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Short communication

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

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Abstract

Falls to the side and those with impact on the hip are risky for hip fractures in the elderly. A previous study has indicated that martial arts (MA) fall techniques can reduce hip impact force, but the underlying mechanism is unknown. Furthermore, the high impact forces at the hand used to break the fall have raised concerns because of the risk for wrist fractures. The purpose of the study was to get insight into the role of hand impact, impact velocity, and trunk orientation in the reduction of hip impact force in MA techniques. Six experienced judokas performed sideways falls from kneeling height using three fall techniques: block with arm technique (control), MA technique with use of the arm to break the fall (MA-a), and MA technique without use of the arm (MA-na). The results showed that the MA-a and MA-na technique reduced the impact force by 27.5% and 30%, respectively. Impact velocity was significantly reduced in the MA falls. Trunk orientation was significantly less vertical in the MA-a falls. No significant differences were found between the MA techniques. It was concluded that the reduction in hip impact force 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. Using the arm to break the fall was not essential for the MA technique to reduce hip impact force. These findings provided support for the incorporation of MA fall techniques in fall prevention programs for elderly.

Keywords: Falls; Hip fracture; Biomechanics; Impact

1. Introduction

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 mechanism 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 programs to

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prevent falls in elderly (Rijken et al., 2005). The high impact force at the hand that is used to break the MA fall have 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 mechanism 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.

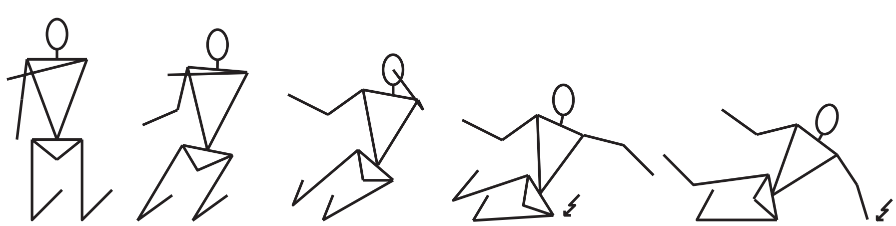
2. Methods

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.

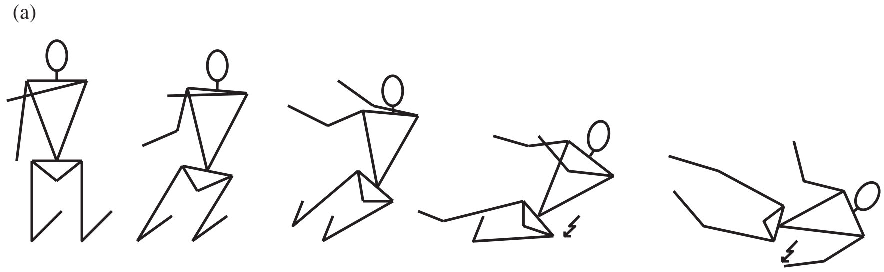
Forces were measured with a force plate (Kistler, size $0.6\,\mathrm{m} \times 0.4\,\mathrm{m}$) at 2400 Hz. The 3D positions of reflective markers were simultaneously registered with a 6-camera motion analysis system (Primas) at 100 Hz. Markers were placed on the left shoulder, wrist, and greater trochanter (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 (Fig. 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 (Fig. 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 (1993). Then the GT marker was removed. The testing protocol was similar to that used by Sabick et al. (1999). The



(a)



(b)

Fig. 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 (↯).

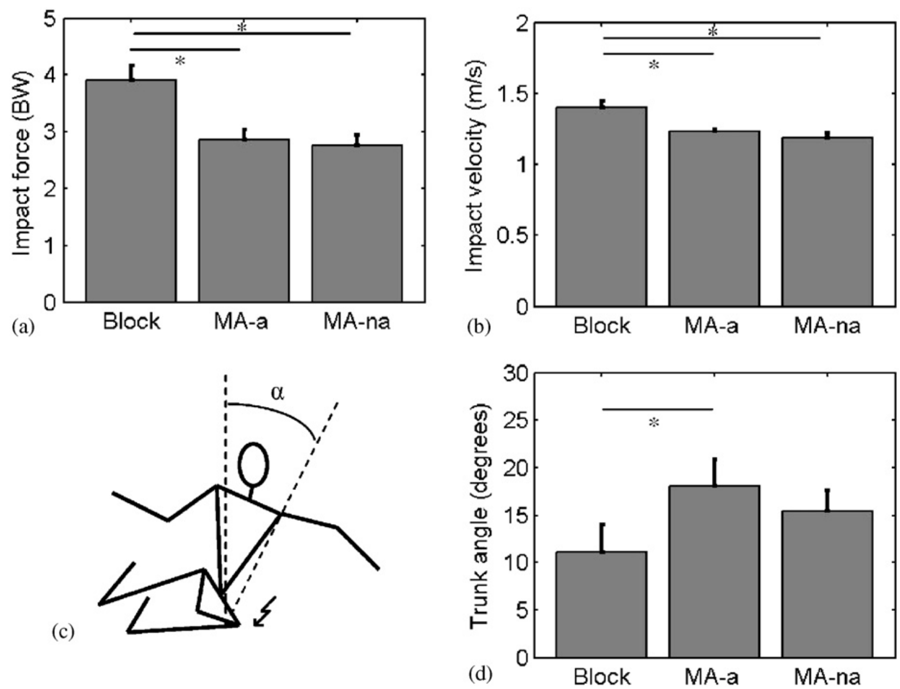


Fig. 2. Mean values ± SEM ($N = 6$) of the impact data. The mean of the (a) hip impact force (normalized for body weight (BW)), (b) hip impact velocity in (m/s), and (d) trunk angle (°) for the block with arm technique (Block), the martial art technique with using the arm to break the fall (MA-a) and 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 maker 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 $p<0.05$).

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 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 (Fig. 2c).

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.

3. Results

The largest mean hip impact forces and velocities and the most vertical trunk orientations were found for the Block falls (Fig. 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 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 ($\Delta 0.17$ m/s; $p = 0.031$) and MA-na ($\Delta 0.21$ 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°; $p = 0.031$), but not for the MA-na falls (4.5°; $p = 0.063$) compared to the Block falls. No significant differences between the MA-fall techniques were observed ($p > 0.05$). Fig. 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.

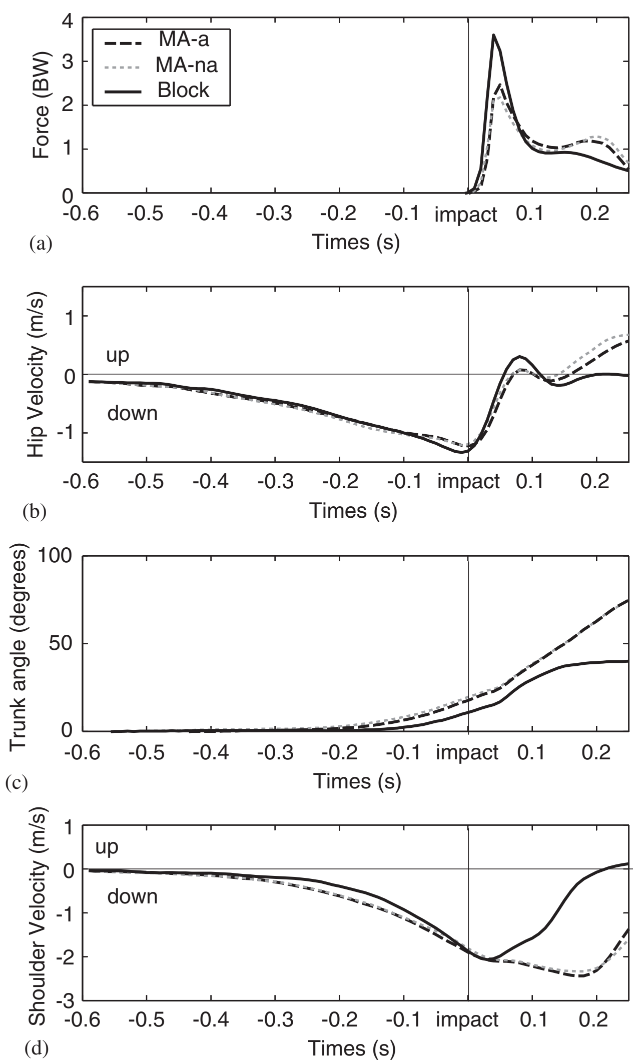


Fig. 3. Time curves of the (a) impact force (BW), (b) hip vertical velocity (m/s), (c) trunk angle (°), and (d) shoulder vertical velocity (m/s) of the three fall techniques of one of the subjects. Note that the difference in hip velocity between the Block and MA falls started prior to hip impact. After hip impact, trunk angle and shoulder vertical velocity increased in the MA falls. Impact is indicated by the vertical line.

4. Discussion

The results showed that the MA-a and MA-na techniques reduced the hip impact force in sideways falls from kneeling height by 27.5% and 30%, 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 Fig. 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 (Fig. 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 fall prevention program (Rijken et al., 2005) 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 programs for elderly.

Acknowledgments

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