 ms, $p = 0.041$, $\eta_p^2 = 0.304$).

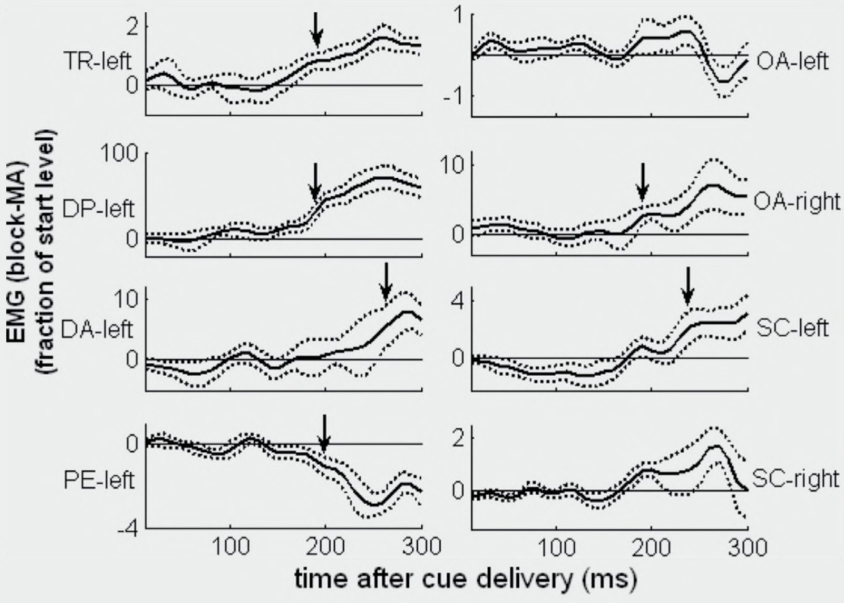
Figure 5.3 Mean normalized EMG amplitudes for MA and Block falls in bins of 10 ms, averaged over all participants. All EMG data were normalized with respect to the mean level of activity during the starting position. Arrows indicate the points of divergence between the EMG patterns of both techniques. For OA-left and SC-right no point of divergence could be detected.



5

To illustrate the distinction between Block and MA techniques more clearly, the differences in EMG amplitudes between the two techniques are plotted in Figure 5.4 (Block minus MA). This figure shows also the standard error of the difference between the EMG amplitudes of Block and MA techniques to give an impression of the between-subjects variability. Following the points of divergence, technique-specific activation levels were higher in Block falls than in MA falls for all the muscles, except for PE. In this muscle, the technique-specific activation was higher in the MA technique. Following the cue, EMG amplitudes in TR, DP, and OA-right during MA falls were 79%, 61%, and 81% of the amplitudes during Block falls. In PE, EMG amplitudes during MA falls were 130% of the amplitudes during Block falls.

Figure 5.4 Difference between mean EMG amplitudes of Block and MA techniques, averaged over all participants, for the eight muscles recorded. Plus and minus one standard error of the difference is shown with dotted lines. Positive values indicate that the amplitudes of Block techniques are higher than of MA techniques. All EMG data were normalized with respect to the mean level of activity during the starting position. For the six muscles that showed a point of divergence, this point is indicated with an arrow.

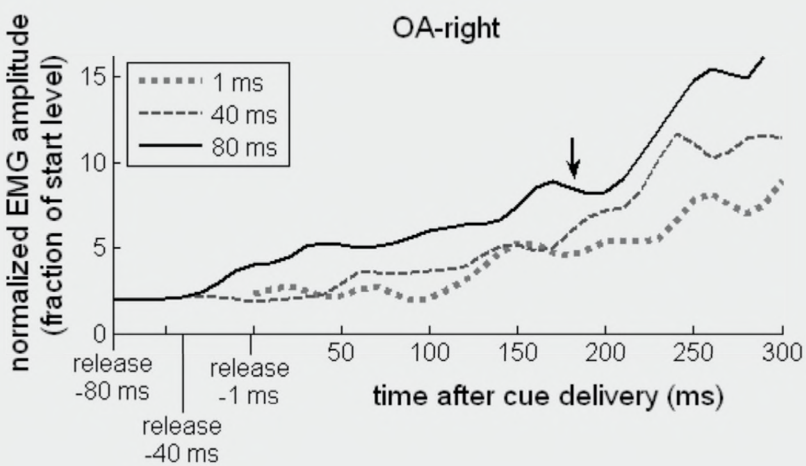


Effects of delay

To investigate whether it is possible to change the fall strategy even if one decides to make such a change after the onset of a fall, several delays were introduced between fall initiation (release) and cue. First, an analysis of the EMGs synchronized to the instant of release of the grip was performed. By means of this analysis of 15 bins (150 ms) following release of the grip, it was investigated whether the subjects indeed postponed the start of a voluntary fall arrest strategy until the cue. Because in this time any cue-related activity was not to be expected, this analysis would also demonstrate the effect of the fall on EMG amplitudes. In all the muscles a gradual increase was obvious.

Figure 5.5 presents the EMG amplitudes in the three delay conditions from release of the grip until 300 ms after the cue for one exemplary muscle. The gradual increase was confirmed by significant main effects of bin in the analyses of all the muscles ($F(14, 168) = 4.426\text{-}19.815$, all p-values < 0.001)

Figure 5.5 Mean EMG amplitudes of one exemplary muscle (OA-right during Block falls) for the three delay conditions, from release of the grip until 300 ms after the cue. All EMG data were normalized with respect to the mean level of activity during the starting position. The point of divergence is indicated with an arrow. For all delay conditions a gradual increase from the instant of release (i.e. 1 ms, 40 ms, and 80 ms before the cue) occurs, resulting in a difference in background activity at the point of divergence.



5

except for TR ($F(14, 168) = 1.069$, $p = 0.389$, $\eta_p^2 = 0.082$) and SC-left ($F(14, 168) = 1.045$, $p = 0.411$, $\eta_p^2 = 0.080$). The analyses failed to show significant effects of technique on EMG amplitudes in any muscle ($F(1, 12) = 0.002$-3.719, all p-values > 0.078), except for SC-left ($F(1, 12) = 5.789$, $p = 0.033$, $\eta_p^2 = 0.325$). In addition there were no significant effects of delay ($F(2, 24) = 0.103$-1.421, all p-values > 0.261 for all the muscles).

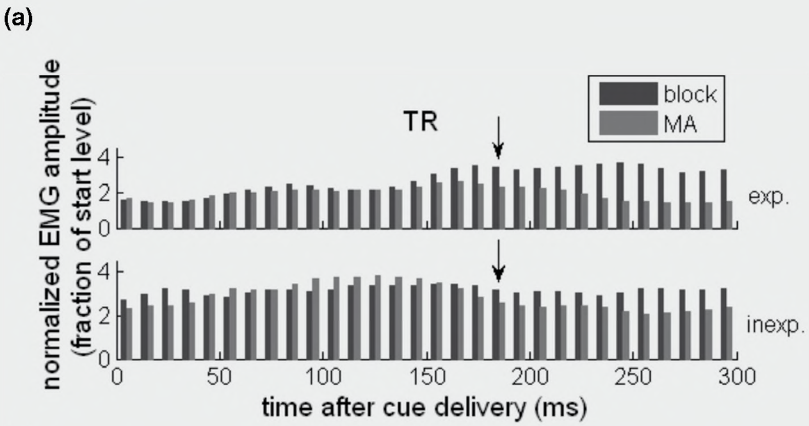
In the second place it was investigated whether EMG amplitudes were differently influenced by the cue delays. In the analysis of EMG amplitudes during 300 ms following the cue, there was a significant main effect of delay on EMG amplitudes in all the muscles ($F(2, 24) = 5.556$–25.735, all p-values < 0.01). In all the muscles, EMG amplitudes increased with increasing cue delay. In the 80 ms delay condition, mean amplitudes were on average 39 ± 14% larger than in the 1 ms delay condition. Post-hoc contrasts revealed that in the 80 ms delay condition all the muscles showed significantly larger overall EMG amplitudes than in the 1 ms delay condition (all p-values < 0.007) and the 40 ms delay condition (except for TR, all p-values < 0.033). In addition, for TR, OA-right and SC-left significantly larger amplitudes were observed in the 40 ms compared to the 1 ms delay condition (p-values < 0.038). To investigate if responses were more vigorous with increasing cue delay, the interaction effects between delay, technique and bin were analysed. For none of the muscles this interaction effect was significant for four bins in a row.

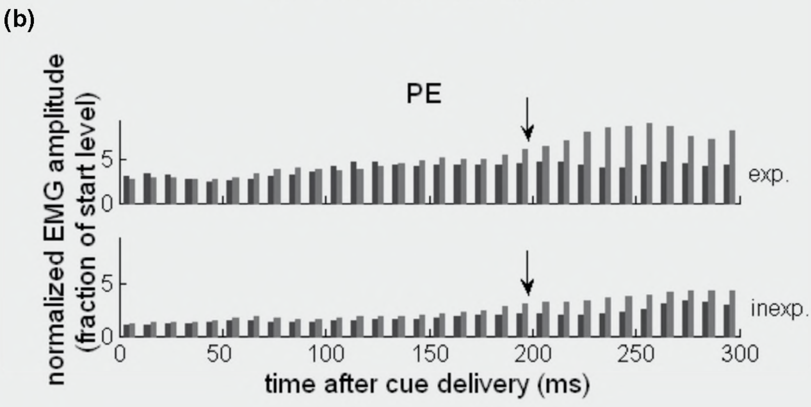
Effects of experience

The influence of experience on the EMG amplitudes of both the Block and MA falls was evaluated by comparisons of the experienced with the inexperienced group in the analysis of the 30 bins following the cue. In the six muscles with a point of divergence, which were TR, DP, DA, PE, OA-right and SC-left, the influence of experience on the differences between the Block and MA techniques could be identified by interaction effects between group and technique. These interaction effects were significant in TR ($F(1, 12) = 4.927$, $p = 0.046$, $\eta_p^2 = 0.291$) and in PE ($F(1, 12) = 6.317$, $p = 0.027$, $\eta_p^2 = 0.345$). For these muscles, MA and Block EMG amplitudes for both groups are shown in Figure 5.6.

With respect to TR (see Figure 5.6a), in the inexperienced group the early activation (before the point of divergence) was relatively high compared to the experienced fallers. Activation remained at this high level after the point of divergence (190 ms) in case of a Block fall, but decreased in case of an MA fall.

Figure 5.6 EMG amplitudes, averaged over the three delay conditions, for the experienced and inexperienced group. All EMG data were normalized with respect to the mean level of activity during the starting position. In graph (a) these records are shown for the trapezius and in graph (b) for the pectoralis. Arrows indicate the points of divergence.





In the experienced group, early activation in TR was relatively low. Activation remained at this low level after the point of divergence in case of an MA fall, but increased in a Block fall. With respect to PE (see Figure 5.6b), there was a steeper increase of MA-specific activity in the experienced group compared to the inexperienced fallers. In addition, analysis yielded a main effect of group for PE ($F(1, 12) = 9.639$, $p = 0.009$, $\eta_p^2 = 0.834$). In PE, the inexperienced fallers had only 42.9% of the overall EMG amplitudes compared to the experienced group.

Discussion

The aim of the present study was to examine the neuromuscular control of a fall technique during a sideways fall. An experiment was conducted in which participants received a cue as to which fall technique (Block or MA) they had to apply during an ongoing fall. The results showed that participants were able to adjust the ongoing falling movement, as they were successful in performing the requested fall techniques in 85% of the falls. Inexperienced fallers, after a 30-min training session in MA fall techniques, were as successful as experienced fallers in this task. There was no difference between the success rates of the two techniques, implying that the experimental set-up did not favour one of the techniques and that the techniques were equally difficult to implement.

Effects of technique

Neuromuscular control characteristics were evaluated on the basis of EMG recordings of eight selected shoulder and trunk muscles. In six muscles, namely TR, DP, DA, PE, OA-right and SC-left, technique-specific differences in EMG amplitudes were observed. Hence, the EMGs of these six muscles could discriminate between the MA and the Block technique. Activity after the point of divergence was significantly higher during Block than during MA techniques in all these muscles except PE, which was more active during an MA fall. In order to understand these differences in activation levels, it is necessary to consider the functions of the muscles in relation to the characteristics of the movements during the two different fall techniques. During a Block fall, the left shoulder is elevated and the arm is outstretched into the direction of the fall, which is consistent with the enhanced activation levels of TR, elevating the shoulder, and DP and DA, abducting the arm. Trunk orientations at impact are more vertical in Block than in MA falls (Groen et al., 2007), which is in line with higher activation levels of the OA-right as a muscle that lateroflexes the trunk to the right. The activation levels in these muscles were reduced in an MA fall. Characteristics of the MA fall are shoulder protraction and arm adduction, which is consistent with higher PE activation levels. The trunk rotation that is characteristic for MA falls could be partly explained by the current results. Activity of OA-left can produce heterolateral rotation of the trunk. Yet, EMG amplitudes of OA-left were not higher for MA than for Block falls. On the other hand, PE is also known to contribute to trunk rotation

(Kumar et al., 2003). This muscle indeed was more active in MA than in Block falls. It might be that other muscles, such as the internal oblique abdominal muscle and paravertebral muscles, were also involved in trunk rotation in the MA technique. Finally, head stabilization is required in both techniques, which explains increased activation levels in SC muscles on both sides. It may be that more activity is required in Block falls in order to prepare for the abrupt landing, in contrast to the rather gentle landing as a result of rolling in the MA fall. Although only SC-left shows a significant point of divergence, a similar tendency can also be observed in SC-right.

In the current study, the earliest points of divergence in the EMG patterns of the two techniques were found at 180-190 ms after the cue. Technique-specific differences in EMG activity were not expected within 150 ms after the cue, because this is the minimum time limit for simple reaction times by cortical pathways (Hase and Stein, 1998). Reaction times to a cue increase if more than one response is possible. The minimum time limit in such a choice reaction task increased by about 23 ms compared to a simple reaction task (Carson et al., 1995). Based on this number, choice reaction times for applying acquired fall techniques during a fall were expected to be at least about 175 ms. Hence, the presently observed reaction times were in line with the literature.

Effects of delay

The successfulness on the task performance was reduced by increasing time pressure. However, this decline was only significant in the highest time pressure condition (80 ms delay) as compared to both the 1 ms and 40 ms delay condition. These results are in agreement with the findings of Feldman and Robinovitch (2004), who tested the ability to avoid hip impact by rotating backward or forward on instruction, during a fall from standing height. They presented the cues with delays ranging from 300 ms before release to 300 ms after release, and found that earlier cue delivery during the fall (indicating the required direction of rotation) led to better performance of the required rotation. They identified a critical window of 200 ms within which rotation should be initiated in order to be effective. In the present study, fall durations were 405 ms on average, and reaction times were 180-190 ms. Hence, in the 80 ms delay condition only 145-155 ms remained as available movement time. This time is probably at the limit of movement times, necessary to perform the fall techniques adequately, as was indicated by the

decreasing success rates in this condition. Because Feldman and Robinovitch (2004) reported only the cue delay without the total fall duration, the minimum reaction and movement time, required for adequate performance of backward and forward rotation could not be estimated from their data.

Absence of significant effects of delay and technique in the analyses of EMG amplitudes during 150 ms following release of the grip showed that there was no effect of the cue in this time. This indicated that participants postponed the start of a voluntary fall strategy until the cue. However, the start of any muscle activation was not postponed. The significant main effects of bin are indicative of increasing muscle activation with increasing time after release of the grip, independent of the cue. It might be that a gradual increase of muscle activity was present as a result of anticipatory activity to the fall arrest itself. The results of the catch trials supported this suggestion of an anticipatory fall arrest activity, as all participants employed some type of fall arrest strategy. This fall arrest, independent of the cue, might have been influenced by perception of the landing surface. In the present study, impacting the judo mat with a drop fall on the side would be at least uncomfortable. As in real-life falls usually occur on hard surfaces, the current results may indicate that the landing surface in the present set-up closely approached real-life situations.

In the analyses of the EMGs during 300 ms following the cue, significant effects of delay on amplitude were present in all the muscles. This suggested that the EMG amplitudes increased as a consequence of shortening of the available time to perform the fall technique, which may have resulted in a more vigorous response. However, when the delay of the cue increased, the cue was delivered at a later instant during the fall. As shown by the analyses of EMG amplitudes during 150 ms following release of the grip, the activity as a result of the fall itself was increased when fall duration increased. It follows that at the time of the point of divergence there was a higher background activity level in the 80 ms delay condition than in the other conditions. In other words, the gradual, fall-related increase of muscle activity was interfering with the activity resulting from a voluntary fall strategy. Hence it cannot be excluded that the increasing amplitudes with increasing cue delay could be attributed to the increasing activity as a result of the fall itself. Significant interaction effects between delay, technique and bin, that could confirm more vigorous responses in increased cue delays, were not present in this study. It might be that with a larger number of subjects these interaction effects would exist.

Effects of experience

The similarity of the success rates over the groups (experienced and inexperienced fallers) suggests that only a brief training would suffice to perform an adequate fall technique. In line with previous studies (Zehr et al., 1997; Yiou and Do, 2001), the present study showed that detailed analyses are needed to reveal differences between experts and novices in sports. Analysis of EMG amplitudes revealed that the amplitudes of TR and PE significantly differed between the groups. The experienced fallers increased MA-specific PE activity more than the inexperienced fallers (see Figure 5.6b). This may have resulted in a more pronounced protraction of the shoulder, adduction of the arm and rotation of the trunk in the experienced fallers. Further analysis of kinematic data is needed to confirm this. In addition, higher early PE activation suggested that the experienced fallers prepared an MA fall, whereas early activity in TR tended to be higher in the inexperienced fallers, possibly indicating a preparation for the Block technique. As a result of years of MA training, experienced fallers might have changed this automated preparation to an impending fall with the Block technique, into a preparation for trunk rotation, initiated with shoulder protraction. A decrease in TR activation could be part of this altered preparation pattern as well. Previous studies showed that reduction of hip impact force by application of the MA fall was more pronounced in judokas than in non-judokas (Weerdesteyn et al., 2008). This larger reduction in experienced fallers may have been caused by the altered preparation and/or more pronounced technique-specific PE activation in this group. This might have resulted in a better trunk curvature, allowing a more optimal distribution of impact forces along the contact path. Further analysis of trunk kinematics and impact forces could provide more insight into this issue.

Limitations of the study

A limitation of the study was that the falls were self-initiated, whereas falls in real life are not. To imitate real-life falls more closely, falls in the present experiment were initiated on command to release the grip. In this way the subjects, just like in real-life falls, could not choose the instant of fall initiation freely. The cue delay was mimicking the time, during a real-life fall, available to detect loss of balance and to decide to apply a fall technique. Falls in real-life may be accompanied by automated reactions, such as startle reactions, as a result of the detected loss of balance. Due to the voluntary nature of the falls, startle reactions were absent in the present

experiment, as evidenced by the absence of short-latency startle reactions in SC, indicative of startling (Carlsen et al., 2003). Since startles are known to speed up voluntary responses, it might be that in real-life falls the reaction times of 180-190 ms, as observed in the present study, could even be advanced.

Secondly, this experiment was performed with young women. The question remains whether the current results of voluntary fall techniques can be extrapolated to the elderly. Reaction times of elderly people to consciously initiate a fall technique are probably longer than those observed in young participants. Previous studies showed increases in latencies of 31-117 ms for voluntary movements in the elderly (Chen et al., 1994; Luchies et al., 1994; Robinovitch et al., 2005; Tirosh and Sparrow, 2005). Moreover, in the elderly movement times increase as well (Robinovitch et al., 2005) as a result of changes in muscle properties and muscle control (Pijnappels et al., 2005; Thelen et al., 2000). Further research has to be done to investigate how much additional time elderly people would need to apply a fall technique properly.

Finally, the sample size in the current study was rather small and unequally divided over the experienced and inexperienced fallers. The unequal distribution of the participants over the groups was due to the hesitation of experienced judokas to participate in a fall study. It might be that, with larger numbers of participants, outcomes would be more pronounced. However, even with the small number of experienced fallers, significant differences were found between the groups.

Implications of the study

MA techniques could be successfully implemented within fall durations of 405 ms. The duration of a real-life fall from standing height has been reported to be 715 ± 160 ms (Robinovitch et al., 2005). Hence, it should be possible to apply these techniques during a real-life fall from standing height as well. The results showed that there is a critical period before impact, within which a fall technique should be initiated, to be performed correctly.

In line with the conclusions of a previous study (Weerdesteyn et al., 2008), the present study showed that the MA fall technique is easy to learn. Previous studies showed that the MA fall technique markedly reduced hip impact forces. For this reason, the MA fall technique should be preferred over the Block technique in reducing fall-related injuries. With these findings, incorporation of fall techniques and in particular of MA techniques in fall prevention programmes is supported.

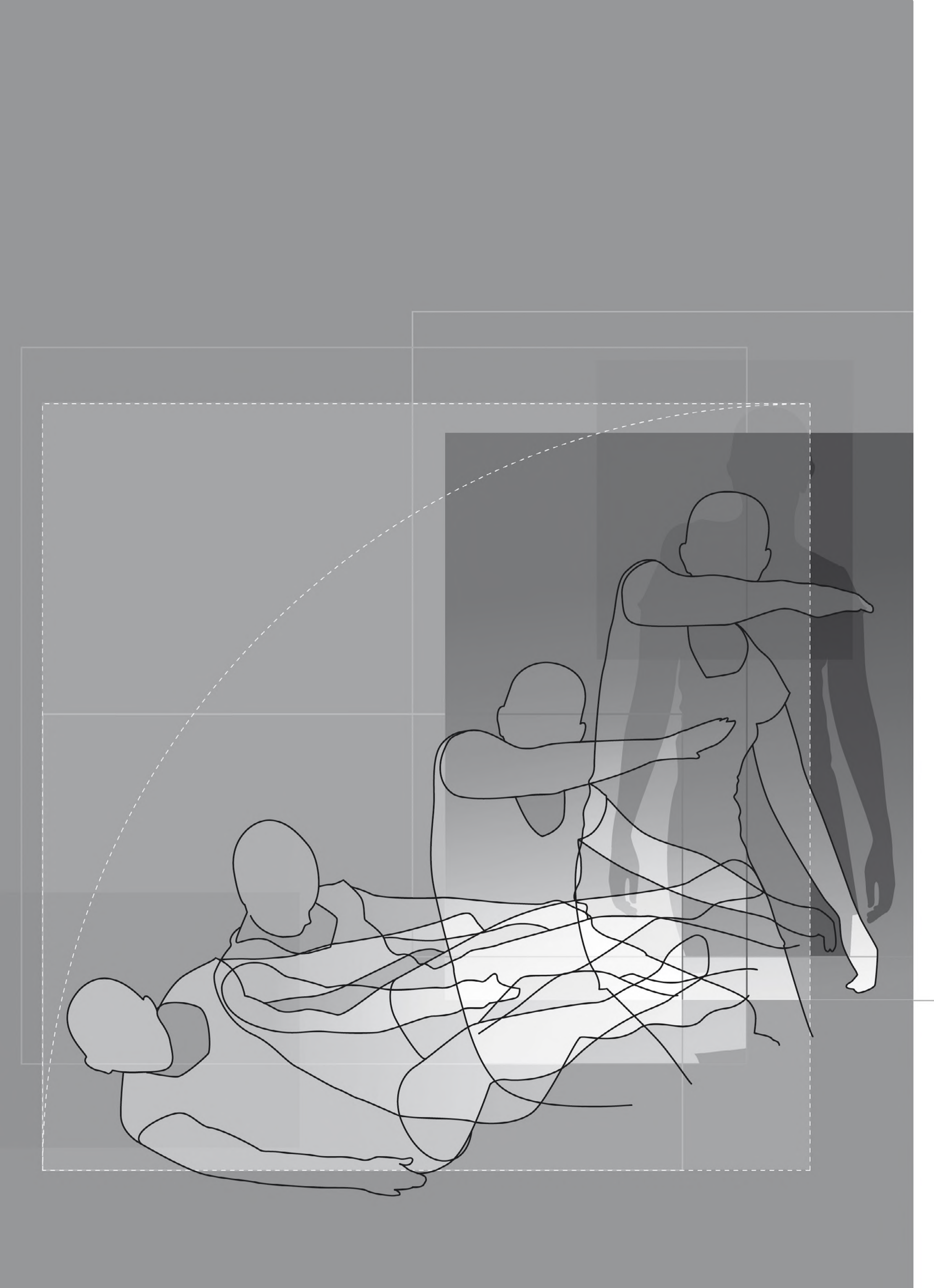
Differences in early activity of PE, as found in the present study, suggested that experienced fallers anticipated a possible fall with a preparation for trunk rotation, in contrast to the inexperienced fallers. Moreover, differences indicated a more pronounced use of PE during an MA fall in experienced fallers. The experience-related differences in activation profiles indicate that in MA falls training the element of shoulder protraction deserves specific attention. The amount of training needed to optimally benefit from training of MA fall techniques (in terms of impact reduction) and their application in real-life falls should be further investigated, to be able to weigh the costs of extensive training against the benefits for additional reduction of injury risk.

Conclusions

The results of this study showed that it was possible to apply a fall strategy that was cued during a fall. The decreasing success rates with increasing cue delay supported the hypothesis that there is a limit in the cue delay still leaving enough time to perform the fall technique. For the application of a voluntary fall technique during a sideways fall from kneeling height this minimum movement time, necessary to perform the fall technique adequately, was about 145-155 ms.

The EMGs showed reactions to the cue at onset latencies of about 180-190 ms, which was the minimum reaction time that could be expected for a choice reaction task, as used in the present experiment. The EMG amplitudes showed technique-specific differences that could mainly be explained by the different functions of the muscles during the techniques.

The effects of time pressure on the performance of the fall technique might be a more vigorous response. In the present study the potential presence of this effect of time pressure was obscured by an increase of EMG amplitudes during the fall, independent of the cue. The observation that only subtle differences could be detected in EMG activity between experienced and inexperienced people supported previous findings that MA fall techniques are easy to learn.



6

Chapter

Martial arts fall training to prevent hip fractures in the elderly

Based on
B.E. Groen, E. Smulders, D. de Kam, J. Duysens, and V. Weerdesteyn
Osteoporosis International 21(2):215-21, 2010

Introduction

Hip fractures are a worldwide health problem. Due to demographic trends, the yearly number of hip fractures is quickly rising and will reach an estimated 6.3 million in 2050 (Cooper et al., 1992). After adjusting for age and previous hospitalization, mortality risk increases threefold during the first six months after a hip fracture and remains substantially increased for at least six years post fracture (Farahmand et al., 2005). In addition, hip fractures are associated with a decrease in physical function, in quality of life, and a loss of independence; they are also responsible for high medical costs (Cummings and Melton, 2002).

About 90% of all hip fractures are caused by falls (Cumming and Klineberg, 1994). Persons with osteoporosis are at high risk for hip fractures because of their low bone strength. Consequently, hip fracture prevention has usually targeted at the prevention of further bone loss, predominantly by the prescription of bisphosphonates (Hochberg et al., 2002; Orwoll et al., 2000; Harris et al., 1999; McClung et al., 2001; Chesnut III et al., 2004). In addition to low bone mineral density, however, the mechanics of a fall are independent and at least as important risk factors for hip fractures. This is particularly true for the fall direction (Greenspan et al., 1994). In case of falls to the side with direct impact on the greater trochanter, the risk for hip fracture increases the most (Nevitt and Cummings, 1993; Wei et al., 2001). In this type of fall, hip protectors might reduce the risk of hip fractures. In vitro experiments have shown that hip protectors indeed decrease the impact load on the greater trochanter (Kannus et al., 1999; Robinovitch et al., 1995a; van Schoor et al., 2006). Clinically, however, the beneficial effect of hip protectors on hip fracture risk has not yet been unequivocally proven (Kiel et al., 2007; Parker et al., 2005).

Alternatively, it may be possible to teach older individuals how to fall safely (DeGoede et al., 2003). Recent experimental studies have indicated that fall training based on martial arts (MA) fall techniques may be useful (Sabick et al., 1999; Groen et al., 2007). An important characteristic of MA fall techniques is that a fall is changed into a rolling movement. By rolling, the forces are distributed over a larger impact site and the amount of energy to be absorbed during impact is reduced because kinetic energy is preserved during the rolling movement. Other characteristics of the MA fall technique are head protection and the use of the arm to break the fall. It was shown that in young, experienced martial artists, MA

fall techniques indeed reduced hip impact forces by 12-27% compared to other types of falls, including a natural fall arrest strategy with an outstretched arm (Groen et al., 2007; Sabick et al., 1999). In addition, MA fall techniques seemed to be easy to learn, since a 30-min training resulted in a 17% reduction of hip impact force in young adults (Weerdesteyn et al., 2008).

From biomechanical modelling studies there is evidence that arrest strategies that involve knee flexion, waist flexion and trunk rotation are most effective to reduce impact forces during a sideways fall (Lo and Ashton-Miller, 2008). Since this movement combination is essential during an MA fall to enable rolling after impact, the study of Lo and Ashton-Miller (2008) confirms the potential effects of MA fall techniques in reducing impact forces and, thereby, reducing the risk for hip fractures. Importantly, they found that such an arrest strategy was effective to reduce the impact forces below the fracture thresholds even when the effects of ageing on muscle forces (reduction of 30% in muscle force) were simulated in the model.

Recently, MA fall training was introduced as an element of a fall prevention programme for healthy, elderly persons (Weerdesteyn et al., 2006). Based on observation, the participants were able to learn these MA fall techniques within five sessions. However, the trainability of these techniques and the effectiveness of the training in elderly persons have not yet been measured. Therefore, the purpose of the present pilot study was to determine whether healthy, older individuals could learn MA fall techniques during a five-session fall training and whether this would result in a reduction of the hip impact force during a sideways fall. It was hypothesized that healthy, older individuals could learn MA fall techniques during the training and that better fall skills would result in a reduction of hip impact force during a sideways fall.

Methods

Participants

For participation in this pilot study, 28 healthy individuals aged between 60 and 81 years were recruited from local sport activities for seniors. Three individuals were not able to complete the study due to medical reasons unrelated to the study. Hence, a total of 25 participants (6 male and 19 female) completed the study (Table 6.1). All participants lived independently and were able to walk without

walking aids for at least 15 min. Exclusion criteria were contraindications for physical exercise, a history of a cerebral vascular accident with remaining symptoms, diseases of the central or peripheral nervous system, use of psychotropic medication, osteoporosis or increased risk for osteoporosis (Elders et al., 2005), body mass index below 20, and prior experience in MA fall techniques. Inclusion and exclusion criteria of the participants were evaluated using structured interviews by telephone. In case of doubt, a physician was consulted to determine whether participation was allowed. All participants signed an informed consent and the Medical Ethical Board for the region Arnhem-Nijmegen approved the protocol.

Table 6.1 Subject characteristics.

Subject characteristics	Mean (SD)	Range
Number	25	
Gender (male/female)	6 / 19	
Age (years)	69.5 (5.9)	60 - 81
Body mass (kg)	72.92 (9.28)	56 - 95
Height (m)	1.66 (0.08)	1.51 - 1.82
Body mass index	26.60 (2.65)	20.25 - 33.46
Number of participants with fall(s) within the previous year	5	

Sample size

The sample size calculation was based on data from a previous study in healthy, young adults demonstrating a reduction in hip impact force after a brief period of MA fall training (Weerdesteyn et al., 2008). In the present study we compared differences in performance of MA techniques, whereas in the previous study different techniques were compared. Therefore, we expected a smaller difference in mean hip impact force (normalized for bodyweight (BW), 0.3 BW instead of 0.41 BW). Furthermore, a larger standard deviation of the differences (0.4 BW instead of 0.31 BW) was expected for the group of older individuals. For the study to have a power of at least 0.9 with α set at 0.05, a sample size of 21 persons would be sufficient. A post-hoc calculation showed an actual power of 0.78.

Study design

For this pilot study we used an experimental within-subject design without control group. Prior to this study it was unknown whether older individuals are able to learn MA fall techniques at all. In addition, it was uncertain if they could participate in fall experiments because, as far as the authors know, this was the very first study in which older individuals participated in fall experiments. Therefore, a pilot study without control group seemed to be warranted to provide provisional evidence before designing a randomized clinical trial.

Intervention

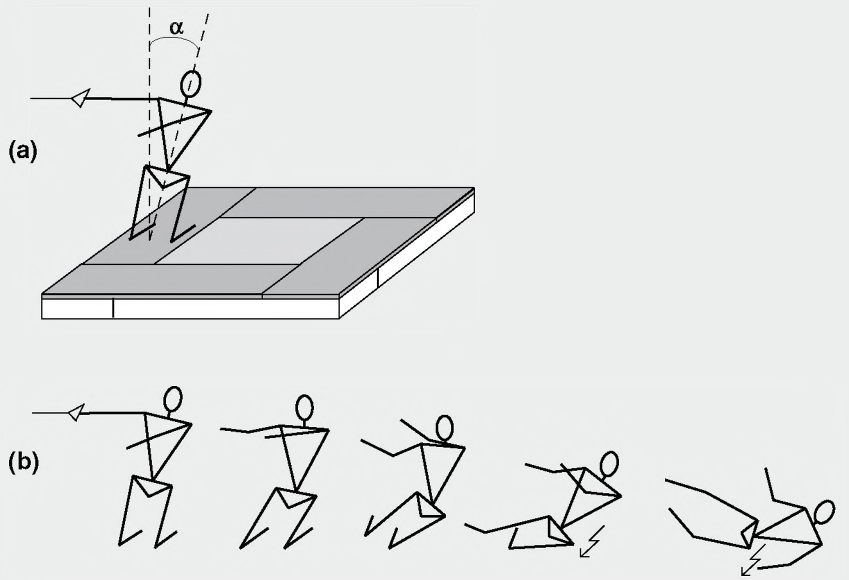
The fall training was identical to the fall training included in the Nijmegen Falls Prevention Program (Weerdesteyn et al., 2006). It consisted of five weekly sessions of 45 min in which the participants learned to apply MA fall techniques in a forward, backward and sideways direction. Fall exercises started in sitting position, followed by falls from a kneeling and standing position.

Experimental set-up and protocol

Fall performance in the sideways direction was assessed both before (within two weeks prior to training) and after the intervention (within one week after training). The participants were kneeling on a padded surface next to the force plate (1.2 m x 1.2 m, Bertec® corporation, Columbus, Ohio, USA, 2400 Hz) that was embedded in a 2.7 m x 2.7 m platform and was covered with judo mats (4 cm polyurethane foam, Agglorex®, Lommel, Belgium). They held on to a grip with the right arm such that the lateral inclination of the trunk and upper legs was 22° relative to the vertical. The left arm was held in front with 90° shoulder flexion and extended elbow (Figure 6.1a). Participants initiated a fall by releasing the grip, immediately after the instruction to do so. A load switch (2400 Hz) that was placed in series with the grip was used to detect the instant of release.

Pre-intervention, the MA fall was demonstrated two times by one of the investigators. Subsequently, participants imitated the technique several times to become familiar with the experimental set-up prior to data collection. It was emphasized that they should not land on the hand first. Post-intervention, only the initial position was demonstrated and no practice trials were allowed. The participants performed a total of five sideways falls per assessment (Figure 6.1b). Additional falls were performed if a participant clearly started to

Figure 6.1 Experimental set-up. (a) The participants started in kneeling position next to the force plate covered with judo mats. They held on to a grip with the outstretched right arm, such that the vertical trunk angle (α) was 22° to the vertical. The participants held the left arm in front of them. (b) Stick figure of a martial arts fall technique from kneeling position. The fall is changed into a rolling movement and the arm is used to break the fall after hip impact. A broken arrow indicates impact.



move prior to releasing the grip. The participants wore soft-shell hip protectors (Lyds international B.V. Amstelveen, The Netherlands).

Prior to data collection, reflective markers were placed on anatomical landmarks of the body. Data collection started with a reference measurement to define the position of the greater trochanter (GT) with respect to a marker frame with three markers that was attached to the femur. The GT marker was subsequently removed. The position of the virtual GT marker during the falls was calculated based on the position and orientation of the marker frame by the method described by Söderkvist and Wedin (1993). The positions of the markers were recorded by a six-camera 3-D motion analysis system (Vicon®, Oxford, UK) at 200 Hz. In addition, two video cameras (Panasonic®SDII, Matsushita Electric Industrial Co., Osaka, Japan, 25 Hz)

recorded the falls from an anterior and lateral (right side) point of view. These videos were rated between one (very poor) and ten (excellent) by two independent physical therapists who are experts in MA (MA-experience for more than 20 years and MA-trainer for more than 10 years). The videos were renamed such that it was not possible for the experts to determine whether it was a pre-intervention or post-intervention video. Visual analogue scale (VAS) scores for general fear of falling in daily life were obtained from the participants. VAS scores are frequently used to measure changes within individuals with respect to a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured, such as pain, fatigue or fear. As we were interested in the (within-subject) changes in general fear of falling as a result of the intervention, we decided to use a single-item VAS score even though it has not been validated for this specific purpose. Post-intervention, the participants answered self-efficacy questions on a five-point scale with regard to their confidence to apply MA techniques during a fall in a training situation and in daily life.

Data analyses

First, the kinematic data were analysed to check if participants did not start moving prior to releasing the grip, as defined by a change in vertical trunk angle of more than 7°. In addition, it was determined whether the hip was the first site of impact using the vertical position of the virtual GT marker at initial impact. Falls were excluded if this was not the case or when hand and hip impact occurred simultaneously. Initial impact was defined as the instant at which the vertical force as measured with the force plate first exceeded 10 N. These instants were automatically detected with a custom written program in MATLAB® (The MathWorks, Natick, Massachusetts, USA).

For the remaining falls, hip impact force was determined as the maximum force in the vertical direction at hip impact, normalized for body weight. The vertical velocity of the hip at impact and the total fall duration were calculated as control variables. Velocity was computed by numerical differentiation and subsequently low-pass filtered with a fourth-order Butterworth filter with a cut-off frequency of 10 Hz. Hip impact velocity was defined as the vertical velocity of the virtual GT marker just before impact (Groen et al., 2007). Fall duration was defined as the time between fall initiation, as detected by the load switch, and initial impact.

To determine the inter-rater reliability of the scores of the two MA experts, a

Pearson correlation coefficient was calculated. For the analysis of fall performance, the scores of the two MA experts were averaged. Paired-sample *t*-tests were used to determine differences between pre-intervention en post-intervention assessments. A Pearson correlation coefficient was calculated to determine the association between the pre-intervention fear of falling and the change in fear of falling post-intervention. For all tests, the level of significance was set at $p < 0.05$.

Results

According to the experts, fall performance improved significantly after training, as reflected in a mean increase of 1.6 (95% confidence interval 1.0-2.1) on a ten-point scale ($p < 0.001$). Pre-intervention, seven participants showed a fair to good fall performance (scores 6 to 10). This number increased to 16 participants post-intervention. The inter-rater Pearson correlation coefficient was $r = 0.69$ ($p < 0.001$). In the analysis of hip impact forces, a total of 84 pre-intervention trials and 83 post-intervention trials for 22 participants could be included. Mean hip impact force was 2.46 ± 0.26 BW during the pre-intervention falls; it decreased significantly by 0.20 BW (95% confidence interval 0.04-0.35 BW) after training ($p = 0.016$). Hip impact velocity and fall duration did not differ significantly between pre-intervention and post-intervention falls (Table 6.2).

Table 6.2 Fall characteristics pre-intervention and post-intervention. Mean (SD) of the hip impact force (normalized for body weight), hip impact velocity and fall duration of the participants (n = 22).

	Hip impact force (BW)	Hip impact velocity (m/s)	Fall duration (ms)
Pre-intervention	2.46 (0.26)	1.22 (0.26)	246 (92)
Post-intervention	2.26 (0.35)	1.26 (0.19)	235 (72)
P-value	0.016 *	0.529	0.561

* = Significant difference ($p < 0.05$)

6

Fear of falling in daily life was determined with a VAS score. The mean pre-intervention VAS score was 3.19 ± 1.99 on a ten-point scale; it decreased significantly by 0.88 (95% confidence interval 0.29-1.48; p = 0.005). Figure 6.2 shows the difference in VAS scores between the pre-intervention and post-intervention assessment as a function of the pre-intervention VAS scores. In general, the VAS score for fear of falling decreased most in participants with higher scores before the start of the training ($p < 0.001$, $r^2 = 0.42$).

Table 6.3 shows the results of the self-efficacy questions. Twenty-one participants were partly or fully confident of being able to apply the MA fall techniques in the training situation. Moreover, 15 participants were also confident of being able to apply these techniques during an unexpected fall in daily life.

Figure 6.2 Scatter plot of the change in fear of falling as a function of the fear of falling before training. Fear of falling was determined with a Visual Analogue Scale (VAS) scale. Negative differences in VAS scores indicate a reduction in fear of falling.

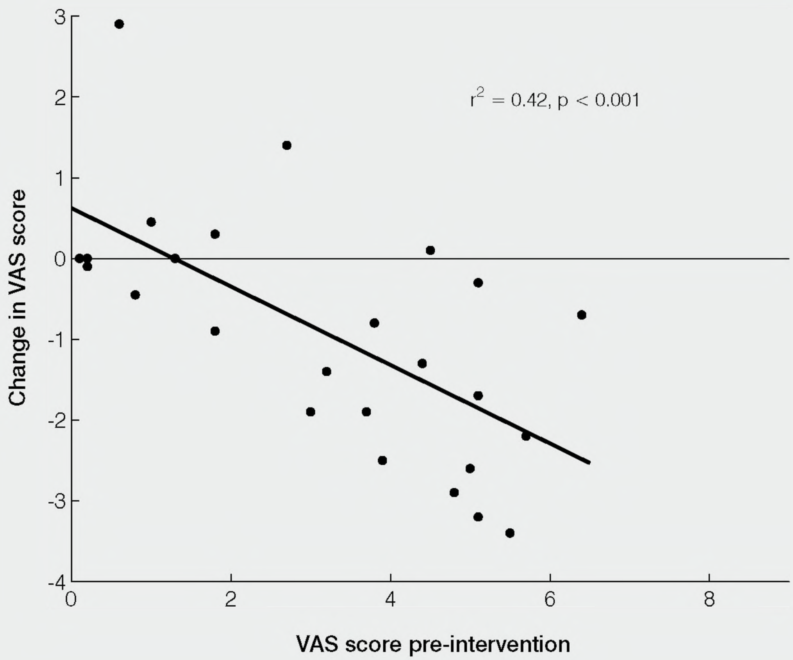


Table 6.3 Self-efficacy. Participants' answers (N = 25) to the questions whether they were confident of their ability to apply the martial arts fall techniques in a training situation and during an unexpected fall in daily life.

	Fully agree	Agree	Neutral	Disagree	Fully disagree
During training	9	12	4	-	-
Unexpected fall	2	13	9	1	-

Discussion

In this pilot study the trainability and the effectiveness of fall techniques in older individuals were investigated for the first time. The results confirm earlier subjective observations (Weerdesteyn et al., 2006) that healthy, older individuals could learn the basics of MA fall techniques within five weekly training sessions. The results showed an increase of 1.6 points on a ten-point scale of fall performance as determined by the MA experts, which was considered a moderate effect. Given the short duration of the fall training of only five sessions, such an effect seems to be realistic to expect. A further improvement of fall performance could be anticipated with additional training sessions, because few participants achieved a near-optimal fall performance after the MA fall training. Participants indeed asked for more training sessions to further improve their fall performance. However, a moderate effect in fall performance after only five sessions shows that MA fall techniques are trainable in older individuals.

Consistent with the hypothesis, the improvement of fall performance after training resulted in a decrease in hip impact force. Although this decrease in hip impact force may not seem particularly large (0.20 BW which corresponds with 8%), it should be noted that the comparison was made after the subjects underwent "minimum learning" (they had seen the technique demonstrated twice and they had limited practice before data collection pre-intervention).

Not surprisingly, the observed reduction in hip impact force during an MA fall after the training was less than the difference in hip impact force between MA falls and natural falls as observed in previous studies (reduction of 0.32-1.56 BW

or 12-27%) (Groen et al., 2007; Weerdesteyn et al., 2008; Sabick et al., 1999). For comparison with these previous studies, it would have been desirable to compare the final trained performance with “natural” falls, but this was not feasible because of safety considerations. It is known that the natural fall arrest strategy, in which the outstretched arm is used to block the fall, could result in wrist fractures, particularly in older individuals. In addition, the (young) participants of our previous studies (Groen et al., 2007; Weerdesteyn et al., 2008) reported the hand impact to be uncomfortable when performing the natural arrest strategy. In contrast, arm impact during an MA fall technique was not reported to be uncomfortable, and it is believed not to be harmful because the impact is distributed over a larger contact area due to the simultaneous impact of hand and forearm (Sabick et al., 1999).

It should be noted that the reduction of hip impact force could not be explained by a reduction in hip impact velocity, which is one of the important determinants of hip impact force (Groen et al., 2008). This suggests that other features such as rolling on after hip impact may indeed play an important role in the reduction of hip impact force (Groen et al., 2007; Groen et al., 2008).

The potential relevance of the MA fall training for hip fracture prevention could be estimated by comparing the observed hip impact reduction of 8% to the increase in bone mineral density due to the prescription of bisphosphonates using the hip fracture risk factor. The hip fracture risk factor is defined by the ratio of force at impact divided by the load necessary to cause a fracture (DeGoede et al., 2003; Lo and Ashton-Miller, 2008). Based on an average load of 3100 N needed to fracture the femur of elderly woman, an average trochanteric bone mineral density of 0.61 g/cm^2 (Cheng et al., 1997) and the reported relation between bone mineral density and hip fracture load (Courtney et al., 1994), it can be calculated that for the same decrease of hip fracture risk, an 8% decrease in impact force corresponds to 4.1% increase in bone mineral density. Clinical studies have shown that bisphosphonates increase trochanteric bone mineral density by approximately 2% to 5.5%, depending upon the agent and dose (Orwoll et al., 2000; Harris et al., 1999; McClung et al., 2001; Chesnut III et al., 2004) in conjunction with a reduction in hip fracture risk in older women with confirmed osteoporosis (McClung et al., 2001). Hence, this calculation suggests that MA fall training might have similar effects for hip fracture prevention as the prescription of bisphosphonates, which is encouraging for future research.

Fear of falling was significantly reduced after the MA fall training. Since a considerable number of participants (10 of 25) experienced little fear of falling (VAS < 3) before training, a floor effect in this group of participants might result in an underestimation of the effects of the fall training on fear of falling. In general, fear of falling decreased more in participants with a higher initial fear of falling. Since fear of falling has been shown to be an independent predictor of falling (Friedman et al., 2002), the reduction in fear of falling might have an additional effect on hip fracture prevention.

A limitation of the present study is the absence of a control group. Therefore, we cannot rule out the possibility that the observed effects are (partly) due to the exposure during the pre-intervention assessment. However, we think that this is unlikely since the MA techniques involve coordinated whole body movements. Usually, such a movement is not performed perfectly after a short demonstration without further explanation and a couple of practice opportunities without feedback on the performance. This is supported by the far from optimal performance scores prior to the training and the clear progress in performance observed by the trainers over the course of the five training sessions.

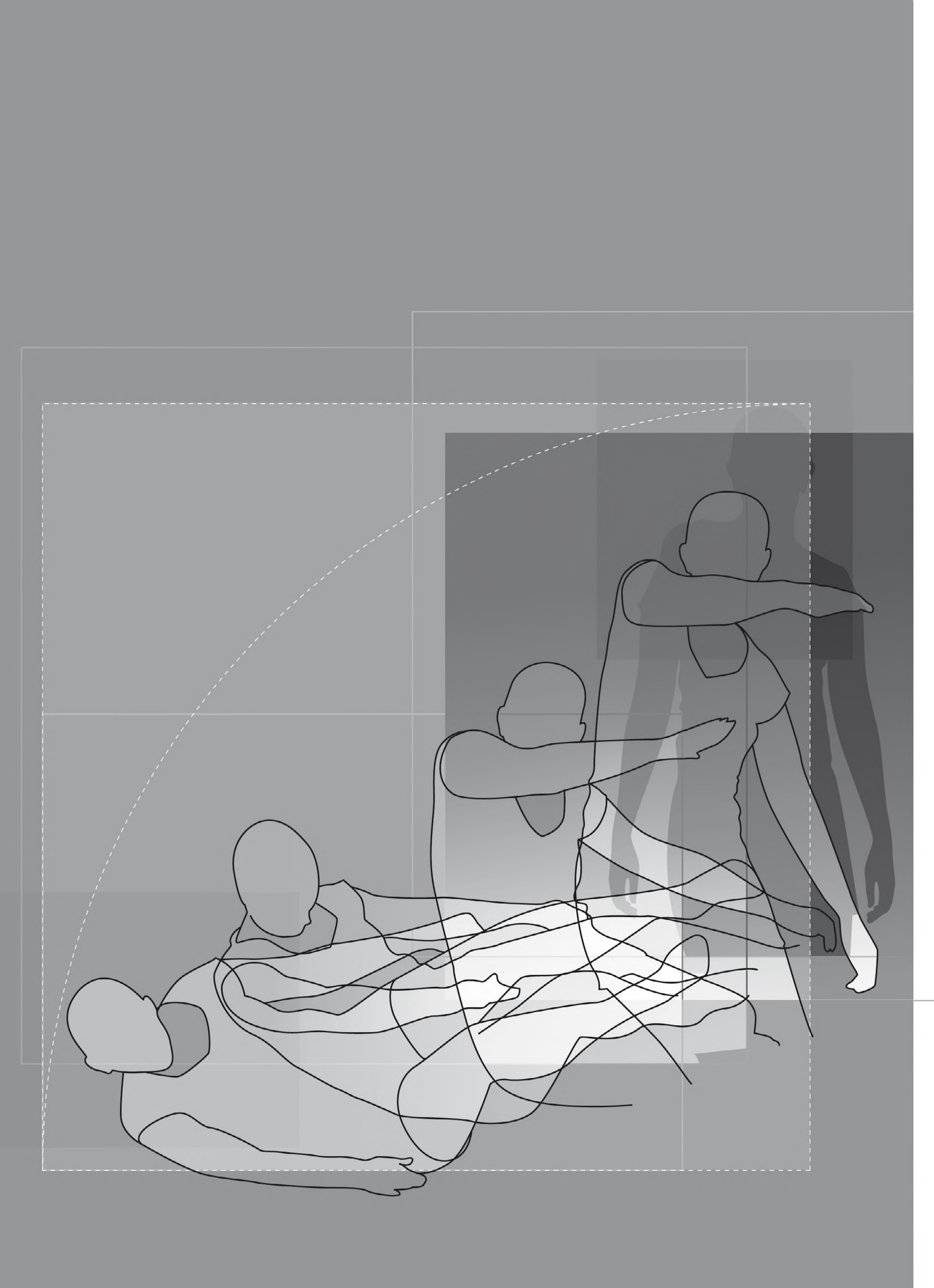
A second limitation is that the subjects groups were not gender balanced. With only 6 of the 25 subjects being male, we cannot be certain that the results are representative for the general population of older males.

Another limitation of the present study is that the falls investigated differ in some aspect from most falls in daily life. For safety reasons, falls were initiated from kneeling position while most fall-related hip fractures occur from standing position. It may be argued that the impact forces increase in falls from standing position because of the added potential energy. Although this is true, it should be noted that the expected increase may be less because of other concomitant movements (such as squatting) (Robinovitch et al., 2004). As the mechanisms responsible for impact reduction in MA fall techniques are comparable for falls from both kneeling and standing position (Groen et al., 2008), it is conceivable that MA fall techniques will also reduce the impact force during falls from standing height.

In addition, falls in the experimental set-up were self-initiated while falls in daily life are generally unexpected. Although self-initiation is likely to reduce the absolute impact values (Robinovitch et al., 2004), self-initiated falls are safer and can be used to determine the trainability and effectiveness of fall training. In the

present study, 15 out of the 25 participants indicated that they were confident of being able to apply the MA fall techniques in unexpected falls in daily life. To be able to consciously apply a fall technique during an unexpected fall, there should be enough time to choose and execute the technique. Previous studies showed that young adults could successfully implement specific fall techniques after initiation of a volitional fall from kneeling position (van Swigchem R. et al., 2009) or an unexpected fall from standing height (Feldman and Robinovitch, 2004). Additional research is needed to determine whether (older) individuals will be able to apply MA fall techniques during unexpected falls in daily life and whether this results in less hip fractures.

In conclusion, the present pilot study suggests that MA fall techniques may be trainable in older individuals, which may reduce hip impact forces in volitional falls from kneeling position. This indicates the potential usefulness of MA fall training for hip fracture prevention in older individuals. In addition, MA fall training could reduce the fear of falling in daily life, which might result in the prevention of falls and related injuries.



7

Chapter

Could martial arts fall training be safe for persons with osteoporosis?: A feasibility study

Based on

B.E. Groen, E. Smulders, J. Duysens, W. van Lankveld, and V. Weerdesteyn

BMC Research Notes 3:111, 2010

Introduction

Hip fractures among the elderly are a health problem associated with high mortality and morbidity rates. In particular persons with osteoporosis or low bone mineral density (BMD) are at risk for hip fractures due to their reduced bone strength (Greenspan et al., 1994; Wei et al., 2001). Therefore, in clinical practice hip fracture prevention focuses mainly on treating osteoporosis.

About 90% of hip fractures are caused by falls (Cumming and Klineberg, 1994). Apart from a low BMD, fall characteristics have been identified as independent risk factors for hip fractures (Greenspan et al., 1994; Wei et al., 2001). Hence, fall prevention and reduction of fall severity may also prevent hip fractures. Falls with the highest risk for hip fractures are sideways falls and falls with direct impact on the greater trochanter of the proximal femur (Wei et al., 2001). To reduce the hip fracture risk in these types of falls, hip protectors may be useful. In vitro experiments have shown that the best hip protectors can attenuate femoral impact forces by as much as 85% (Kannus et al., 1999; Robinovitch et al., 1995a). However, to prevent hip fractures in everyday life, user compliance is a problem (Parker et al., 2006).

Alternatively, people may be taught safe fall arrest strategies. Recent studies have indicated that fall strategies based on martial arts (MA) fall techniques reduce the impact forces during a volitional fall. When using an MA fall technique, the fall is changed into a rolling movement. During the roll the forces are distributed over a larger impact site. Furthermore, the amount of energy to be absorbed during impact is reduced because kinetic energy is preserved during the rolling movement. Experimental studies have shown that MA techniques during a volitional fall reduce hip impact forces, which presumably reduces the hip fracture risk as well (Groen et al., 2007; Weerdesteyn et al., 2008; Sabick et al., 1999). Recently, MA fall training that consisted of five weekly training sessions of 45 min was included in a successful falls prevention programme for healthy, elderly persons (Weerdesteyn et al., 2006). A further experimental study revealed that older participants were able to learn the MA techniques during the five weekly training sessions; the improved performance reduced the hip impact force during a volitional fall (Groen et al., 2010). For safety reasons, persons with osteoporosis have been excluded from these fall training studies. However, persons with osteoporosis are expected to experience the most benefits from such training because of their high fracture risk if they fall.

Figure 7.1 Photo series of martial arts fall techniques from a kneeling position. (a) Martial arts fall techniques during a forward fall and (b) during a sideways fall from kneeling position on the judo mat.

The purpose of the present study was to determine whether MA fall training is safe for persons with osteoporosis. For obvious safety reasons, this could not be directly assessed using persons with osteoporosis. Therefore, we measured the hip impact forces during the MA fall exercises from a kneeling and a standing position onto both a judo mat and a thick mattress in a group of young adults. We focused on sideways and forward falls, as these falls have the highest risk for direct hip impact and hip fractures. To determine whether the impact forces are within the safety limits for persons with osteoporosis, two safety criteria were defined based on the femoral fracture load in elderly women (Cheng et al., 1997). It was hypothesized that for persons with osteoporosis practicing falls from a kneeling position are only safe if performed on a thick mattress while falls from a standing position are never safe.

Methods

Participants

Healthy, young individuals without prior experience in MA fall techniques participated in this study. Six participants (age: 23-44 years, weight: 57-85 kg, height: 1.74-1.86 m) performed the MA fall training on a judo mat and six participants (age: 23-44 years, weight: 55-73 kg, height: 1.71-1.86 m) performed the training on a thick mattress. All participants signed informed consent prior to participation. The Ethical Board for the region Arnhem-Nijmegen approved the protocol (2004/152).

Fall training

Each participant received individual fall training for approximately two hours. The fall exercises that were performed were the sideways and forward fall techniques as included in the Nijmegen Falls Prevention Program (Weerdesteyn et al., 2006). The three most important characteristics of MA techniques are the rolling movement, head protection by neck flexion and the use of the arm to stop the rolling movement. In forward falls, trunk flexion and rotation enable participants to roll over the scapula of the ipsilateral shoulder and diagonally across the back to the contralateral hip region (Figure 7.1a). In sideways falls, participants roll over the ipsilateral hip to the scapula of the ipsilateral shoulder; this is achieved by

flexion, lateral flexion and rotation of the trunk (Figure 7.1b). Both sideways and forward fall exercises started in a sitting position; these were not measured since they were assumed to have no hip fracture risk. Thereafter, falls from kneeling and standing positions followed. The fall exercises were performed either on the judo mat (4 cm thick polyurethane foam, size 1.2 m x 1.2 m) or on the 25 cm thick gymnasium mattress (size 2.5 m x 1.25 m). Each fall condition was performed for at least 8 trials.

Data collection

During the trials, force data were collected by a force plate (1.2 m x 1.2 m, Bertec® Corporation, Columbus, Ohio, USA) at a sample rate of 2400 Hz, which was embedded in a 2.2 m x 2.7 m platform and covered with judo mats or the thick mattress. It must be emphasized that the judo mat or mattress was not supported by any other surface than the force plate. Hence, all (vertical) forces that are applied to the mat are measured by the force plate. Similar set-ups are used by other groups, for instance, for mechanical testing of the force-attenuating effects of low stiffness floors on peak impact forces on the skin surface of the greater trochanter of the femur and the femoral neck (Laing and Robinovitch, 2009). A 6-camera 3-D motion analysis system (Primas, Delft University of Technology, Delft, The Netherlands) was used to collect the 3-D positions of reflective markers at 100 Hz. The markers were attached bilaterally to the wrist, elbow, acromion and the pelvis. Kinematic and force data were collected synchronously.

Data analyses

For all falls from kneeling and standing positions, hip impact forces were determined. Hip impact force was, in general, the first distinct peak in the force curve after fall initiation. Kinematic data were used to confirm whether indeed this peak corresponded to hip impact using the vertical position of the markers. For each fall condition, the maximum vertical hip impact force was determined for each participant (Fmax). For each fall exercise, the highest Fmax observed during all the trials of all participants was used to assess the safety of the fall training.

Safety criteria

Two safety criteria were constructed to determine which fall exercises and conditions were considered to be safe for persons with osteoporosis. Both safety

criteria were based on the femoral fracture load of elderly women. Following Kannus and coworkers (Kannus et al., 1999), we used the mean femoral fracture load of 3100 N ± 1200 N as determined for cadaveric femora of a group of elderly women by Cheng and coworkers (Cheng et al., 1997).

The first safety criterion implied that the femoral load during a fall exercise should not exceed the average fracture load for elderly women minus 2 SD (700 N: 3100 N – 2 * 1200 N). In other words, the threshold was set at a value that should be safe for 97.7% of the elderly women. Because the femoral load is not equal to the external hip impact force as measured with the force plate, we took two mediating factors into account. Firstly, we included the expected protective effects of soft tissue around the hip. The mean attenuation of the peak impact force caused by soft tissue is 13% in elderly men and women (Robinovitch et al., 1995b). Because persons with osteoporosis often have relatively little adipose tissue, we used a 10% reduction of Fmax by soft tissue padding. Secondly, we decided that persons with osteoporosis have to wear hip protectors during the MA fall training. If participants wear hip protectors, the actual impact forces exerted on the femur will be substantially reduced. It has been shown that the best hip protectors reduce impact forces by between 65% and 85% (Robinovitch et al., 1995a; Kannus et al., 1999). According to the first safety criterion a fall was safe if the highest Fmax measured reduced by 10% for soft tissue padding and by 65% for the use of hip protectors, was lower than the threshold of 700 N (highest Fmax * 0.9 * 0.35 < 700 N).

For the second safety criterion we took into account that hip protectors are not always placed correctly with respect to the greater trochanter to optimally attenuate the impact forces (Minns et al., 2007; van Schoor et al., 2003). In this second safety criterion we therefore left out the factor of force attenuation by hip protectors; the threshold was set at the average femoral fracture load for elderly minus one standard deviation (1900 N: 3100 N – 1200 N). Hence, the threshold was set at a value that should be safe for 84.1% of the elderly women if they did not wear hip protectors. According to the second safety criterion, a fall was safe if the highest Fmax measured, reduced by 10% for soft tissue padding, did not exceed the threshold of 1900 N (highest Fmax * 0.9 < 1900 N).

Results

In general, the highest Fmax observed during the forward MA falls was higher than that found during the sideways falls under similar floor and fall height conditions (Table 7.1). Figure 7.2 shows the highest Fmax of all participants in the MA in sideways and forward falls from kneeling position on the judo mat and the thick mattress and from standing position on the thick mattress in relation to the thresholds of the two safety criteria.

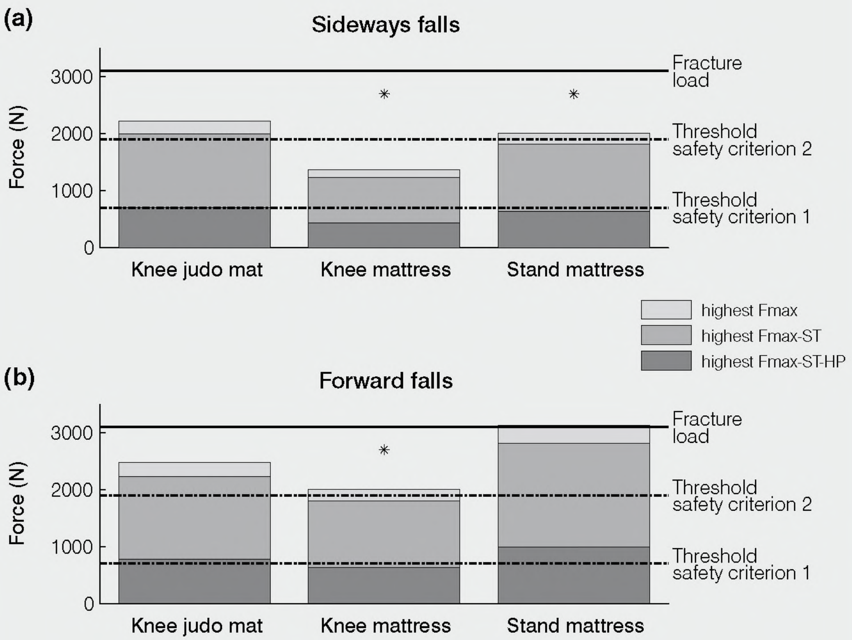
For the sideways falls, the Fmax corrected for both soft tissue padding and hip protectors was lower than 700 N in all fall conditions. Hence, all the sideways falls met the first safety criterion (corrected Fmax was lower than 700 N). The Fmax if only corrected for soft tissue padding exceeded 1900 N in some of the participants during falls from kneeling position on the judo mat. Hence, the sideways falls from kneeling position on the judo mat did not meet the second safety criterion (range Fmax 1260-2219 N). If performed on the mattress, however, the sideways falls from kneeling position as well as from standing position met the second safety criterion (range Fmax 878-1426 N and 1216-2012 N, respectively) (Table 7.1, Figure 7.2).

Table 7.1 Descriptive statistics of the maximum hip impact force (Fmax) for the different fall conditions.

Fall exercise			Fmax (N)		
Fall direction	Fall height	Fall surface	Median	IQR	Max
Sideways	Knee	Judo mat	1769	407	2219
	Knee	Mattress	1330	131	1426
	Stand	Mattress	1551	439	2012
Forward	Knee	Judo mat	1745	624	2474
	Knee	Mattress	1453	669	2006
	Stand	Mattress	1833	419	3132

IQR= interquartile range, Max= highest Fmax.

Figure 7.2 Maximal hip impact forces for sideways and forward MA fall exercises. The maximal hip impact force among all participants (highest Fmax) was corrected either for soft tissue padding (ST, 10% reduction) and wearing hip protectors (HP) that could attenuate the maximum hip impact force by at least 65% (safety criterion 1) or soft tissue padding only (10% reduction) (safety criterion 2). The corrected highest Fmax values were compared with thresholds of safety criterion 1 (700 N: average femoral fracture load for elderly minus two standard deviations) and safety criterion 2 (1900 N: average femoral fracture load for elderly minus one standard deviation), respectively. Asterisks (*) indicate fall conditions that met both safety criteria.



For the forward falls, the falls from kneeling position did neither meet the first nor the second safety criterion if performed on the judo mat (range Fmax 1173-2474 N). However, if forward falls from kneeling position were performed on the mattress, Fmax met both safety criteria (range Fmax 1028-2006 N). Forward falls from standing position even when performed on the mattress did neither meet the first nor the second safety criterion (range Fmax 1389-3132 N) (Table 7.1, Figure 7.2).

Discussion

This study determined whether MA fall training could be considered to be safe for persons with osteoporosis as extrapolated from the data of young adults and using stringent safety criteria. The results showed that sideways falls from kneeling and standing position met the safety criteria if performed on a thick mattress. Forward falls only met the safety criteria if performed from kneeling position on the thick mattress. Hence, in order for the MA fall training to be safe for persons with osteoporosis, the fall training should be performed on a thick mattress and forward falls from a standing position should be excluded. In addition, participants should wear hip protectors that attenuate the maximum hip impact force by at least 65%. Specific data on the femoral fracture load of osteoporotic women have not been reported in the literature. Therefore, we based the safety criteria on the mean proximal femoral fracture load of elderly women (n = 28) with a mean age of 71 years (3100 ± 1200 N) (Cheng et al., 1997). It is very likely that at least some of these women had osteoporosis. Because of the strong correlation between fracture load and femoral neck BMD (Cheng et al., 1997; Courtney et al., 1995), the osteoporotic women were probably those with the lowest fracture loads. Fracture load is hard to estimate since it also depends on the loading rate (Courtney et al., 1994) and direction of impact (Pinilla et al., 1996). Therefore, we proposed a conservative first safety threshold of two standard deviations below the mean fracture load of elderly women, 700 N, which was lower than any individual femoral fracture load found in cadaveric studies (Cheng et al., 1997; Courtney et al., 1995; Courtney et al., 1994; Pinilla et al., 1996; Lotz and Hayes, 1990). For extra safety, we set a rather low threshold in the second safety criterion. In addition, the decision to include fall exercises was based on the highest Fmax observed among all participants. Hence, we think that our safety criteria are stringent enough to guarantee the safety of the included fall exercises for persons with mild to moderate osteoporosis.

In the present study, the safety of the MA fall training was determined only with respect to the risk for hip fractures. Falls may also result in other injuries, such as bruises, or head, arm and wrist injuries. The most important characteristics of the MA fall techniques are the rolling movement and head protection. To change the fall into a rolling movement, one should curve the trunk and neck. The trunk and neck flexion also prevent the head from impacting the ground. The risk of

head impact is further reduced by slapping the arm to stop the rolling movement, which is another characteristic of the MA fall techniques. This arm slap is not believed to be harmful because the impact is distributed over a larger contact area due to the simultaneous impact of hand and forearm (Sabick et al., 1999; Groen et al., 2010). In previous studies with older, healthy individuals, it was indeed not reported to be uncomfortable (Groen et al., 2010; Weerdesteyn et al., 2006).

The safety of such MA fall training for persons with osteoporosis was recently confirmed by Smulders and coworkers (Smulders et al., 2008). Based on the results of the present study, the MA fall training of the original Nijmegen Falls Prevention Program (Weerdesteyn et al., 2006) was modified. Thus far, 31 persons with osteoporosis (lowest T-score for proximal femur and lumbar vertebrae was between -4 and -2.5) participated and no injuries or adverse physical effects were reported during or after the training (Smulders et al., 2008).

In experimental studies, MA fall techniques have been demonstrated to effectively reduce hip impact forces and, therefore, have the potential to reduce the hip fracture risk. MA fall techniques reduced the hip impact forces during a volitional fall by 12-27% when performed by experienced martial artists (Groen et al., 2007; Sabick et al., 1999) and by 17% in young adults without previous experience in MA fall techniques after a 30-min training session (Weerdesteyn et al., 2008). In addition, it was demonstrated that MA fall techniques were trainable in older individuals. After a five-session MA fall training, the fall performance improved and the hip impact force during a volitional fall was reduced by 8%. It was suggested that the MA fall training may have similar effects for hip fracture prevention as the prescription of bisphosphonates (Groen et al., 2010). The effectiveness of MA fall techniques in reducing the hip impact forces are in line with the results of the biomechanical modelling study of Lo and coworkers (2008). That study revealed that a combination of knee flexion, waist flexion and trunk rotation is the most effective movement strategy to reduce the impact forces during a sideways fall (reduction of 56% compared to a 'broomstick' strategy). In addition, they found that this movement strategy was effective in reducing impact forces below the fracture load even when the effect of aging on muscle forces (reduction of 30% in muscle force) was simulated (Lo and Ashton-Miller, 2008). Since the combination of knee flexion, waist flexion and trunk rotation is characteristic of MA fall techniques to enable rolling after impact, the study of Lo

and coworkers (2008) confirms the potential beneficial effects of MA fall techniques for hip fracture prevention.

The effects of MA fall techniques on hip fracture risk in daily life, however, should be further investigated. A prerequisite for MA fall techniques to potentially contribute to hip fracture prevention in daily life, is the trainability of these techniques in the persons with osteoporosis. The results of a previous study on MA fall training in healthy, elderly persons showed that they were indeed able to learn and apply these MA techniques during a volitional sideways fall from kneeling height. In addition, 15 of the 25 participants reported that they were also confident of being able to apply the MA fall techniques during an unexpected fall in daily life (Groen et al., 2010).

There is no conclusive evidence, however, for the applicability of the fall techniques in daily life, yet some indirect evidence is available. Although it is often suggested that a fall may happen too quickly to be able to select and execute a learned fall technique, the duration of a fall from standing height has been reported to be 715 ± 160 ms (Hsiao and Robinovitch, 1998). Given a voluntary reaction time of 180 ms for initiation a fall technique (van Swigchem R. et al., 2009), there is some time to subsequently execute the fall technique before impact. The minimum movement time to execute the MA fall technique adequately was only 145-155 ms in young adults (van Swigchem R. et al., 2009). Although previous studies reported increased reaction times of 31-80 ms (Robinovitch et al., 2005; Chen et al., 1994; Tirosh and Sparrow, 2005) and increased movement times for voluntary movements in the elderly (Robinovitch et al., 2005), this probably still leaves sufficient time to select and execute a fall technique.

A limitation of the present study was that young adults participated instead of older persons to determine whether MA fall exercises could be safe for persons with osteoporosis. In general, the performance of fall exercises by older adults is expected to be less fluent than the performance by younger adults caused by a slower reaction time and poorer ability to coordinate muscle actions. This may result in higher hip impact forces. On the other hand, older adults are expected to have more fear of falling and are more cautious in their performance of the fall exercises, which presumably results in lower impact velocities and, consequently, lower hip impact forces.

Another limitation was the small sample size in the present study. It may not represent the normal variability in the normal population. Because it is likely that

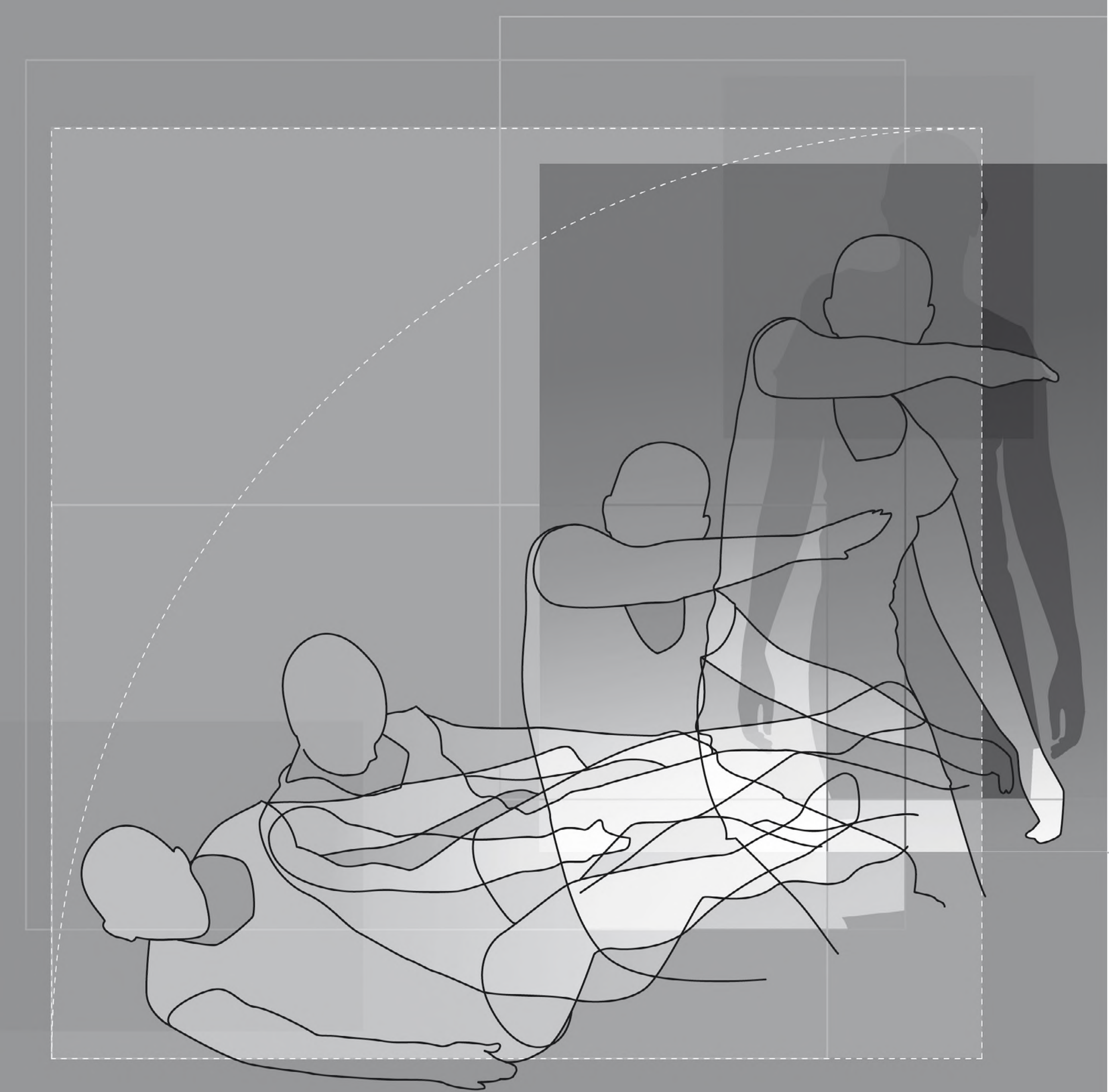
heavier and/or taller persons experience higher hip impact forces during a fall, it could affect the decision whether the fall exercises of the MA fall training is safe or not in the present study. On the other hand, older age and a low body mass (rather than a high body mass) are the most important risk and screening factors for osteoporosis (Waugh et al., 2009; Dargent-Molina et al., 2006) and are used to predict bone mineral density (T-score) (Wildner et al., 2003). It indicates that heavier persons have stronger bones. In addition, it is expected that heavier persons have a thicker soft tissue layer overlying the greater trochanter of the femur that can absorb energy during hip impact. Increased soft-tissue thickness is strongly correlated with decreased peak femoral impact force (Robinovitch et al., 1995b). We, therefore, believe that the fall exercises that we identified as safe in the present study are also safe for heavier persons who may experience higher hip impact forces, but also have more soft tissue padding and stronger bones than the bone strength as used in the safety criteria.

Conclusions

Based on the data of young adults and stringent safety criteria, the MA fall training was expected to be safe for persons with osteoporosis if they wear hip protectors that could attenuate the maximum hip impact force by at least 65% during the training, perform fall exercises on a thick mattress, and avoid forward fall exercises from a standing position. Since MA techniques reduce hip impact forces and can be learned by older persons, MA fall training may prevent hip fractures among persons with osteoporosis.

Acknowledgements

This study was supported by the POM, Nijmegen, the Organisation for Healthcare Research in the Netherlands (ZonMW) and the Department of Rheumatology of the Sint Maartenskliniek, Nijmegen. Written consent for publication was obtained from the subject.



8

Chapter

General discussion

The main purpose of this thesis was to explore the potential usefulness of MA fall training for hip fracture prevention in the elderly. To address this, we defined four aims. The first aim was to study the effect of MA fall techniques on fall severity and to detect experience-related differences. The second aim was to gain knowledge about the working mechanisms by which MA fall techniques reduce the impact on the hip during a sideways fall. The third aim was to determine the trainability of MA fall techniques in young adults and older individuals. The fourth aim was to investigate the safety of the MA fall training for persons with osteoporosis.

This general discussion starts with an overview and discussion of the main results presented in this thesis. In addition, the experimental limitations of the studies included in this thesis are described and recommendations for further research are given.

Effect of MA fall techniques on fall severity

A reduction in the fall severity by the MA fall techniques is a prerequisite for these techniques to be useful in hip fracture prevention in the elderly. Therefore, the first step was to determine the effect of the MA fall techniques on the impact force. Epidemiological studies have shown that falls with the highest risk for hip fracture are sideways falls and falls with direct impact on the greater trochanter of the proximal femur (Nevitt and Cummings, 1993; Wei et al., 2001). Therefore, we focused on the effect of the MA fall techniques during sideways falls with direct impact on the greater trochanter. Since it is unknown how much training is needed to master MA fall techniques, we determined the effect of MA fall techniques on the impact force for different levels of experience.

To determine whether MA fall techniques could be effective in reducing fall severity, the participants of the first fall experiment were highly experienced judokas (experience: 13.0 ± 6.8 years)(Chapter 2). During volitional sideways falls from kneeling position, the MA fall techniques with use of the arm reduced the hip impact force by 27% as compared with a natural fall arrest strategy in which the outstretched arm is used to block the fall (Block strategy). Even in young adults without prior MA fall experience we found that it was possible to reduce the hip impact force during a sideways fall from kneeling position using MA fall techniques after only a brief training (Chapter 4). Not surprisingly, the reduction in hip impact force by the MA fall techniques in these young adults was smaller than in the experienced judokas (17% and 27%, respectively). In comparison, using a similar

experimental set-up, Sabick et al. (1999) found a hip impact force reduction of 12% compared with the broomstick strategy if performed by experienced members of aikido clubs (experience: 5.2 ± 6.7 years). This reduction was even smaller than in our inexperienced group, therefore, the differences between the study by Sabick et al. (1999) and our studies are likely due to differences in the reference strategies (Broomstick versus Block strategy).

Working mechanisms of MA fall techniques

Given the observation that MA fall techniques did indeed reduce the hip impact force during a volitional sideways fall from a kneeling height, the next question was which mechanisms contributed to this reduction.

Since the arm is used to break the fall using an MA fall technique, it may be hypothesized that hand impact contributes to the reduction in hip impact force. In general, the hand impact occurs after hip impact and prior to shoulder impact during sideways MA falls if performed by young adults with experience in MA fall techniques (Sabick et al., 1999). Hsiao and Robinovitch (1998) proposed that the hand impact could reduce the hip impact force during a fall, if there was a near-simultaneous impact (within 50 ms) of the hand and hip, because this would allow sharing of impact energy. In a previous study on the effects of MA fall techniques, Sabick et al. (1999) suggested that hand impact could indeed play a role in the reduction of hip impact force during sideways MA falls. Unfortunately, they did not support this suggestion with data concerning, for example, the time interval between hand and hip impact. In contrast, we found no differences in hip impact force between the sideways MA falls with and without the use of the arm to break the fall both in experienced judokas (Chapter 2) and in young adults with a brief training in sideways MA fall techniques (Chapter 4). Hence, our results reveal that hand impact is not an essential element of the technique to reduce hip impact force. However, this does not imply that arm use has no benefits during falling. In general, arm movement are important in the process of regaining stability in the initial stages of a fall (Pijnappels et al., 2010). Furthermore, in MA falls, we hypothesized that hand impact is important to protect the upper body and the head. Some preliminary evidence was provided by Sabick et al. (1999) as they found that the MA fall technique reduced the shoulder impact force during volitional sideways falls and observed that the hand impact generally precedes shoulder impact (Sabick et al., 1999).

Another hypothesis was that MA fall techniques reduce hip impact force by reducing the hip impact velocity prior to impact, based on the assumption that impact velocity strongly affects impact force. In experimental studies on the effect of fall strategies on the fall severity, impact velocity is often used to measure fall severity instead of impact force. As mentioned in Chapter 4, the rationale for the use of impact velocity to determine fall severity is based on simple impact models. In these models, the body is represented as an undamped single-degree-of-freedom mass-spring system with a linear spring constant. The impact force is determined by the hip impact velocity, the effective mass of that part of the body that is moving in the vertical direction prior to impact, and the overall stiffness of the soft tissue overlying the hip. The spring constant accounts for soft tissue overlying the hip and the stiffness of the body, including the actions of the muscles (van den Kroonenberg et al., 1995). In such a model, impact velocity is proportional to impact force. In our studies, we found a significant positive linear correlation between the hip impact velocity and the hip impact force within each fall technique (Chapter 3). The strength of the correlation was low to fairly good (explained variance of 20-49%). The relationship between the hip impact velocity and hip impact force depended heavily on the fall technique used. In sideways falls from a kneeling position with comparable hip impact velocities, the hip impact forces in Block falls were larger than in MA falls. In addition, in sideways falls with comparable hip impact forces, hip impact velocities in MA falls from a standing height were larger than in the Block falls from a kneeling height. Hence, hip impact velocity may only be useful to make an approximate prediction of hip impact force within a fall technique. Furthermore, the reduction in hip impact velocity was much lower than the reduction in hip impact force using the MA technique as compared to the Block strategy. This was true for both the experienced judokas (Chapter 2) and the young adults with a brief MA fall training (Chapter 4). Based on these results, we concluded that MA fall techniques may reduce hip impact force partly by reducing hip impact velocity, but it is likely that other mechanisms also play a role.

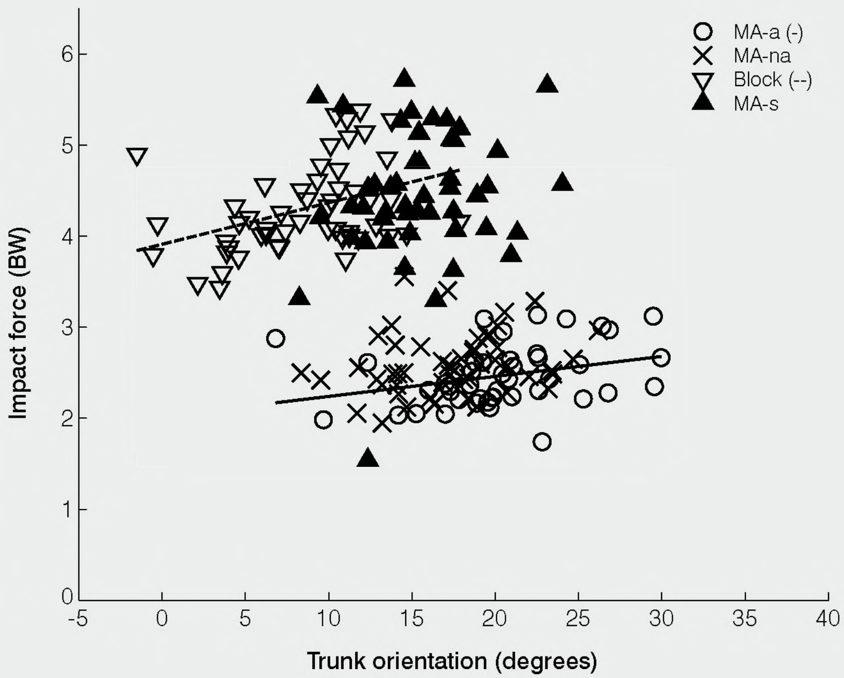
One of these mechanisms may be related to the orientation of the trunk. As mentioned above, in simple impact models, hip impact force is also affected by the effective mass of that part of the body that is moving prior to impact. Theoretically, the effective mass is dependent on trunk orientation at impact in such way that a less vertical trunk orientation would result in a lower effective mass, which would in turn reduce the impact force (van den Kroonenberg et al.,

1995). In an experimental (Unpublished) study, however, no effect of trunk orientation on the effective mass was detected (Hayes et al., 1996). Others predicted that a less vertical trunk orientation would increase the exchange of potential energy to kinetic energy during a fall, and consequently it would increase the impact velocity (Sandler and Robinovitch, 2001). The increase in impact velocity would increase the impact force and, thereby, counterbalance the possible effects of a lower effective mass. Hence, the (theoretical) effects of trunk orientation on hip impact force seem to be unclear. In our experiments, we found for the experienced judokas a less vertical trunk orientation in the MA falls as compared to the Block falls from a kneeling height. The difference was small in the MA falls without the use of the hand, and larger and significant in the MA falls with the use of the arm to break the fall (Chapter 2). In the group of young adults with a brief MA fall training (Chapter 4), we found a similar pattern of results (Unpublished data). On the other hand, the hip impact forces were significantly and equivalently reduced during the MA falls both with and without the use of the arm to break the fall. These results indicate that trunk orientation does not seem to play a major role in reducing hip impact force.

To further examine the effect of trunk orientation during the fall experiments some additional analyses were performed. Analyses of the data of a single judoka performing a large number of falls, including a series of MA falls from a standing position (Chapter 4), showed a significant positive correlation between the trunk orientation and the hip impact force within the MA falls with the use of the arm to break the fall ($R(44) = 0.308$; $p = 0.037$) and Block falls ($R(50) = 0.389$; $p = 0.004$) from a kneeling position. However, the strength of the correlation was low: the variation in trunk orientation explained only 10-15% of the variance in hip impact force. Furthermore, no significant correlations were found for the MA falls without the use of the arm from a kneeling position and the MA falls with the use of the arm to break the fall from a standing position (Figure 8.1)(Unpublished data). Hence, from our data the effect of trunk orientation on the hip impact force does not seem to play an essential role.

A characteristic of MA fall techniques that may play a more important role in reducing the hip impact force during a sideways MA fall is the rolling motion after impact. In sideways MA falls, subjects roll over the ipsilateral hip towards the scapula of the ipsilateral shoulder. This is achieved by flexion, lateral flexion and rotation of the trunk. Rolling after impact is a technique not only used during

Figure 8.1 Hip impact force (normalized for body weight) plotted as a function of trunk angle (°) for falls of the single judoka. Each fall is represented by one symbol.



martial arts but also during other sports in which falls with high impacts are common, such as free running and parachute landing. During the roll, the forces are distributed over a larger impact site. Furthermore, the amount of kinetic energy to be absorbed during impact is reduced because kinetic energy is preserved during the roll. Therefore, a smaller amount of kinetic energy has to be transferred into strain energy, resulting in lower impact forces. To study the effect of the roll on hip impact force, the kinetic energy, both prior to and after impact, should be determined as well as the hip impact force. As the amount of kinetic energy is determined by the mass and the velocity of the moving segments while the mass of the moving segments remains constant, the velocity of the segments should give insight into the kinetic energy. The small number of markers used in our studies did not allow us to calculate the trunk movement in three dimensions.

However, we observed a larger shoulder vertical velocity in the MA falls as compared to the Block falls after impact in the experienced judokas (Chapter 2), which may be indicative of increased kinetic energy of the trunk after impact.

From a biomechanical modelling study, there is evidence that an arrest strategy that involves knee flexion, waist flexion, and trunk rotation prior to impact is the most effective way to reduce hip impact forces as well as the (vertical) hip impact velocities during a sideways fall (Lo and Ashton-Miller, 2008). Importantly, Lo and Asthon-Miller (2008) predicted that such an arrest strategy was effective in reducing the impact forces to below the fracture thresholds even when the effects of age on muscles forces (reduction of 30% in muscle force) were simulated in the model. Since the movement combination of knee flexion, waist flexion and axial trunk rotation prior to impact is essential during a sideways MA fall to enable the roll after impact, the study by Lo and Asthon-Miller (2008) confirms the effect of MA fall techniques on hip impact force. However, the instruction by itself (hip and knee flexion in combination with forward or lateral bending of the spinal column) did not affect the hip impact velocity in sideways falls from a standing height when compared to falls using the broomstick strategy (Inoue, 2005). This may indicate that other trunk and/or leg movements may be essential, although it should be mentioned that hip impact velocity may not be a valid variable to compare the fall severity between different techniques (Chapter 3).

To summarize, MA fall techniques reduce the hip impact force as compared with Block falls, although in both techniques the hip is the first impact site. The hip impact force may be partly reduced by the decrease in hip impact velocity. Based on the literature, it may be hypothesized that the reduction in hip impact velocity is due to movements involving knee flexion, hip flexion and axial trunk rotation prior to impact. In addition, the roll after impact during an MA fall may reduce the kinetic energy to be absorbed after impact and thereby, reduce the hip impact force. The hand impact is not essential in MA techniques to reduce hip impact force, neither does trunk orientation.

Trainability of the MA fall techniques

Another prerequisite for MA fall techniques to be useful for hip fracture prevention is their trainability. It is obvious that children and young adults are able to master the MA fall techniques during extensive training in judo and aikido clubs, for example. However, in order for these techniques to be beneficial for hip fracture

prevention, it would be necessary that they are easy to learn within a short training period in both young and older subjects. In our study with young adults without prior MA fall experience, we found that a brief training of only 30-min was sufficient to reduce the hip impact force during a sideways fall from a kneeling position using the MA fall techniques as compared to the Block fall (Chapter 4). Hence, it seems that extensive training is not required in order to benefit from these techniques in terms of hip impact force reduction. Importantly, the briefly trained young adults were able to initiate and successfully apply the fall technique in falls in which an auditory cue was given to use either the Block or MA technique after fall initiation (Chapter 4 and 5). Surprisingly, the success rate of these inexperienced fallers was not significantly different from that of the highly experienced judokas (Chapter 5), supporting the hypothesis that MA fall techniques are easily to learn and to apply.

There were, however, experience-related differences in EMG activity during the volitional sideways MA falls from a kneeling height. Compared to the experienced judokas, more Trapezius muscle (TR) activation was observed in the inexperienced fallers, in conjunction with less pronounced Pectoralis muscle (PE) activation (Chapter 4). Similar differences in EMG activity were found between the inexperienced fallers and experienced judokas in falls in which either the Block or MA technique was auditorily cued after fall initiation (Chapter 5). The PE is mainly active in trunk rotation (Kumar et al., 2003), whereas it is conceivable that TR is more involved in trunk lateral flexion and arm abduction to block the fall with the outstretched arm. Therefore, the higher PE activation in the experienced judokas may suggest that they had prepared an MA fall.

More crucial, however, is the question whether MA fall techniques are also trainable in older individuals. We found that healthy, older individuals over the age of 60 years were able to learn the basics of the MA fall techniques within five weekly 45-min training sessions, which resulted in a significant improvement in MA fall performance. In addition, the hip impact force decreased by 8% during volitional sideways falls from a kneeling position (Chapter 6). According to the MA experts scoring the falls, 16 of the 25 participants showed a fair to good performance (scores 6 to 10) after the fall training. The self-efficacy questions revealed that 21 participants were partly or fully confident of being able to apply the MA fall techniques during the training situation (Chapter 6). We think that further improvement of the fall performance could be obtained with additional

training sessions because few participants achieved a near optimal fall performance by the end of the training. Participants indeed asked for more training sessions for this reason. However, the improvement in performance and the reduction in hip impact force showed that MA fall techniques are both trainable and effective in healthy, older individuals after only five training sessions.

To determine whether the effect of the MA fall training was retained, we evaluated the MA fall performance in the older participants 6-7.5 months after the fall training had ended (Unpublished data). The loss to follow up was unexpectedly high due to (serious) medical reasons unrelated to the training. Hence, the MA fall performance could only be evaluated in a total of 14 older individuals (age: 69.3 ± 5.4 years; weight: 72.9 ± 8.3 kg; height: 1.66 ± 0.09 m). According to the MA fall experts the mean pre-training (after a short demonstration) MA fall performance on a ten-point scale was 6.4 ± 0.8 and it was 6.5 ± 1.1 at follow-up, indicating the improvements had not been retained. The mean hip impact force normalized for body weight (BW) was 2.56 ± 0.25 BW during the pre-intervention falls versus 2.42 ± 0.23 BW during the follow-up (n = 11). The difference was not significant, again indicating an absence of retention of the effects of the MA fall training after 6-7.5 months. However, we should be careful when making inferences on the basis of the results of this small group. The study had little power (Power of 0.61) due to the small number of subjects, which increases the chance of falls-negative results (type II error). Using post-hoc power analysis, we calculated that, based on the observed results for hip impact force, a group of 39 persons was needed to detect statistically significant differences (Power of 0.8 and α = 0.05). It must be noted that this does not answer the important question how many persons should be treated to prevent a hip fracture with MA fall training. To answer this question, a (large) intervention study should be conducted with hip fractures as outcome measure.

Safety of the MA fall training for persons with osteoporosis

It is obvious that the MA fall training should be safe to be useful in hip fracture prevention. The MA fall training was introduced as an element in the Nijmegen Falls Prevention Program for healthy, elderly persons (Weerdesteyn et al., 2006) for whom it was considered to be safe. Indeed, no adverse physical effects were reported during or after the training. For safety reasons, persons with osteoporosis were excluded from participating in the MA fall training. Hence, the persons who

could be expected to experience the most benefits from such training are excluded because of their high fracture risk if they fall. We, therefore, evaluated the fall exercises and found that an MA fall training is safe for persons with osteoporosis if appropriate safety measures are taken. During the training, persons with osteoporosis should wear hip protectors that could attenuate the maximum hip impact force by at least 65%. Furthermore, they should perform the sideways and forward fall exercises on a thick mattress, and should avoid forward fall exercises from a standing position (Chapter 7).

The study on the safety of the MA fall training for persons with osteoporosis focused only on the risk of hip fractures. However, falls in daily life also have risks for other injuries, such as bruises, or head, arm and wrist injuries. It remains to be determined whether MA techniques are useful in preventing these injuries as well. In addition, the working mechanisms should be investigated.

The safety of such MA fall training for persons with osteoporosis was recently confirmed by Smulders and coworkers (Smulders et al., 2008). Based on the results of Chapter 7, the MA fall training used in the original Nijmegen Falls Prevention Program (Weerdesteyn et al., 2006) was modified. Thus far, 31 persons with osteoporosis (lowest T-score for proximal femur and lumbar vertebrae was between -4 and -2.5) have participated and no injuries or adverse physical effects have been reported during or after the training (Smulders et al., 2008).

Experimental limitations and recommendations

A limitation of this thesis is that it is mainly focused on sideways falls. The reason for this is that sideways falls have the highest risk for hip fractures (Nevitt and Cummings, 1993; Wei et al., 2001), amongst the most serious fall-related injuries among the elderly. Hip fractures are associated with high mortality and morbidity rates. Although hip fractures also occur in forward and backward falls, these falls are generally associated with a higher risk for wrist fractures. The arms are often instinctively used to prevent or reduce hip and head impact, at the expense of risking wrist fractures (Nevitt and Cummings, 1993). Studies on forward falls have mainly been focused on landing strategies onto both hands and the effect on the risk for wrist fractures. An overview of the biomechanical factors associated with upper extremity injuries in forward falls has been given by De Goede et al. (2003). It has been demonstrated that fall arrest strategies that include elbow flexion and low wrist velocity at impact reduce the wrist impact force during a forward fall

(DeGoede and Ashton-Miller, 2002; DeGoede and Ashton-Miller, 2003). Recent computer simulations have predicted an additional important role for hip flexion prior to impact (Lo and Ashton-Miller, 2008). An experimental study showed that young, healthy males were indeed able to learn to reduce the wrist impact force by instructions such as to flex the elbow and to reduce the wrist impact velocity after a short (10 min) training. Unfortunately after three weeks, the retention was poor, suggesting that the instruction had only a short-term effect (Lo et al., 2003). In addition, it has been predicted that typical age related reduction in arm muscle strength can substantially reduce the ability of older women to use their arms to safely arrest a forward fall with this strategy (DeGoede and Ashton-Miller, 2003). Increased reaction time and excessive pre-impact reflexive activation of the arms in older individuals may further decrease the effectiveness of the fall technique, particularly in falls with a short available response time (Kim and Ashton-Miller, 2003; Robinovitch et al., 2005). MA fall techniques may be an alternative. Based on our observations, healthy, older participants (Weerdesteyn et al., 2006) and persons with osteoporosis (Smulders et al., 2010) are able to safely learn MA fall techniques during a forward fall. Although the effect of these techniques during a forward fall should be further investigated, we expect that the roll mechanism may also play a role in reducing wrist fracture risk during forward falls.

Backward falls are less common than forward falls (O'Neill et al., 1994; Nevitt and Cummings, 1993) but have the highest risk for wrist fractures (Nevitt and Cummings, 1993), which may be explained by the larger wrist impact velocities that occur during a backward fall (Tan et al., 2006). Fall experiments with backward falls have focused on the squat response during descent. By squatting during a backward fall from a standing height, subjects were able to reduce the impact velocity of both the hip (Robinovitch et al., 2004) and the wrist (Tan et al., 2006). The age-related decline in lower extremity strengths (Sandler and Robinovitch, 2001) and the increased reaction times (Robinovitch et al., 2005) are predicted to reduce the effectiveness of the squat response. In MA falls, the roll mechanism is expected to reduce hip impact force. In addition, the risk for wrist fractures is also expected to be reduced, as arm impact during an MA fall is distributed over a larger impact area and occurs after hip impact. Further research is needed to determine the effect of MA fall techniques in both forward and backward falls.

A second limitation of this thesis is that the effect of MA techniques on fall severity has primary been defined by the maximum external vertical hip impact

force. There are, however, several other variables that may differ between fall techniques and may affect fall severity, such as the point of application and the direction of the external impact force. The potential effect of differences in the point of application and the direction of the external impact force on the force applied to the femoral bone is linked to soft tissue thickness. If the soft tissue thickness increases, the peak force decreases and the tissue energy absorption increases (Robinovitch et al., 1995b). Furthermore, soft tissues overlying the anterior and posterior aspects of the hips are thicker than the soft tissue overlying the lateral aspect. Consequently, the attenuation of the peak impact forces by soft tissues may depend on the point of application and the direction of the external impact force. The direction of the force will also affect the fall severity because of its effect on fracture load (Pinilla et al., 1996). This is due to the fact that femoral fracture risk is not only dependent on the load applied, but also on the load necessary to cause a fracture (DeGoede et al., 2003; Hayes et al., 1996). In vitro studies have shown that the fracture load of the femur is dependent on several factors such as bone mineral density of the femur (Courtney et al., 1995; Pinilla et al., 1996; Cheng et al., 1997), femoral geometry (Cheng et al., 1997; Kukla et al., 2002), the direction of impact (Pinilla et al., 1996), and the loading rate (Courtney et al., 1994). Ideally these should also be taken into account to determine the effect of MA fall techniques on fall severity. The fracture load may be determined by mechanical testing of cadaveric femurs. However these bones hardly ever have the same properties, making it difficult to compare the effect on fracture load of two or more fall techniques. Finite element analyses may be of value since these models can be used an infinite numbers of times. In addition, using these models it is possible to determine the effect of each individual variable by changing that variable while keeping all the others constant. However, finite element models to determine the effect of fall techniques on fracture load are not yet available. In the future they will need to be developed and validated by mechanical testing.

Another limitation is that the sideways falls investigated in fall experiments differ in some aspects from most sideways falls in daily life. For safety reasons, the falls during our fall experiments were initiated from a kneeling position while most fall-related hip fractures occur from a standing position. It may be argued that the impact forces increase in falls from a standing position because of the added potential energy. Although this is true, it should be noted that because of

additional effect of impact reducing mechanisms such as the squat response the increase in impact force may be less than expected based on the added potential energy. Squatting reduces the impact velocity by absorbing energy in three different ways: 1) eccentric contraction of lower extremity muscles of the lower extremity, 2) reduction of the total potential energy involved in the fall due to the body's impacting the ground in upright position, and 3) a transfer of impact energy into horizontal (as opposed to vertical) kinetic energy by knee extension during the final stage of descent (Sandler and Robinovitch, 2001; Robinovitch et al., 2004). However, because squatting is applicable in almost all falls from a standing position, independent of the use of the MA fall techniques, it is not expected to explain differences between fall techniques. Sideways MA falls from either a standing or a kneeling position have similar main characteristics. Therefore, it is conceivable that MA fall techniques will also reduce the impact force during falls from a standing position. A direct comparison of the hip impact forces between the Block fall and the MA fall from a standing position is not possible, because sideways falls from a standing position onto the ground are dangerous and can cause a hip fracture even in young adults (Kannus et al., 2006). However, the reduction of impact force by MA falls from a standing position is indirectly supported by the finding that the hip impact forces of the MA fall from a standing position were similar to the hip impact forces of the Block falls from a kneeling position in the single experienced judoka (Chapter 3).

In addition, falls in the experimental set-up were self-initiated while falls in daily life are generally unexpected. Although self-initiation is likely to reduce the absolute impact values (Robinovitch et al., 2004; Kim and Ashton-Miller, 2003), in particular in falls with a short available response time (Kim and Ashton-Miller, 2003), such falls seem to be useful to study the working mechanisms by which MA fall techniques reduce hip impact force. In addition, they are safer and, therefore, suitable to determine the trainability of MA fall training in older individuals. In self-initiated falls, the fall can be pre-planned, which is usually not the case for falls in daily life. It has often been suggested that a fall may happen too quickly to be able to select and execute a learned fall technique. However, previous studies have shown that young adults could successfully implement specific fall techniques after initiation of a volitional fall from a kneeling position (Chapter 5) or an unexpected fall from a standing position (Feldman and Robinovitch, 2004). In an unexpected fall from a standing position, hip impact

occurs 715 (SD 160) ms after the onset of a perturbation (Hsiao and Robinovitch, 1998). Given a voluntary reaction time of 180 ms to initiate a fall technique (Chapter 5) there is still time to subsequently execute the fall technique before impact. The minimum movement time to adequately execute the MA fall technique was only 145-155 ms (Chapter 5). Although previous studies have reported increased reaction times of 19-80 ms (Robinovitch et al., 2005; Chen et al., 1994; Tirosh and Sparrow, 2005) and increased movement times for voluntary arm movements in the elderly (Robinovitch et al., 2005), probably sufficient time is left to select and execute a fall technique.

To deal with the latter two limitations, several studies have investigated unexpected falls from a standing height. However, the falls in these experiments still differ from falls in daily life, making it difficult to extrapolate the results. In most of these fall experiments, the subjects are unexpectedly made to fall by an abrupt translation of a moving platform (Hsiao and Robinovitch, 1998; Feldman and Robinovitch, 2007) or by releasing a tether that supported the subject in a leaning angle from the vertical (Robinovitch et al., 2003; Feldman and Robinovitch, 2004). In these experimental set-ups the subject usually falls on a thick mattress, which is softer than most fall surfaces in daily life. In addition, in most of these experiments, the subjects receive some instructions on how to fall, and they are concentrated and prepared to fall, because they know that they are going to fall, which is also usually not the case in daily life. Moreover, the falls during these experiments are initiated from a stationary standing position, while most falls in daily life occur during walking (Cumming and Klineberg, 1994; Nevitt and Cummings, 1993). The influence of instruction has been nicely demonstrated in a recent study of Feldman and Robinovitch (2007). The participants (judokas and healthy controls) stood on top of a large platform and were subjected to a strong postural perturbation. When they were instructed to maintain their balance, both groups showed similar fall strategies if they did not succeed in recovering balance. However, when the judokas were instructed to use MA fall techniques to fall safely, they performed MA fall techniques.

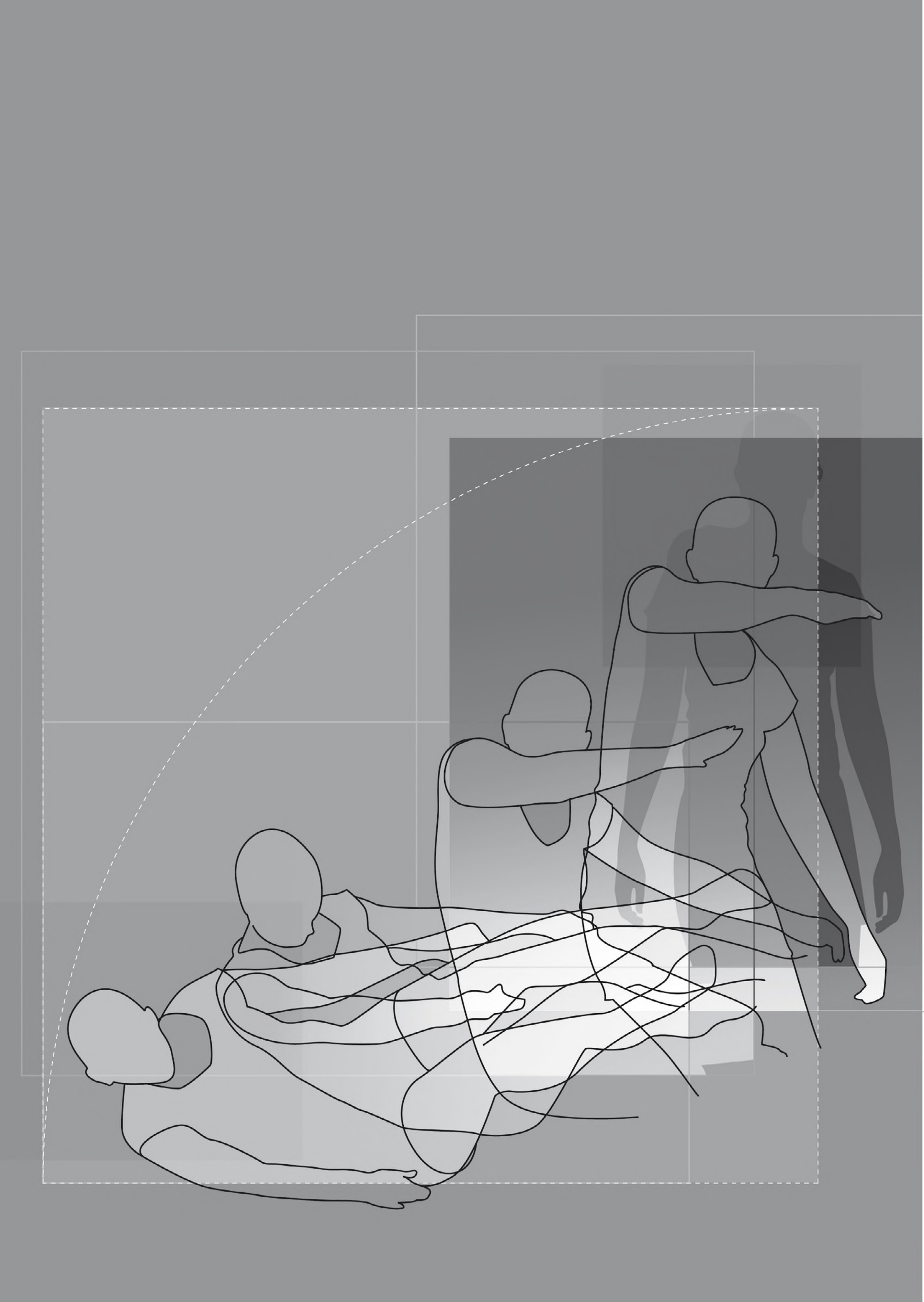
Another limitation of fall experiments from a standing position is that direct impact force measurements are often not possible. Instead, kinematic variables are used to estimate fall severity, in particular impact velocity and kinetic energy measures. We found, however, that hip impact velocity is not always a valid predictor for hip impact force in comparisons between different fall techniques

(Chapter 3). To improve the estimation of hip impact force using kinematic data, validated energy models including the 3-D movement of all body parts prior to and after impact may be useful. To measure the 3-D movement, the system should preferably be wireless to minimize interference with the movement. It will be a challenge to measure the 3-D movements based on the position data of reflective markers because some of the markers are likely to be invisible during (part of) the fall as they are obscured by the body. Therefore, the use of other wireless movement measurement systems, such as gyroscopes and accelerometers, should be considered for the development of these energy models.

The question whether MA fall techniques are potentially applicable in daily life, in particular in older individuals, should be addressed in further research. It should be investigated whether (older) individuals will be able to apply MA fall techniques during unexpected falls in daily life and whether this results in fewer hip fractures. A first attempt was made by evaluating falls in daily life from participants of our Falls prevention programme for persons with osteoporosis during the year following training (Smulders et al., 2010). Using a questionnaire, we evaluated in more detail 26 falls in the training group and 18 falls in the control group. The results showed that in 45% of the falls, the person was aware of falling during the fall. This may indicate that in almost half of the falls in daily life it may be possible to select a fall technique. In 45% of these falls in the training group, the fallers indeed reported that they were able to apply the MA fall technique during the fall. Hence after fall training, some participants seem to be able to select and execute MA fall techniques during an unexpected real-life fall. Based on the more detailed questions about the fall, it seems that in 77% of the falls in the training group, the faller had been able to apply at least one element of the MA fall technique, in particular controlling the head (58%) and avoiding the use of the outstretched arms to block the fall (46%). However, this was also true for 50% of the falls in the control group in which the head was controlled (39%) and the use of the outstretched arms was avoided (33%). Rolling was reported in only three (11%) falls in the training group and not at all in falls for the control group. Statistical testing showed that there were no significant differences for individual elements of the MA fall techniques between the two groups (Unpublished data). These results are in agreement with the results with respect to the retention of the effect of the MA fall training in the healthy, older individuals, as described earlier, and

indicate that a five-session MA fall training is likely to be too short and/or the training should be repeated from time to time to be effective in falls occurring in daily life. Additional research is needed to study the optimal training intensity to master the MA fall techniques.

None of the falls mentioned above resulted in a hip fracture (Unpublished data). This is not surprising because hip fractures only occur in 1-2% of the falls in the elderly (Tinetti et al., 1988). Hence, to evaluate the effect of MA fall techniques to prevent of hip fractures, very large sample sizes will be needed. Such a large training study is time consuming and very expensive and should, therefore, be performed in the final stage of a study on hip fracture prevention. To determine the potential beneficial effects of MA fall training to prevent hip fractures, a first step may be to compare, in an epidemiological study, the risk of hip fractures among older (ex-) judokas with the risk of the general population.



References

Ahmed, A. A., Ashton-Miller, J. A., (2007). On use of a nominal internal model to detect a loss of balance in a maximal forward reach. J.Neurophysiol. 97, 2439-2447.

Allum, J. H., Carpenter, M. G., Honegger, F., Adkin, A. L., Bloem, B. R., (2002). Age-dependent variations in the directional sensitivity of balance corrections and compensatory arm movements in man. J. Physiol 542, 643-663.

Avenell, A., Gillespie, W. J., Gillespie, L. D., O'Connell, D., (2009). Vitamin D and vitamin D analogues for preventing fractures associated with involutional and post-menopausal osteoporosis. Cochrane. Database.Syst.Rev. CD000227.

Brauer, C. A., Coca-Perraillon, M., Cutler, D. M., Rosen, A. B., (2009). Incidence and mortality of hip fractures in the United States. JAMA 302, 1573-1579.

Cameron, I. D., Robinovitch, S., Birge, S., Kannus, P., Khan, K., Lauritzen, J., Howland, J., Evans, S., Minns, J., Laing, A., Cripton, P., Derler, S., Plant, D., Kiel, D. P., (2010). Hip protectors: recommendations for conducting clinical trials--an international consensus statement (part II). Osteoporos.Int. 21, 1-10.

Carlsen, A. N., Chua, R., Inglis, J. T., Sanderson, D. J., Franks, I. M., (2003). Startle response is dishabituated during a reaction time task. Exp.Brain Res. 152, 510-518.

Carson, R. G., Chua, R., Goodman, D., Byblow, W. D., Elliott, D., (1995). The preparation of aiming movements. Brain Cogn 28, 133-154.

Chen, H. C., Ashton-Miller, J. A., Alexander, N. B., Schultz, A. B., (1994). Effects of age and available response time on ability to step over an obstacle. J.Gerontol. 49, M227-M233.

Cheng, X. G., Lowet, G., Boonen, S., Nicholson, P. H., Brys, P., Nijs, J., Dequeker, J., (1997). Assessment of the strength of proximal femur in vitro: relationship to femoral bone mineral density and femoral geometry. Bone 20, 213-218.

Chesnut III, C. H., Skag, A., Christiansen, C., Recker, R., Stakkestad, J. A., Hoiseth, A., Felsenberg, D., Huss, H., Gilbride, J., Schimmer, R. C., Delmas, P. D., (2004). Effects of oral ibandronate administered daily or intermittently on fracture risk in postmenopausal osteoporosis. J.Bone Miner.Res. 19, 1241-1249.

Consument en Veiligheid, (2005). Het letsellastmodel-zorgconsumptie, verzuim en verlies aan kwaliteit van leven door letsel in Nederland. Consument en Veiligheid.

Cooper, C., (1997). The crippling consequences of fractures and their impact on quality of life. Am.J.Med. 103, 12S-17S.

Cooper, C., Campion, G., Melton, L. J., III, (1992). Hip fractures in the elderly: a world-wide projection. Osteoporos.Int. 2, 285-289.

Courtney, A. C., Wachtel, E. F., Myers, E. R., Hayes, W. C., (1994). Effects of loading rate on strength of the proximal femur. Calcif.Tissue Int. 55, 53-58.

Courtney, A. C., Wachtel, E. F., Myers, E. R., Hayes, W. C., (1995). Age-related reductions in the strength of the femur tested in a fall-loading configuration. J.Bone Joint Surg.Am. 77, 387-395.

Cumming, R. G., Klineberg, R. J., (1994). Fall frequency and characteristics and the risk of hip fractures. J.Am.Geriatr.Soc. 42, 774-778.

Cummings, S. R., Melton, L. J., (2002). Epidemiology and outcomes of osteoporotic fractures. Lancet 359, 1761-1767.

Dargent-Molina, P., Piault, S., Breart, G., (2006). Identification of women at increased risk of osteoporosis: no need to use different screening tools at different ages. Maturitas 54, 55-64.

DeGoede, K. M., Ashton-Miller, J. A., (2002). Fall arrest strategy affects peak hand impact force in a forward fall. J.Biomech. 35, 843-848.

DeGoede, K. M., Ashton-Miller, J. A., (2003). Biomechanical simulations of forward fall arrests: effects of upper extremity arrest strategy, gender and aging-related declines in muscle strength. J.Biomech. 36, 413-420.

DeGoede, K. M., Ashton-Miller, J. A., Schultz, A. B., (2003). Fall-related upper body injuries in the older adult: a review of the biomechanical issues. J.Biomech. 36, 1043-1053.

Do, M. C., Bussel, B., Breniere, Y., (1990). Influence of plantar cutaneous afferents on early compensatory reactions to forward fall. Exp.Brain Res. 79, 319-324.

Do, M. C., Roby-Brami, A., (1991). The influence of a reduced plantar support surface area on the compensatory reactions to a forward fall. Exp.Brain Res. 84, 439-443.

Elders, P., Leusing, G., Graafmans, W., Bolhuis, A., Van der Spoel, O., Keimpema, J., (2005). NHG-standaard Osteporose, Huisarts Wet 2005.

Ensrud, K. E., Lui, L. Y., Taylor, B. C., Schousboe, J. T., Donaldson, M. G., Fink, H. A., Cauley, J. A., Hillier, T. A., Browner, W. S., Cummings, S. R., (2009). A comparison of prediction models for fractures in older women: is more better? Arch.Intern.Med. 169, 2087-2094.

Farahmand, B. Y., Michaelsson, K., Ahlbom, A., Ljunghall, S., Baron, J. A., (2005). Survival after hip fracture. Osteoporos.Int. 16, 1583-1590.

Feldman, F., Robinovitch, S. N., (2007). Do judo athletes utilize ukemi falling techniques during unexpected sideways falls? Proceedings of the 18th Conference of the International Society for Posture and Gait Research, Burlington, Vermont, USA, 14-18 July, Abstract TP-68 p148.

Feldman, F., Robinovitch, S. N., (2004). Safe landing during a fall: effect of response time on ability to avoid hip impact during sideways falls. Proceedings of the 28th annual meeting of the American society of biomechanics, Portland, Oregon, USA, 4-11 September.

Friedman, S. M., Munoz, B., West, S. K., Rubin, G. S., Fried, L. P., (2002). Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. J.Am.Geriatr.Soc. 50, 1329-1335.

Gallagher, J. C., Melton, L. J., Riggs, B. L., (1980). Examination of prevalence rates of possible risk factors in a population with a fracture of the proximal femur. Clin.Orthop.Relat Res. 153, 158-165.

Gillespie, L. D., Gillespie, W. J., Robertson, M. C., Lamb, S. E., Cumming, R. G., Rowe, B. H., (2003). Interventions for preventing falls in elderly people. Cochrane.Database.Syst.Rev. CD000340.

Gillespie, L. D., Robertson, M. C., Gillespie, W. J., Lamb, S. E., Gates, S., Cumming, R. G., Rowe, B. H., (2009). Interventions for preventing falls in older people living in the community. Cochrane.Database.Syst.Rev. CD007146.

Greenspan, S. L., Myers, E. R., Maitland, L. A., Resnick, N. M., Hayes, W. C., (1994). Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. JAMA 271, 128-133.

Groen, B. E., Smulders, E., de Kam, D., Duysens, J., Weerdesteyn, V., (2010). Martial arts fall training to prevent hip fractures in the elderly. Osteoporos.Int. 21, 215-221.

Groen, B. E., Weerdesteyn, V., Duysens, J., (2008). The relation between hip impact velocity and hip impact force differs between sideways fall techniques. J.Electromyogr.Kinesiol. 18, 228-234.

Groen, B. E., Weerdesteyn, V., Duysens, J., (2007). Martial arts fall techniques decrease the impact forces at the hip during sideways falling. J.Biomech. 40, 458-462.

Gullberg, B., Johnell, O., Kanis, J. A., (1997). World-wide projections for hip fracture. Osteoporos.Int. 7, 407-413.

Haleem, S., Lutchman, L., Mayahi, R., Grice, J. E., Parker, M. J., (2008). Mortality following hip fracture: trends and geographical variations over the last 40 years. Injury 39, 1157-1163.

Harmenberg, J., Ceci, R., Barvestad, P., Hjerpe, K., Nystrom, J., (1991). Comparison of different tests of fencing performance. Int.J.Sports Med. 12, 573-576.

Harris, S. T., Watts, N. B., Genant, H. K., McKeever, C. D., Hangartner, T., Keller, M., Chesnut, C. H., III, Brown, J., Eriksen, E. F., Hoseyni, M. S., Axelrod, D. W., Miller, P. D., (1999). Effects of risedronate treatment on vertebral and nonvertebral fractures in women with postmenopausal osteoporosis: a randomized controlled trial. Vertebral Efficacy With Risedronate Therapy (VERT) Study Group. JAMA 282, 1344-1352.

Hase, K., Stein, R. B., (1998). Analysis of rapid stopping during human walking. J.Neurophysiol. 80, 255-261.

Hayes, W. C., Myers, E. R., Robinovitch, S. N., Van Den, K. A., Courtney, A. C., McMahon, T. A., (1996). Etiology and prevention of age-related hip fractures. Bone 18, 77S-86S.

Hochberg, M. C., Greenspan, S., Wasnich, R. D., Miller, P., Thompson, D. E., Ross, P. D., (2002). Changes in bone density and turnover explain the reductions in incidence of nonvertebral fractures that occur during treatment with antiresorptive agents. J.Clin.Endocrinol.Metab 87, 1586-1592.

Hsiao, E. T., Robinovitch, S. N., (1998). Common protective movements govern unexpected falls from standing height. J.Biomech. 31, 1-9.

Inoue, K., (2005). Protective movements during sideways falls from standing height. J.Physiol Anthropol. Appl.Human Sci. 24, 371-374.

Kanis, J. A., Johnell, O., De Laet, C., Jonsson, B., Oden, A., Ogelsby, A. K., (2002). International variations in hip fracture probabilities: implications for risk assessment20. J.Bone Miner. Res. 17, 1237-1244.

Kanis, J. A., Johnell, O., Oden, A., Johansson, H., McCloskey, E., (2008). FRAX and the assessment of fracture probability in men and women from the UK. Osteoporos.Int. 19, 385-397.

Kannus, P., Leiponen, P., Parkkari, J., Palvanen, M., Jarvinen, M., (2006). A sideways fall and hip fracture. Bone 39, 383-384.

Kannus, P., Niemi, S., Parkkari, J., Palvanen, M., Jarvinen, M., Vuori, I., (2000). Unintentional injury deaths in an adult Finnish population from 1971-1997. Epidemiology 11, 598-602.

Kannus, P., Parkkari, J., Poutala, J., (1999). Comparison of force attenuation properties of four different hip protectors under simulated falling conditions in the elderly: an in vitro biomechanical study. Bone 25, 229-235.

Keene, G. S., Parker, M. J., Pryor, G. A., (1993). Mortality and morbidity after hip fractures. BMJ 307, 1248-1250.

Kiel, D. P., Magaziner, J., Zimmerman, S., Ball, L., Barton, B. A., Brown, K. M., Stone, J. P., Dewkett, D., Birge, S. J., (2007). Efficacy of a hip protector to prevent hip fracture in nursing home residents: the HIP PRO randomized controlled trial. JAMA 298, 413-422.

Kim, K. J., Ashton-Miller, J. A., (2003). Biomechanics of fall arrest using the upper extremity: age differences. Clin.Biomech.(Bristol., Avon.) 18, 311-318.

Kukla, C., Gaebler, C., Pichl, R. W., Prokesch, R., Heinze, G., Heinz, T., (2002). Predictive geometric factors in a standardized model of femoral neck fracture. Experimental study of cadaveric human femurs. Injury 33, 427-433.

Kumar, S., Narayan, Y., Garand, D., (2003). An electromyographic study of isokinetic axial rotation in young adults. Spine J. 3, 46-54.

Laing, A. C., Robinovitch, S. N., (2009). Low stiffness floors can attenuate fall-related femoral impact forces by up to 50% without substantially impairing balance in older women. Accid.Anal.Prev. 41, 642-650.

Lo, J., Ashton-Miller, J. A., (2008). Effect of pre-impact movement strategies on the impact forces resulting from a lateral fall. J.Biomech. 41, 1969-1977.

Lo, J., McCabe, G. N., DeGoede, K. M., Okuizumi, H., Ashton-Miller, J. A., (2003). On reducing hand impact force in forward falls: results of a brief intervention in young males. Clin.Biomech.(Bristol., Avon.) 18, 730-736.

Lotz, J. C., Hayes, W. C., (1990). The use of quantitative computed tomography to estimate risk of fracture of the hip from falls. J.Bone Joint Surg.Am. 72, 689-700.

Luchies, C. W., Alexander, N. B., Schultz, A. B., Ashton-Miller, J., (1994). Stepping responses of young and old adults to postural disturbances: kinematics. J.Am.Geriatr.Soc. 42, 506-512.

McClung, M. R., Geusens, P., Miller, P. D., Zippel, H., Bensen, W. G., Roux, C., Adami, S., Fogelman, I., Diamond, T., Eastell, R., Meunier, P. J., Reginster, J. Y., (2001). Effect of risedronate on the risk of hip fracture in elderly women. Hip Intervention Program Study Group. N.Engl.J.Med. 344, 333-340.

Minns, R. J., Marsh, A. M., Chuck, A., Todd, J., (2007). Are hip protectors correctly positioned in use? Age Ageing 36, 140-144.

Nankaku, M., Kanzaki, H., Tsuboyama, T., Nakamura, T., (2005). Evaluation of hip fracture risk in relation to fall direction. Osteoporos.Int. 16, 1315-1320.

Nevitt, M. C., Cummings, S. R., (1993). Type of fall and risk of hip and wrist fractures: the study of osteoporotic fractures. The Study of Osteoporotic Fractures Research Group. J.Am.Geriatr.Soc. 41, 1226-1234.

O'Neill, T. W., Varlow, J., Silman, A. J., Reeve, J., Reid, D. M., Todd, C., Woolf, A. D., (1994). Age and sex influences on fall characteristics. Ann.Rheum.Dis. 53, 773-775.

Orwoll, E., Ettinger, M., Weiss, S., Miller, P., Kendler, D., Graham, J., Adami, S., Weber, K., Lorenc, R., Pietschmann, P., Vandormael, K., Lombardi, A., (2000). Alendronate for the treatment of osteoporosis in men. N.Engl.J.Med. 343, 604-610.

Owen, R. A., Melton, L. J., III, Ilstrup, D. M., Johnson, K. A., Riggs, B. L., (1982). Colles' fracture and subsequent hip fracture risk. Clin.Orthop.Relat Res. 171, 37-43.

Parker, M. J., Gillespie, W. J., Gillespie, L. D., (2006). Effectiveness of hip protectors for preventing hip fractures in elderly people: systematic review. BMJ 332, 571-574.

Parker, M. J., Gillespie, W. J., Gillespie, L. D., (2005). Hip protectors for preventing hip fractures in older people. Cochrane.Database.Syst.Rev. CD001255.

Parkkari, J., Kannus, P., Palvanen, M., Natri, A., Vainio, J., Aho, H., Vuori, I., Jarvinen, M., (1999). Majority of hip fractures occur as a result of a fall and impact on the greater trochanter of the femur: a prospective controlled hip fracture study with 206 consecutive patients. Calcif.Tissue Int. 65, 183-187.

Pijnappels, M., Bobbert, M. F., van Dieen, J. H., (2005). Control of support limb muscles in recovery after tripping in young and older subjects. Exp.Brain Res. 160, 326-333.

Pijnappels, M., Kingma, I., Wezenberg, D., Reurink, G., van Dieen, J. H., (2010). Armed against falls: the contribution of arm movements to balance recovery after tripping. Exp.Brain Res. 201, 689-699.

Pinilla, T. P., Boardman, K. C., Bouxsein, M. L., Myers, E. R., Hayes, W. C., (1996). Impact direction from a fall influences the failure load of the proximal femur as much as age-related bone loss. Calcif. Tissue Int. 58, 231-235.

Poos, M. J. J. C., Smit, J. M., Groen, J., Kommer, G. J., Slobbe, L. C. J., (2008). Cost of illness in the Netherlands 2005. RIVM-rapport nr.270751019, Bilthoven: RIVM.

Province, M. A., Hadley, E. C., Hornbrook, M. C., Lipsitz, L. A., Miller, J. P., Mulrow, C. D., Ory, M. G., Sattin, R. W., Tinetti, M. E., Wolf, S. L., (1995). The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials. Frailty and Injuries: Cooperative Studies of Intervention Techniques. JAMA 273, 1341-1347.

Robertson, M. C., Campbell, A. J., Gardner, M. M., Devlin, N., (2002). Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data. J.Am.Geriatr.Soc. 50, 905-911.

Robinovitch, S. N., Brumer, R., Maurer, J., (2004). Effect of the “squat protective response” on impact velocity during backward falls. J.Biomech. 37, 1329-1337.

Robinovitch, S. N., Evans, S. L., Minns, J., Laing, A. C., Kannus, P., Cripton, P. A., Derler, S., Birge, S. J., Plant, D., Cameron, I. D., Kiel, D. P., Howland, J., Khan, K., Lauritzen, J. B., (2009). Hip protectors: recommendations for biomechanical testing--an international consensus statement (part I). Osteoporos.Int. 20, 1977-1988.

Robinovitch, S. N., Hayes, W. C., McMahon, T. A., (1995a). Energy-shunting hip padding system attenuates femoral impact force in a simulated fall. J.Biomech.Eng 117, 409-413.

Robinovitch, S. N., Hayes, W. C., McMahon, T. A., (1991). Prediction of femoral impact forces in falls on the hip. J.Biomech.Eng 113, 366-374.

Robinovitch, S. N., Inkster, L., Maurer, J., Warnick, B., (2003). Strategies for avoiding hip impact during sideways falls. J.Bone Miner.Res. 18, 1267-1273.

Robinovitch, S. N., McMahon, T. A., Hayes, W. C., (1995b). Force attenuation in trochanteric soft tissues during impact from a fall. J.Orthop.Res. 13, 956-962.

Robinovitch, S. N., Normandin, S. C., Stotz, P., Maurer, J. D., (2005). Time requirement for young and elderly women to move into a position for breaking a fall with outstretched hands. J.Gerontol.A Biol. Sci.Med.Sci. 60, 1553-1557.

Roche, J. J., Wenn, R. T., Sahota, O., Moran, C. G., (2005). Effect of comorbidities and postoperative complications on mortality after hip fracture in elderly people: prospective observational cohort study. BMJ 331, 1374.

Sabick, M. B., Hay, J. G., Goel, V. K., Banks, S. A., (1999). Active responses decrease impact forces at the hip and shoulder in falls to the side. J.Biomech. 32, 993-998.

Sandler, R., Robinovitch, S., (2001). An analysis of the effect of lower extremity strength on impact severity during a backward fall. J.Biomech.Eng 123, 590-598.

Sawka, A. M., Boulos, P., Beattie, K., Thabane, L., Papaioannou, A., Gafni, A., Cranney, A., Zytaruk, N., Hanley, D. A., Adachi, J. D., (2005). Do hip protectors decrease the risk of hip fracture in institutional and community-dwelling elderly? A systematic review and meta-analysis of randomized controlled trials. Osteoporos.Int. 16, 1461-1474.

Schwartz, A. V., Kelsey, J. L., Sidney, S., Grisso, J. A., (1998). Characteristics of falls and risk of hip fracture in elderly men. Osteoporos.Int. 8, 240-246.

Smulders, E., Weerdesteyn, V., Groen, B. E., Duysens, J., Eijsbouts, A., Laan, R., Van Lankveld, W., (2010). A randomized controlled trial on the efficacy of a short multidisciplinary falls prevention program for elderly persons with osteoporosis and a fall history. Submitted.

Smulders, E., Weerdesteyn, V., Groen, B. E., Duysens, J., Laan, R., Van Lankveld, W., (2008). The development of a multidisciplinary fall prevention program for persons with osteoporosis. In: Vincent, M. L., Moreau, T. M. (Eds.), Accidental Falls: Causes, Preventions and Interventions. Nova Science Publisher, Hauppage NY, pp. 185-201.

Soderkvist, I., Wedin, P. A., (1993). Determining the movements of the skeleton using well-configured markers. J.Biomech. 26, 1473-1477.

Tan, J. S., Eng, J. J., Robinovitch, S. N., Warnick, B., (2006). Wrist impact velocities are smaller in forward falls than backward falls from standing. J.Biomech. 39, 1804-1811.

Thelen, D. G., Muriuki, M., James, J., Schultz, A. B., shton-Miller, J. A., Alexander, N. B., (2000). Muscle activities used by young and old adults when stepping to regain balance during a forward fall. J. Electromyogr.Kinesiol. 10, 93-101.

Tinetti, M. E., Speechley, M., Ginter, S. F., (1988). Risk factors for falls among elderly persons living in the community. N.Engl.J.Med. 319, 1701-1707.

Tirosh, O., Sparrow, W. A., (2005). Age and walking speed effects on muscle recruitment in gait termination. Gait.Posture. 21, 279-288.

van den Kroonenberg, A. J., Hayes, W. C., McMahon, T. A., (1996). Hip impact velocities and body configurations for voluntary falls from standing height. J.Biomech. 29, 807-811.

van den Kroonenberg, A. J., Hayes, W. C., McMahon, T. A., (1995). Dynamic models for sideways falls from standing height. J.Biomech.Eng 117, 309-318.

van Schoor, N. M., Asma, G., Smit, J. H., Bouter, L. M., Lips, P., (2003). The Amsterdam Hip Protector Study: compliance and determinants of compliance. Osteoporos.Int. 14, 353-359.

van Schoor, N. M., Deville, W. L., Bouter, L. M., Lips, P., (2002). Acceptance and compliance with external hip protectors: a systematic review of the literature. Osteoporos.Int. 13, 917-924.

van Schoor, N. M., van der Veen, A. J., Schaap, L. A., Smit, T. H., Lips, P., (2006). Biomechanical comparison of hard and soft hip protectors, and the influence of soft tissue. Bone 39, 401-407.

van Swigchem R., Groen, B. E., Weerdesteyn, V., Duysens, J., (2009). The effects of time pressure and experience on the performance of fall techniques during a fall. J.Electromyogr.Kinesiol. 19, 521-531.

Wang, Y., Zatsiorsky, V. M., Latash, M. L., (2006). Muscle synergies involved in preparation to a step made under the self-paced and reaction time instructions. Clin.Neurophysiol. 117, 41-56.

Waugh, E. J., Lam, M. A., Hawker, G. A., McGowan, J., Papaioannou, A., Cheung, A. M., Hodsman, A. B., Leslie, W. D., Siminoski, K., Jamal, S. A., (2009). Risk factors for low bone mass in healthy 40-60 year old women: a systematic review of the literature. Osteoporos.Int. 20, 1-21.

Weerdesteyn, V., Groen, B. E., van Swigchem, R., Duysens, J., (2008). Martial arts fall techniques reduce hip impact forces in naive subjects after a brief period of training. J.Electromyogr.Kinesiol. 18, 235-242.

Weerdesteyn, V., Rijken, H., Geurts, A. C., Smits-Engelsman, B. C., Mulder, T., Duysens, J., (2006). A five-week exercise program can reduce falls and improve obstacle avoidance in the elderly. Gerontology 52, 131-141.

Wei, T. S., Hu, C. H., Wang, S. H., Hwang, K. L., (2001). Fall characteristics, functional mobility and bone mineral density as risk factors of hip fracture in the community-dwelling ambulatory elderly. Osteoporos.Int. 12, 1050-1055.

Wells, G., Cranney, A., Peterson, J., Boucher, M., Shea, B., Robinson, V., Coyle, D., Tugwell, P., (2008a). Risedronate for the primary and secondary prevention of osteoporotic fractures in postmenopausal women. Cochrane.Database.Syst.Rev. CD004523.

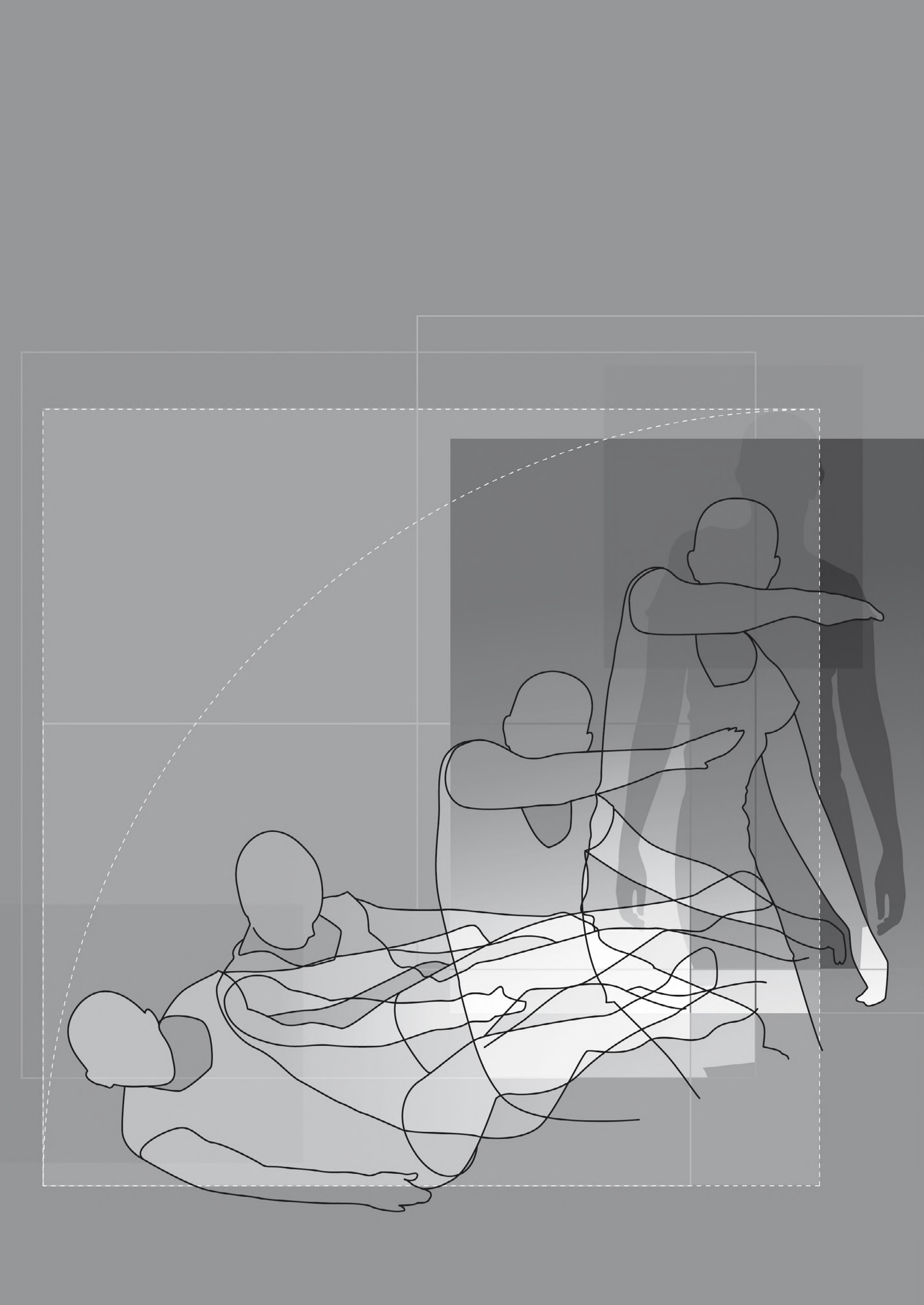
Wells, G. A., Cranney, A., Peterson, J., Boucher, M., Shea, B., Robinson, V., Coyle, D., Tugwell, P., (2008b). Alendronate for the primary and secondary prevention of osteoporotic fractures in postmenopausal women. Cochrane.Database.Syst.Rev. CD001155.

Wells, G. A., Cranney, A., Peterson, J., Boucher, M., Shea, B., Robinson, V., Coyle, D., Tugwell, P., (2008c). Etidronate for the primary and secondary prevention of osteoporotic fractures in postmenopausal women. Cochrane.Database.Syst.Rev. CD003376.

Wildner, M., Peters, A., Raghuvanshi, V. S., Hohnloser, J., Siebert, U., (2003). Superiority of age and weight as variables in predicting osteoporosis in postmenopausal white women. Osteoporos.Int. 14, 950-956.

Yiou, E., Do, M. C., (2001). In a complex sequential movement, what component of the motor program is improved with intensive practice, sequence timing or ensemble motor learning? Exp.Brain Res. 137, 197-204.

Zehr, E. P., Sale, D. G., Dowling, J. J., (1997). Ballistic movement performance in karate athletes. Med. Sci.Sports Exerc. 29, 1366-1373.



Summary

Samenvatting

Summary

1. General introduction

Hip fractures among elderly are a major health problem. These fractures are associated with high mortality and morbidity rates; they are also responsible for high medical costs. The most important clinical risk factors for hip fractures are a low bone mineral density, high age, fracture history, and being female. In clinical practice, hip fracture prevention has traditionally been focused on treating persons with low bone minderal density (osteoporosis). However, since the majority of hip fractures are caused by falls, it is to be expected that fall prevention would also reduce the hip fracture risk. Furthermore, hip fractures may also be prevented by decreasing the severity of a fall, thereby, limiting the potential consequences. Hip protectors do seem to be useful, although user compliance remains a problem. A feasible alternative may be to teach older individuals how to fall safely. This thesis focuses on limiting fall severity by means of using martial arts (MA) techniques. Since sideways falls with direct impact on the greater trochanter have the highest risk for a hip fracture, we focused on sideways falls. The main purpose was to explore the potential usefulness of MA fall training for hip fracture prevention in the elderly. Four aims were investigated in the experimental studies described in Chapter 2-7. The first aim was to study the effect of MA fall techniques on fall severity and to detect experience-related differences (Chapter 2 and 4). The second aim was to gain knowlegde about the working mechanisms by which MA fall techniques reduce the impact on the hip during a sideways fall (Chapter 2-4). The third aim was to determine the trainability of MA fall techniques in young and older individuals (Chapter 4-6). The fourth aim was to investigate the safety of the MA fall training for persons with osteoporosis (Chapter 7).

2. Martial arts fall techniques decrease the impact forces at the hip during sideways falling

In Chapter 2 the effects and the working mechanisms of the MA fall technique during a volitional sidways fall were studied in a group of experienced judokas. Based on simple impact models, it was hypothesized that hip impact velocity and trunk orientation may play a role in reducing hip impact force. In addition, the effect of the use of the arm to break the fall was determined since it has been

suggested that hand impact also plays a role. Six experienced judokas each performed a total of 30 sideways falls from kneeling height using three fall techniques: the block with arm technique (Control or Block), the MA technique with the use of the arm to break the fall (MA-a), and the MA technique without the use of the arm (MA-na). After voluntary initiation of the fall, the subjects received a short verbal instruction indicating which technique was to be performed. The results showed that the MA-a and MA-na technique reduced the impact force by 27% and 29.5%, respectively, and the impact velocity by 12% and 15%, respectively. The trunk orientation was significantly less vertical only in the MA-a falls. No significant differences were found between the MA techniques. It was concluded that hip impact force reduction was associated with a lower impact velocity and, to a lesser extent, with a less vertical trunk orientation. The roll after impact, a characteristic of MA falls, is thought to contribute to the reduction of impact forces. However, using the arm to break the fall was not essential to reduce hip impact forces during MA falls.

3. The relation between hip impact velocity and hip impact force differs between sideways fall techniques

A fundamental variable for fall severity is impact force. However, in experimental studies on the effect of fall strategies on fall severity, impact velocity has often been used instead. The purpose of the study described in Chapter 3 was to determine whether impact velocity is a valid measure to determine differences in fall severity between different techniques. Five young experienced judokas performed sideways falls from kneeling height using the same experimental set-up as described in Chapter 2. They performed the following three techniques: the Block, the MA-a, and the MA-na fall technique. In addition, one subject performed several extra series of falls, including a series of MA falls from standing height. Linear regression analysis showed a moderate relation between hip impact velocity and force, which was heavily dependent on the technique used. In falls with comparable impact velocities, forces found for MA falls were lower than those for Block falls. Therefore, the impact velocity itself could not predict the differences in the impact force. Thus, although hip impact velocity may be useful in making an approximate prediction of impact force within fall techniques, it is not always a valid predictor to determine differences between techniques. We therefore proposed that that if direct impact force measurements are not possible,

a more valid estimate of hip impact force might be obtained by combining impact velocity with energy estimates before and after impact.

4. Martial arts fall techniques reduce hip impact forces naïve subjects after a brief period of training

It is not known how much training is needed to master the MA fall techniques. In Chapter 4 we investigated whether a short training in MA techniques is sufficient to produce hip impact force reduction. Ten young subjects (without prior MA fall experience) participated in an individual 30-min training session in sideways MA fall techniques. Using the experimental set-up described in Chapter 2, the impact forces and impact velocities were measured during volitional sideways falls from kneeling postion during the Block, MA-a and MA-na fall techniques. To identify experience-related differences, additional EMG data during the Block and MA falls were collected in ten inexperienced fallers and five experienced judokas. The results indicated that MA-a and MA-na falls had significantly smaller hip impact forces (-16.7 % and -15.5%) and velocities (both -6.7%) compared to Block falls. The EMG results revealed experience-related differences in pectoralis muscle and trapezius muscle activity during the execution of the MA fall, indicating that the inexperienced fallers had a less pronounced trunk rotation. This may explain why this group had a smaller reduction in impact forces compared to the experienced fallers reported in Chapter 2. It can be concluded that extensive training is not required to reduce the hip impact forces in young adults, indicating that the effective MA techniques are easy to learn. The experience-related differences, however, indicate that a 30-min MA training is not long enough for subjects to fully benefit from the protective effects of MA fall techniques.

5. The effect of time pressure and experience on the performance of fall techniques during a fall

Although MA fall techniques do reduce the hip impact force, it is not clear whether individuals would be able to apply the acquired techniques during an actual fall in daily-life. It is not known how much time it takes to initiate and to successfully execute these techniques or what the influence is of MA experience. In Chapter 5 we investigated the neuromuscular control during voluntary fall techniques in five experienced judokas and in nine inexperienced fallers. All started from a kneeling position. They held on to a grip with the right arm such that the lateral inclination

of the trunk and upper legs was 22° relative to the vertical. Auditory cues was given at 1 ms, 40 ms or 80 ms after the onset of the fall as to whether a Block or an MA-a fall should be performed. EMG data from shoulder and trunk muscles were collected. The mean duration of the fall was found to be 405 ms. The requested technique was successfully executed in 85% of the falls. Experience and fall technique did not affect the success rate. The success rates for falls with a cue delay of 1 ms and 40 ms were, however, higher than in falls with an 80 ms cue delay. Following the cue, the EMG amplitudes of the fall techniques started to diverge after 180-190 ms, indicating a minimum reaction time of 180-190 ms for voluntary initiation of a fall technique. The minimum time to successfully execute the fall techniques was calculated to be 145-155 ms. In general, the EMG amplitudes were similar for both groups, but experience-related differences were found for the Pectoralis and Trapezius muscles. It could be concluded that voluntary motor control is possible within the fall duration, even by inexperienced fallers. The differences in EMG activity might suggest that experienced fallers modified their reaction to possible falls by changing from a preparation for arm abduction to one for trunk rotation.

6. Martial arts fall training to prevent hip fractures in the elderly

In Chapter 6 we described a pilot study to determine whether older individuals could learn martial arts (MA) fall techniques and whether this resulted in a reduced hip impact force during a sideways fall. Six male and nineteen female healthy, older individuals completed a five-session MA fall training. The MA fall performance during volitional sideways falls from kneeling position were evaluated before and after the training. During each fall, force and kinematic data were collected. Two MA experts evaluated the fall performance. In addition, fear of falling was measured with a visual analogue scale. After the fall training, the fall performance had improved, in combination with a reduction in the hip impact force of 8%. In addition, fear of falling was also reduced. The results indicate that MA fall techniques may be trainable in older individuals, and a better performance may reduce the hip impact force in a volitional sideways fall from a kneeling position. The additional reduction in fear of falling might result in the prevention of falls and related injuries.

7. Could martial arts fall training be safe for persons with osteoporosis?: A feasibility study

Osteoporosis is a well-established risk factor for fall-related hip fractures. However, persons with osteoporosis, who are expected to experience the most benefits from an MA fall training, have been excluded because of their high fracture risk. Therefore, the purpose of the study described in Chapter 7 was to determine whether MA fall training is safe for persons with osteoporosis. For obvious safety reaons, this could not be directly assesed by training individuals with osteoporosis. Therefore, we measured the hip impact force during MA fall exercises in a group of young subjects. To determine whether the fall exercises were safe, the highest hip impact forces during the exercises were compared with two safety criteria based on the femoral fracture load and the use of a hip protector. The young adults performed sideways and forward MA falls from a kneeling position on both a judo mat and a mattress as well as from a standing position on a mattress. Hip impact forces and kinematic data were collected. The results showed that the highest hip impact forces during the various fall conditions ranged between 1426 N and 3132 N. Sideways falls from a kneeling and standing position met the safety criteria if performed on the mattress but not if the falls from a kneeling position were performed on the judo mat. Forward falls only met the safety criteria if performed from a kneeling position on the mattress. Forward falls from a kneeling position on a judo mat and forward falls from a standing position on the mattress did not meet both safety criteria. Based on the data from young adults and our safety criteria, the MA fall training could be expected to be safe for persons with osteoporosis provided that the appropriate safety measures are taken: 1) During the training persons with osteoporosis should wear hip protectors that could attenuate the maximum hip impact force by at least 65%, 2) they should perform the fall exercises on a thick mattress, and 3) they should avoid forward fall exercises from a standing position.

8. General discussion

In general, the results reported in this thesis are encouraging for the potential use of MA fall training for hip fracture prevention in the elderly. MA fall techniques were effective in reducing the hip impact force during a sideways fall. The mechanisms likely to be responsible for this reduction are a decrease in hip impact velocity by the combination of knee and trunk movements prior to impact and the rolling

motion after impact which reduces the amount of energy to be absorbed during impact. Neither hand impact nor trunk orientation seem to play an essential role. However, further research is needed to determine in more detail the effect of the roll mechanism. The MA fall techniques are trainable in older individuals, however, these individuals did not seem to be able to retain these skills in the period following the training. The MA fall training also seems to be safe for persons with osteoporosis if appropriate safety measures are taken. A limitation of this thesis is that it is primarily focused on sideways falls. For forward and backward falls, additional research is needed to determine the effects of MA fall techniques. Another limitation is that the fall severity was primary defined by the maximal external vertical hip impact force. Finite element models may possibly be developed to determine the effects of other fall parameters on fracture load and, subsequently, hip fracture risk. A third limitation is that the falls in our fall experiments were volitional falls from a kneeling position, whereas most falls in daily life occur from a standing position. The impact force estimated for these falls based on kinematic data, should be further improved for example by using validated energy models. In addition, further research is required to determine the optimal training intensity necessary to master these MA fall techniques and to determine the effects of MA fall training on hip fracture prevention in daily life. A first step may be to determine the hip fracture risk among older (ex-)judokas in comparison to the risk in the general population.

Samenvatting

1. Algemene inleiding

Heupfracturen vormen een groot gezondheidsprobleem voor ouderen. Heupfracturen zijn geassocieerd met een hoge mortaliteit en morbiditeit en gaan gepaard met hoge medische kosten. De belangrijkste (klinische) risicofactoren voor heupfracturen zijn een lage botdichtheid, een fractuur verleden en een hoge leeftijd; vrouwen hebben een hoger risico dan mannen. In de klinische praktijk is de preventie van heupfracturen vooral gericht op het behandelen van mensen met een lage botdichtheid (osteoporose). Omdat de meeste heupfracturen het gevolg zijn van een val, mag verwacht worden dat het risico op een heupfactuur ook door valpreventie verminderd kan worden. Bovendien zouden heupfacturen voorkomen kunnen worden door de ernst van de val, en daarmee de consequenties van de val, te verminderen. Heupprotectoren zijn hiervoor mogelijk geschikt, alhoewel de acceptatie, voornamelijk vanwege cosmetische redenen, nog een probleem is. Een alternatief is om ouderen te leren veilig te vallen. Dit proefschrift richt zich op het verminderen van de valernst door judovaltechnieken. Het hoogste risico op een heupfractuur treedt op bij een zijwaartse val waarbij je op de heup landt. Dit proefschrift beperkt zich daarom tot de zijwaartse val. Het algemene doel was om te onderzoeken of een judovaltraining bruikbaar zou kunnen zijn voor de preventie van heupfracturen bij ouderen. In de experimenten zoals beschreven in Hoofdstuk 2-7 werden vier doelen nagestreefd. Het eerste doel was om de effecten van judovaltechnieken op valernst te bestuderen en de invloed van ervaring met judovaltechnieken hierop (Hoofdstuk 2 en 4). Het tweede doel was om kennis te verkrijgen over werkingsmechanismen waarmee judovaltechnieken de impact op de heup tijdens een zijwaartse val verminderen (Hoofdstuk 2-4). Het derde doel was om te bepalen of judovaltechnieken bij zowel jongeren als ouderen kunnen worden aangeleerd (Hoofdstuk 4-6). Het vierde doel was om te bepalen of een judovaltraining ook veilig is voor mensen met osteoporose (Hoofdstuk 7).

2. Judovaltechnieken verminderen de impactkracht op de heup tijdens een zijwaartse val

In Hoofdstuk 2 zijn de effecten en het werkingsmechanisme van de judovaltechnieken tijdens een vrijwillige zijwaartse val bestudeerd bij een groep ervaren judoka's. Op basis van een simpel impactmodel werd verwacht dat de impactsnelheid van de heup en de romporiëntatie een rol zouden spelen bij het verminderen van de impactkracht op de heup. Het effect van het afslaan met de arm om de val te breken werd ook onderzocht, omdat dit mogelijk ook een rol zou kunnen spelen bij het verminderen van de impactkracht op de heup. Zes ervaren judoka's lieten zich elk 30 keer in zijwaartse richting vallen vanuit een knielende startpositie, waarbij ze één van de volgende drie valtechnieken gebruikten: de natuurlijke valtechniek waarbij de arm wordt gebruikt om de val te blokkeren (controle of 'Blok'), de judovaltechniek met afslaan met de arm om de val te breken (JV-a) of de judovaltechniek zonder het gebruik van de arm (JV-na). Nadat de val vrijwillig was ingezet, ontvingen de proefpersonen een korte verbale instructie om aan te geven welke techniek gebruikt moest worden. De resultaten lieten zien dat de JV-a en de JV-na de impactkracht op de heup tijdens een val verminderden met respectievelijk 27% en 29,5%, en de impactsnelheid met respectievelijk 12% en 15%. De romporiëntatie was minder verticaal tijdens de JV technieken, maar dit was alleen significant tijdens de JV-a vallen. Er werden geen significante verschillen gevonden tussen de twee judovaltechnieken. De conclusie was dat een reductie in de impactkracht op de heup geassocieerd was met een lagere impactsnelheid, en in mindere mate met een minder verticale romporiëntatie. Het is aannemelijk dat de rolbeweging na impact, als één van de specifieke kenmerken van een judoval, bijdraagt aan het verminderen van de impactkrachten. Het afslaan van de arm om de val te breken speelt daarentegen geen essentiële rol in de reductie van de impactkrachten op de heup tijdens een judoval.

3. De relatie tussen de impactsnelheid van de heup en de impactkracht op de heup verschilt voor zijwaartse valtechnieken

De impactkracht is een fundamentele variabele voor de mate van valernst. In experimentele studies naar het effect van valtechnieken wordt echter in plaats van de impactkracht vaak de impactsnelheid gebruikt als maat voor valernst. Het doel van de studie beschreven in Hoofdstuk 3 was om te bepalen of de impactsnelheid een valide maat is om verschillen in valernst tussen verschillende

valtechnieken te detecteren. Vijf jonge, ervaren judoka's lieten zich vanuit een knielende startpositie in zijwaartse richting vallen. De onderzoeksopstelling was gelijk aan die beschreven in Hoofdstuk 2. Zij gebruikten iedere keer één van de volgende drie technieken: de Blok, de JV-a en de JV-na valtechniek. Eén judoka voerde een aantal extra series uit, waaronder een serie van judovaltechnieken vanaf staande positie. Een lineaire regressieanalyse liet een matig sterke relatie zien tussen de impactsnelheid van de heup en impactkracht op de heup. Deze relatie was sterk afhankelijk van de valtechniek. Wanneer een Judoval en een Blokval een vergelijkbare impact snelheid hadden, was de impactkracht tijdens de Judoval lager dan die tijdens een Blokval. Op basis van de impactsnelheid alleen kon het verschil in impactkracht dus niet voorspeld worden. Alhoewel de impactsnelheid van de heup van nut kan zijn om een ruwe schatting te maken van de impactkracht op de heup binnen een valtechniek, is zij niet altijd een valide voorspeller voor verschillen tussen valtechnieken. Er werd geopperd dat als de impactkracht niet direct gemeten kan worden, de impactkracht op de heup meer valide geschat zou kunnen worden door een combinatie van de impactsnelheid en de hoeveelheid kinetische energie voor en na impact.

4. Judovaltechnieken reduceren de impactkracht op de heup bij onervaren proefpersonen na een korte judovaltraining

Het is niet bekend hoeveel training nodig is om judovaltechnieken te leren beheersen. In Hoofdstuk 4 is onderzocht of een korte training in judovaltechnieken voldoende is om de impactkracht op de heup te verminderen. Tien jonge volwassenen (zonder ervaring in judovaltechnieken) namen deel aan een 30 minuten durende individuele training in zijwaartse judovaltechnieken. Gebruikmakend van dezelfde experimentele opzet als in Hoofdstuk 2, werden de impactkrachten en impactsnelheden van de Blok, JV-a en JV-na valtechnieken gemeten tijdens een vrijwillige zijwaartse val vanuit een knielende startpositie. In aanvulling hierop werden bij tien onervaren volwassenen en vijf ervaren judoka's EMG data verzameld tijdens Blok- en Judovallen om ervaringsgerelateerde verschillen te identificeren. De resultaten lieten zien dat de impactkracht op de heup tijdens de JV-a en JV-na vallen significant lager waren dan tijdens de Blokvallen (respectievelijk, -16,7% en -15,5%). De impact snelheid van de heup was ook significant lager tijdens de Judovallen (beide -6,7%). Tijdens de uitvoering van de JV techniek was de spieractiviteit van de M. Pectoralis lager, en de

spieractiviteit van de M. Trapezius hoger bij de onervaren deelnemers dan bij de ervaren judoka's, wat erop wijst dat onervaren vallers een minder uitgesproken romprotatie hadden dan de ervaren judoka's. Dit zou kunnen verklaren waarom de impact kracht minder afnam in deze groep dan in de ervaren judoka's, zoals beschreven in Hoofdstuk 2. Op basis van de resultaten werd geconcludeerd dat judovaltechnieken gemakkelijk zijn aan te leren en dat er geen intensieve judovaltraining vereist is om de impactkracht op de heup bij jonge volwassenen te verminderen. De ervaringsgerelateerde verschillen wijzen er echter op dat een training van 30 minuten niet voldoende is om optimaal te kunnen profiteren van de beschermende effecten van judovaltechnieken.

5. Het effect van tijdsdruk en ervaring op de uitvoering van valtechnieken tijdens een val

Alhoewel judovaltechnieken de impactkracht op de heup kunnen verminderen, is het niet duidelijk of deze aangeleerde technieken toegepast zouden kunnen worden tijdens een echte val in het dagelijks leven. Het is onbekend hoeveel tijd het kost om een val te initiëren en de technieken met succes toe te passen. Ook is onbekend wat de invloed van ervaring in judo hierop is. In Hoofdstuk 5 werd de neuromusculaire controle tijdens een vrijwillige val onderzocht in vijf ervaren judoka's en negen onervaren vallers. De val werd gestart vanuit een knielende positie. De deelnemers hielden met de gestrekte rechter arm een handvat vast, zodat de romp en de bovenbenen een hoek van 22^o maakten met de verticaal. Op 1 ms, 40 ms of 80 ms na de start van de val kregen de deelnemers een auditief signaal te horen waarmee werd aangegeven of ze een Blok of JV-a techniek moesten gebruiken. Tijdens de val werden EMG data van de schouder en rompspieren verzameld. De gemiddelde valduur was 405 ms. In 85% van de vallen werd de gevraagde techniek succesvol uitgevoerd. Ervaring en de gevraagde valtechniek hadden geen effect op de mate van succes. Voor vallen waarbij het auditieve signaal op 1 ms en 40 ms na de start van de val werd gegeven was de mate van succes hoger dan voor vallen met het signaal op 80 ms na de start van de val. Vanaf 180-190 ms na het auditieve signaal begonnen de EMG amplitudes tussen de twee technieken van elkaar af te wijken, wat aangeeft dat dit de minimum reactietijd is om een valtechniek vrijwillig in te zetten. De minimum bewegingstijd om een valtechniek succesvol uit te voeren was volgens onze berekening 145-155 ms. In het algemeen was de EMG-activiteit

vergelijkbaar voor beide groepen. Er werden echter ervaringsgerelateerde verschillen gevonden voor de M. Pectoralis en de M. Trapezius. Er werd geconcludeerd dat binnen de duur van de val vrijwillige bewegingssturing mogelijk is, zelfs door onervaren vallers. Het verschil in EMG activiteit zou kunnen suggereren dat de primaire reactie van ervaren judoka's op een potentiële val veranderd is van een voorbereiding voor een arm abductie in een voorbereiding voor romprotatie.

6. Judovaltraining om heupfracturen bij ouderen te voorkomen

In Hoofdstuk 6 is een pilotstudie beschreven om te bepalen of oudere personen judovaltechnieken kunnen leren en of dit resulteert in een vermindering van de impactkracht op de heup. Zes gezonde, oudere mannen en negentien gezonde, oudere vrouwen hebben deelgenomen aan een judovaltraining bestaande uit vijf bijeenkomsten. Voor en na de training werd de uitvoering van de judoval vanuit een knielende startpositie geëvalueerd. Tijdens elke val werden impactkrachten en kinematische data verzameld. Twee judo-experts beoordeelden de uitvoering van de val. De angst voor vallen werd gemeten met een visueel analoge schaal. Na de valtraining was de uitvoering van de judoval verbeterd, en de impactkracht op de heup met 8% verminderd. De angst voor vallen was ook afgenomen. De resultaten lieten zien dat judovaltechnieken kunnen worden aangeleerd bij oudere personen en dat een betere uitvoering gepaard gaat met een vermindering van de impactkracht op de heup tijdens een vrijwillige zijwaartse val vanuit een knielende startpositie. De gevonden afname in angst voor vallen zou bovendien kunnen bijdragen aan de preventie van vallen en van de daarbij behorende blessures.

7. is judovaltraining veilig voor mensen met osteoporose? Een haalbaarheidsstudie

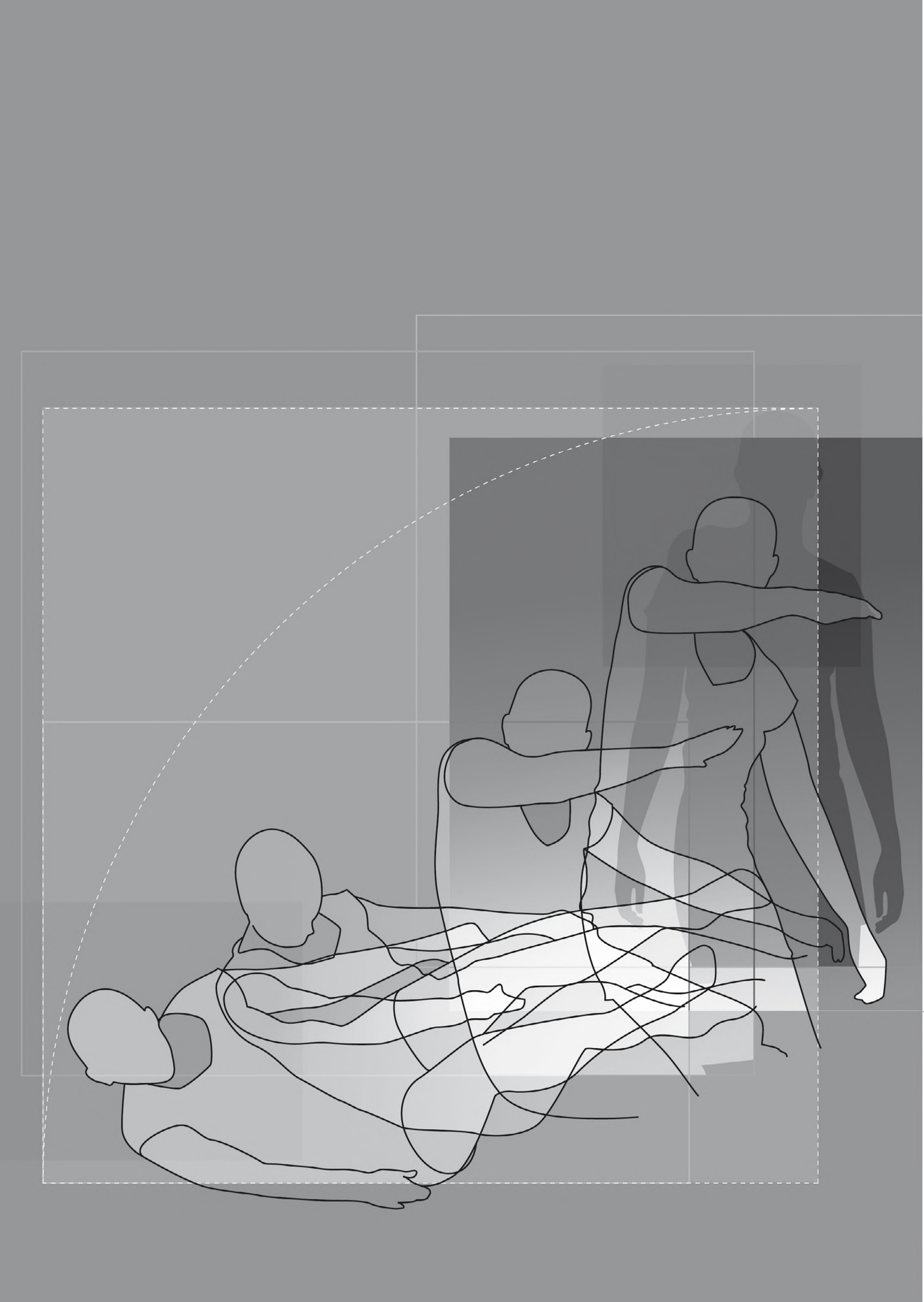
Osteoporose is een bewezen risicofactor voor valgerelateerde heupfracturen. Mensen met osteoporose kunnen naar verwachting het meeste profiteren van een judovaltraining. Zij zijn tot nu toe echter geëxcludeerd voor deelname vanwege hun hoge risico op fracturen. Het doel van de studie beschreven in Hoofdstuk 7 was om te bepalen of judovaltraining veilig is voor mensen met osteoporose. Vanwege voor de hand liggende veiligheidsredenen kon dit niet direct bepaald worden bij mensen met osteoporose. Daarom hebben we de impactkracht op de

heup tijdens de valoefeningen gemeten bij een groep jongeren. Om te bepalen of de valoefeningen veilig waren werden de hoogste impactkrachten die tijdens de valoefeningen gemeten waren, vergeleken met twee veiligheidscriteria gebaseerd op de faalkracht (kracht nodig om bot te breken) van het proximale femur en het gebruik van een heupbeschermer. Vanuit een knielende startpositie voerden de jongeren zijwaartse en voorwaartse judovallen uit op zowel een judomat als een dikke mat, en vanuit stand op een dikke mat. De impactkrachten op de heup en de kinematische data werden verzameld. De resultaten lieten zien dat de hoogste impactkracht op de heup voor de verschillende valcondities lag tussen de 1426 N en 3132 N. Zijwaartse vallen vanuit knielende en staande positie voldeden aan de veiligheidscriteria als ze uitgevoerd werden op een dikke mat, maar niet als ze uitgevoerd werden op een judomat. Voorwaartse vallen vanuit knielende positie voldeden alleen aan de veiligheidscriteria als ze uitgevoerd werden op een dikke mat. Voorwaartse vallen vanuit knielende positie op een judomat, zowel als voorwaartse vallen vanuit staande positie op een dikke mat voldeden niet aan beide veiligheidscriteria. Gebaseerd op deze data van jongere proefpersonen en de gebruikte veiligheidscriteria, werd geconcludeerd dat judovaltraining veilig is voor mensen met osteoporose mits de juiste veiligheidsmaatregelen worden genomen: 1) tijdens de training moeten mensen met osteoporose heupprotectoren dragen die de maximale impactkracht op de heup met minimaal 65% verminderen, 2) zij moeten de valoefeningen op een dikke mat uitvoeren en 3) voorwaartse vallen vanuit staande positie moeten vermeden worden.

8. Algemene discussie

Over het algemeen zijn de resultaten zoals gerapporteerd in dit proefschrift bemoedigend voor potentieel gebruik van judovaltraining bij de preventie van heupfracturen bij ouderen. Judovaltechnieken waren effectief in het verminderen van de impactkracht op de heup tijdens een zijwaartse val. De mechanismen die waarschijnlijk verantwoordelijk zijn voor deze reductie zijn een afname in impactsnelheid van de heup door de combinatie van knie- en rompbewegingen vóór impact en de rolbeweging ná impact. Door deze rolbeweging is er een afname van de hoeveelheid energie die tijdens impact geabsorbeerd moet worden. Handimpact noch romporiëntatie lijken hierbij een essentiële rol te spelen. Er is vervolgonderzoek nodig om het effect van de rolbeweging in meer detail te onderzoeken. De resultaten van de vijf weken durende trainingsstudie

toonden aan dat de oudere personen de judovaltechnieken kunnen aanleren. Aanvullende analyses lieten echter zien dat deze personen de vaardigheden niet vast lijken te houden in de periode na training, wat erop wijst dat de valtraining niet lang genoeg was. De judovaltraining lijkt ook veilig voor mensen met osteoporose mits de juiste veiligheidsmaatregelen worden genomen. Dit proefschrift heeft zich echter hoofdzakelijk beperkt tot de zijwaartse val en aanvullend onderzoek is nodig om de effecten te bepalen van judovaltechnieken tijdens voorwaartse en achterwaartse vallen. Een andere beperking is dat de valernst uitsluitend gedefinieerd wordt door de externe verticale impactkracht op de heup. Eindige elementen modellen zouden kunnen helpen om de effecten van andere variabelen op de faalkracht, en daarmee het heupfractuurrisico, te bepalen. Een derde beperking van het werk gepresenteerd in dit proefschrift is dat de bestudeerde val in de beschreven valexperimenten een vrijwillige val vanuit een knielende startpositie betrof, terwijl in het dagelijkse leven meestal vanuit een staande positie gevallen wordt. De schatting van de impactkracht voor deze vallen op basis van kinematische data zou verbeterd moeten worden door bijvoorbeeld het gebruik van gevalideerde energiemodellen. Ook is er vervolgonderzoek nodig om de optimale trainingsintensiteit te bepalen die nodig is om de judovaltechnieken te leren beheersen en om de preventieve effecten van een judovaltraining op heupfracturen in het dagelijkse leven te bepalen. Een eerste stap zou kunnen zijn om het heupfractuurrisico van oudere (ex-)judoka's te vergelijken met het risico in de algemene oudere bevolking.



Dankwoord

Publications

Curriculum Vitae

Dankwoord

Een promotie-onderzoek is niet het werk van een enkele persoon, maar is een samenwerkingsproject van vele mensen. Op deze plaats wil ik iedereen bedanken die heeft bijgedragen aan dit proefschrift. Een aantal mensen wil ik graag bijzonder bedanken.

Als eerste wil ik mijn promotor Jaak Duysens en copromotor Vivian Weerdesteyn hartelijk bedanken voor de prettige begeleiding. Jaak, jouw grote wetenschappelijke kennis, positieve instelling en enthousiasme hebben mij altijd weten te motiveren om een stapje extra te doen. Ondanks je drukke agenda had je altijd tijd voor vragen en het corrigeren van mijn werk. Dank je wel! Vivian, dankzij jouw voorwerk is judovaltraining het onderwerp van mijn proefschrift geworden. Bedankt voor je introductie in de judovaltechnieken, de vele discussies en je enthousiaste hulp bij het opzetten en uitproberen van de labexperimenten. Ik vind het dan ook erg leuk dat je gaandeweg mijn copromoter bent geworden.

Bart Nienhuis en Jacques van Limbeek wil ik bedanken voor de mogelijkheid die zij mij gegeven hebben om een promotie-onderzoek te kunnen doen. Bedankt voor jullie vertrouwen in mij. Bart, jouw technische kennis was onmisbaar voor de uitvoering van de experimenten. Bedankt voor het delen van je enorme hoeveelheid kennis, je hulpvaardigheid, je gezelligheid en samenwerking in het lab. Jacques, voor vragen over statistiek en methodologie kon ik altijd bij jouw terecht. Bedankt voor je colleges!

Veel dank ben ik verschuldigd aan de proefpersonen. Zonder hun vrijwillige deelname aan de valexperimenten waren er geen resultaten geweest. Ik bedank mijn collega's, stagiaires en judoka's voor hun inzet. In het bijzonder bedank ik alle oudere proefpersonen die hebben deelgenomen aan de valtraining.

Mijn collega's van RD&E bedank ik voor hun gezelligheid, medeleven en hulpvaardigheid. Dankzij jullie is er een open werksfeer en voel ik me thuis op het werk. Mijn kamergenootjes Vivian, Noël en Maartje bedank ik voor hun luisterende oor. Jullie waren vaak degenen die mijn eerste reactie van blijdschap of frustratie hebben aangehoord. Noël, bedankt voor je hulp en je eerlijke mening. Maartje, met een gerust hart kon ik de klinische metingen aan jou over laten. Zonder jou, was dit proefschrift nog lang niet afgerond. Mijn stagiaires, Digna en Roos bedank ik voor hun inzet. Jullie stages zijn bekroond met een publicatie. Ik wens jullie veel succes met jullie eigen promotie-onderzoeken. Patsy, heel hartelijk bedankt

voor de tijd die je hebt gestoken in het corrigeren van mijn Engels. Bedankt voor je geduldige en duidelijke uitleg! Natuurlijk is er ook een speciale dank voor mijn mede-auteurs. Jullie frisse en kritische blik hebben mijn onderzoeken en manuscripten naar een hoger niveau gebracht.

Petra en Ellen, ik ben trots dat jullie mijn paranimfen willen zijn. Petra, lief en leed van het promoveren hebben we van begin tot einde met elkaar gedeeld. Dank je voor de vele liters thee, je goede zorgen en adviezen. Ellen, bedankt voor je fijne samenwerking. Zonder jouw inzet, hadden we de valtraining voor ouderen niet kunnen evalueren. Ook bedankt voor je frisse blik en je opbouwende commentaar op mijn manuscripten. Op naar jullie promoties en een goede verdere samenwerking in de toekomst!

Mijn familie wil ik bedanken voor hun liefde en steun. Papa en mama, ik dank jullie voor de steun die jullie me gegeven hebben om te doen wat ik leuk vond. Bedankt voor jullie belangstelling in mijn werk. Irma, ook jou dank ik voor je oprechte interesse en goede zorgen. Tot slot, lieve Stefan, jij stond altijd voor me klaar en hield me in evenwicht ook als ik iets te veel hooi op mijn vork had genomen. Bedankt voor je liefde en hulp.

Publications

Articles in international journals

Groen, B. E., Weerdesteyn, V., Duysens, J. Martial arts fall techniques decrease the impact forces at the hip during sideways falling. Journal of Biomechanics 40(2):458-462, 2007.

Gaasbeek, R. D. A., Groen, B. E., Hampsink, B., van Heerwaarden, R. J., Duysens, J. Valgus bracing in patients with medical compartment osteoarthritis of the knee. A gait-analysis study of a new brace. Gait and Posture 26(1):3-10, 2007.

Groen, B. E., Weerdesteyn, V., Duysens, J. The relationship between hip impact velocity and hip impact force differs between sideways fall techniques. Journal of Electromyography and Kinesiology 18(2):228-234, 2008.

Weerdesteyn, V., Groen, B. E., van Swigchem, R., Duysens, J. Martial arts fall techniques reduce hip impact forces in naïve subjects after a brief period of training. Journal of Electromyography and Kinesiology 18(2):235-242, 2008.

van Swigchem, R., Groen, B. E., Weerdesteyn, V., Duysens, J. The effects of time pressure and experience on the performance of fall techniques during a fall. Journal of Electromyography and Kinesiology 19: 521-531, 2009.

Groen, B. E., Smulders, E., De Kam, D., Duysens, J., Weerdesteyn, V. Martial arts fall training to prevent hip fractures in the elderly. Osteoporosis International 21(2):215-21, 2010.

Groen, B. E., Smulders, E., Duysens, J., van Lankveld, W., Weerdesteyn, V. Could martial arts fall training be safe for persons with osteoporosis?: a feasibility study. BMC Research Notes 3:111, 2010.

Smulders, E., Weerdesteyn, V., Groen, B. E., Duysens, J., Eijsbouts, A., Laan, R., van Lankveld, W. A randomized controlled trial on the efficacy of a short multidisciplinary falls prevention program for elderly persons with osteoporosis and a fall history. Accepted by Archives of Physical Medicine and Rehabilitation

Bookchapter

Smulders, E., Weerdesteyn, V., Groen, B. E., Duysens, J., Laan, R., van Lankveld, W. The development of a multidisciplinary fall prevention program for persons with osteoporosis. In: Vincent, M. L. and Moreau, T.M. (eds.) Accidental Falls : Causes, Preventions and Interventions. Nova Science Publishers, Hauppage NY, pp 185-201, 2008.

Abstracts

Romkes, J., Groen, B. E., de Koning, J. Mechanical Efficiency in Arm Cranking Exercise. 2nd International workshop on wheelchair propulsion, Amsterdam, December 1998. In: van der Woude, L. H. V., Hopman, M. T. E., van Kemenade C. H. (Eds.) Assistive Technology Research Series, Volume 5: Biomedical Aspects of Manual Wheelchair Propulsion, The State of the Art II, IOS Press, Amsterdam, pp 172-174, 1999.

Groen, B. Loopanalyse bij patiënten met een varus deformiteit van de knie. Symposium 'Sterk in beweging en kracht', Nijmegen, oktober 2002.

Duysens, J. and Groen, B. The foot pressure and pressure-time integral in Diabetic patients during walking. Footscan® user meeting, Beveren, February 2003.

Groen, B., Weerdesteyn, V., Nienhuis, B., Duysens, J. Martial arts fall techniques decrease the impact forces at the hip during falling. KUN-KUL Workshop anticipation and perception in movement regulation. Leuven, May 2004.

Groen , B. E., Weerdesteyn, V., van Lankveld, W., Duysens, J. Hand impact is not essential for martial arts fall techniques to reduce hip impact force. BioMove, Manchester, April 2005.

Groen, B., Weerdesteyn, V., van Lankveld, W., Duysens, J. Hip impact velocity and trunk orientation play a role in the reduction of hip impact force by martial arts fall techniques. XVIIth Conference of International Society for Posture and Gait Research, May 2005. Gait and Posture 21 (S1): S115, 2005.

Groen, B.E., Heesterbeek, P. J. C., van Limbeek, J., Duysens, J. Walking velocity is an important determinant for the forefoot pressure-time integral, but not for the peak pressure in diabetic patients and controls. Footscan® user meeting, Prague, August 2005.

Groen, B.E., Weerdesteyn, V., van Lankveld, W. G. J. M., Duysens, J. Judo-valtechnieken tijdens een zijwaartse val reduceren de kracht op de heup bij impact. Najaarsdagen Reumatologie, Veldhoven, september 2005. Nederlands Tijdschrift voor Reumatologie, Extra Uitgave, p 96, 2005

Weerdesteyn, V., Groen, B., van Lankveld, W. G. J. M., van den Hoogen, F. H. J. Valpreventietraining voor mensen met osteoporose: een adaptatie van het succesvolle programma Vallen Verleden Tijd. Najaarsdagen Reumatologie, Veldhoven, september 2005. Nederlands Tijdschrift voor Reumatologie, Extra Uitgave, p 50, 2005

Groen, B. E., Weerdesteyn, V., van Lankveld, W., Duysens, J. Reduction of hip impact force after a brief training in martial arts techniques. 21st Paulo Symposium on Preventing Bone Fragility and Fractures, Tampere, Finland, May 2006.

Smulders, E., Weerdesteyn, V., Groen, B.E., van Lankveld, W., Duysens, J. A new intervention to prevent falls and fractures in osteoporosis. 21st Paulo Symposium on Preventing Bone Fragility and Fractures, Tampere, Finland, May 2006.

Groen, B. E., Weerdesteyn, V., van Lankveld, W., Duysens, J. Martial arts fall techniques can reduce fall severity after a short training. RU-KUL Workshop Motor Control, Nijmegen, May 2006.

Smulders, E., Weerdesteyn, V., Groen, B. E., van Lankveld, W., Duysens, J. Prevention of falls and fractures in osteoporosis: a new intervention. RU-KUL Workshop Motor Control, Nijmegen, May 2006.

van Swigchem, R., Groen, B. E., Weerdesteyn, V., Duysens, J. Neuromuscular control of conscious fall techniques during a fall. RU-KUL Workshop Motor Control, Nijmegen, May 2006.

Groen, B.E., Weerdesteyn, V., van Lankveld, W., Duysens, J. Intervention including martial arts fall training to prevent fractures in patients with osteoporosis: reduction of hip impact force after a brief training. 7th Annual European Congress of Rheumatology (EULAR), Amsterdam, June 2006. Annals of Rheumatic Diseases 65(SII): S419, 2006.

Smulders, E., Weerdesteyn, V., Groen, B.E., Duysens, J., van Lankveld, W. Prevention of falls in people with osteoporosis: an adjusted version of the Nijmegen Falls Prevention Program. 7th Annual European Congress of Rheumatology (EULAR), Amsterdam, June 2006.

Groen, B.E., Weerdesteyn, V., Duysens, J. The relation between hip impact velocity and hip impact force in different sideways fall techniques. 5th World Congress of Biomechanics, Munich, Germany, July 2006. Journal of Biomechanics 39 (S1): S88, 2006.

Weerdesteyn, V., Groen, B. E., van Lankveld, W., Duysens, J. Martial arts fall techniques reduce hip impact forces in naïve subjects after a brief period of training. 5th World Congress of Biomechanics, Munich, Germany, July 2006. Journal of Biomechanics 39 (S1): S89, 2006.

van Swigchem, R., Groen, B.E., Weerdesteyn, V., Duysens, J. The neuromuscular control of voluntary fall techniques during a fall. European Workshop On Movement Science (EWOMS), Amsterdam, The Netherlands, May 2007.

Groen, B. E., Weerdesteyn, V., Duysens, J. Experience related differences in performance of martial arts sideways fall techniques. 18th Conference of the International Society for Posture and Gait Research, Burlington, Vermont, USA, July 2007.

Groen, B. E., de Kam, D., Weerdesteyn, V., Smulders, E., Duysens, J. Effectiveness of a five-sessions fall training in healthy older persons. Seminar 'Prevention of fall-related injuries', UMC St Radboud, Nijmegen, November 2007.

Smulders, E., Weerdesteyn, V., Groen, B. E., van Lankveld, W., Duysens, J. Fall prevention and fall training in people with osteoporosis. Seminar 'Prevention of fall-related injuries', UMC St Radboud, Nijmegen, November 2007.

Groen, B. E., Geurts, M. P. J., Nienhuis, B., Duysens, J. Sensitivity of the OLGA and VCM models to erroneous marker placement in 3D-gait analysis. 17th Annual meeting of the European Society for Movement analysis for Adults and Children, Antalya, Turkey, September 2008. Gait and Posture 28 (S1): S34, 2008.

Groen, B. E., Smulders, E., de Kam, D., Duysens, J., Weerdesteyn, V. Healthy elderly are able to learn martial arts fall techniques to reduce hip impact force. 19th Conference of the International Society for Posture and Gait Research, Bologna, Italy, June 2009.

Groen, B. E., van der Zijden, A. M., Nienhuis, B., Keijsers, N. L. W. Sensitivity of muscle-tendon lengths to marker displacement in 3D-gait analysis. 18th Annual meeting of the European Society for Movement analysis for Adults and Children, London, United Kingdom, September 2009. Gait and Posture 30 (S2): S33, 2009.

van der Zijden, A. M., Groen, B. E., Keijsers, N. L. W., Nienhuis, B. The introduction and development of the FAMP-coach; a tool to guide marker placement in clinical gait analysis. 18th Annual meeting of the European Society for Movement analysis for Adults and Children, London, United Kingdom, September 2009. Gait and Posture 30 (S2): S35-S36, 2009.

van der Zijden, A. M., Tanck, E., Verdonschot, N., Nienhuis, B., Groen, B. E., Weerdesteyn, V. Combining in-vivo fall assessments and finite element modeling to estimate the protective effects of Martial Arts fall techniques on femoral fracture risk. 6th World Congress of Biomechanics, Singapore, August 2010.

Curriculum vitae

Brenda Groen was born on November 26, 1974 in De Lier, the Netherlands. In 1993, she earned her secondary school diploma at the Interconfessioneel Westland College in Naaldwijk and started to study at the Faculty of Human Movement Sciences at the Vrije Universiteit in Amsterdam. During her study Brenda performed an internship at the Human Performance Laboratory at the University of Calgary in Canada. In 1998, she followed a course in didactics at the Faculty of Human Movement Sciences and graduated cum laude. She started working at various temporary jobs at the Bureau of Student Affairs at the Vrije Univeriteit in Amsterdam. A year after graduation she became an assitant lecturer at the Faculty of Human Movement Sciences. In 2000, Brenda was given the opportunity to start as a researcher at the department of Research, Development and Education at the Sint Maartenskliniek in Nijmegen. She worked in the gait laboratory supporting experimental studies and clinical gait analysis. In addition, she conducted research to evaluate and improve the quality of clinical gait analyses. Since 2004, she combined her work in the gait laboratory with her PhD project on the effect of martial arts fall techniques on fall severity which resulted in this thesis. Currently, she continues her research work in the gait laboratory and supports a project on the effect of martial arts fall techniques using finite element models. Brenda is married to Stefan te Winkel.