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Full Length Research paper

Mechanical impacts analysis in judoists body of different weight categories

Tatiane Piucco* and Dra. Saray Giovana dos Santos

Laboratório de Biomecânica, Centro de Desportos Universidade Federal de Santa Catarina, Florianópolis SC Brasil.

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This study aimed to analyze the impacts generated in different body regions of judoists of different weight categories during falls cushioning. Four black belt judoist, with at least 14 years of experience, participated in this study: three "uke" half-light, half-middle and half-heavy categories were thrown in "ippon-seoi-nage" technique by a "tori" with 77 kg. A triaxial Brüel and Kjaer accelerometer was alternately fastened with straps in the "uke" fist, hip and ankle to verify the impacts. Descriptive statistics, one way ANOVA and Tukey test were applied, with p≤0.05. The bigger impact magnitudes occurred in vertical axis, in the fist and for the half-middle category judoist; the impact times were larger in the hip for all athletes and in vertical axis. According to Macaulay criteria, the impact values founded represents severe injury risks in fist and ankle and moderate risk in judoists hip. Initiatives should be taken to reduce the damage due to impact during judo training and competitions.

Key words: Judo, impact, transitory, vibrations, injury.

INTRODUCTION

The mechanical impacts, also defined as transient vibrations, occur frequently in sports, not only in combative sports, when the body sock against a fixed external surface, like landing in the ground or falling (Roquette, 1994). Although the agreement in literature that mechanical impacts comprise vibration levels dangerous to the organism (Mansfield, 2005), there is no rules that limit human exposure to transient vibrations, especially those that occur during sports performance. The only criterion that can be taken as reference for sports impacts is the one elaborated for Macaulay (1987). This criterion consider the pulse duration as the total time of impact, and is graphically plotted for three regions: a short-term region from 0.001 to 0.01 s, an intermediate-term region and a long-term region to impact time durations larger than 0.1 s. This criterion postulates that the lower the impact duration, greater accelerations the body can stand without being damaged. On the other hand, it is not mentioned in this criterion the number of impact events that the body can withstand during a specified period of time, neither the minimum interval required between impact repetitions. Some researchers like Voloshin (2004), Lafortune et al. (1995) and Derrick and Mercer (2003) and others point out that the repetition of sports movements are the main mechanisms of sports injuries. As a result, sports which require high magnitudes of impact applied without rest period, like the landings in volleyball and basketball and falls in combative sports, are the ones who mostly collaborate for athlete damages during regular practice (Santos and Piucco, 2006).

In judo practice, the transient vibrations occur frequently in the judokas body during damping falls (ukemi) of different throw techniques. The number of ukemi accomplished during a judo training sessions comes to 73.60 ± 42.34 (Santos and Melo, 2003), and it depends of the training stage, intensity and the athlete's technical level (Melo et al., 2009). The high rates of "ukemi" repetition is a contributing factor for the trauma occurrence (James and Pieter, 2003), as well as the incorrect "ukemi" results in many kind of injuries (Santos and Shigunov, 2001; Santos and Melo, 2003; Santos, 2003), what indicates that is necessary to accomplish

*Corresponding author. E-mail: tatianepiucco@yahoo.com.br. Tel: (48) 3721 8530. Fax: (048) 3721-9792.

Figure 1. Accelerometer settling at the judokas wrist, hip and ankle, according to the method adopted by Santos (2003). Source: Santos (2003: 45).

more researches to assess the implications of consecutive falls on a judoka body. Despite the constant exposure of judokas to transient vibration, few studies like those of Santos (2003) and Piucco and Santos (2010) investigated the vibrations generated in the judokas body during falls, and there is no investigation about the impacts on the body of judokas of different weight categories. Thus, based on the theoretical assumptions pointed out, and considering the importance of studying the variables that can provide damages to the athlete's body to propose future actions to prevent or at least mitigate the adverse effects, the following questions were proposed: what are the magnitude and duration of impacts suffered by judokas of different weight categories during the ukemi? Are these impacts harmful to them? Considering these issues, this study aimed at analyzing the transient vibrations generated in three different judokas body regions and weight categories, during the ukemi in ippon-seoi-nage throwing techniques.

METHODS

Three judokas of different weight categories were investigated (designed by uke): one of half lightweight category, brown belt, 21 years old, 168 cm, 63 kg and 16 years of practice; one of half middleweight category, black belt, 27 years old, 175 cm, 74 kg and 15 years of practice; one of half heavyweight category, black belt, 24 years old, 175 cm, 95 kg and 14 years of practice. These three judokas were projected by a "tori" black belt, with 27 years old, 174 cm, 77 kg and 15 years of practice, using the "ippon-seoi-nage" judo technique. The acceleration (m/s^2) generated by the shock of judoka on the mat was measured using a triaxial accelerometer type 4321 from Brüel and Kjaer, previously calibrated, made of titanium, with dimensions of 28.6 x 28.6 x 17 mm, maximum shock of 1000 g (gravity acceleration), frequency range of 0.1 to 12,000 Hz, sensitivity of 10 pC/g and resonance frequency of 40 kHz. For the amplification and filtering of signals three pre-amplifiers type 2635 from Brüel and Kjaer were used, and signal acquisition was made by a Lynks module MCS1000-v2, composed of 16 channels with configurable output voltage ± 10 V. The signals were digitally converted by a Lynks A/D converter model AC1112 with 16 analog inputs and 12 bit resolution. From the fulfillment of legal requirements of National Health Council, Resolution 196/96, and upon approval by the Ethics Committee of Universidade Federal de Santa Catarina (project number 073/07), the athletes signed an informed consent before the data collection.

Samples were collected in a laboratory where an area was mounted with three mats of 297.0 x 199.0 x 4.0 cm in total size. The accelerometer was fixed at the judokas wrist (on the left distal radioulnar joint), hip (in the upper right iliac crest) and ankle (two cm proximal to the left medial malleolus) (Figure 1), according to Santos (2003) methodology. The judokas were projected 30 times (10 times for each body segment - wrist, hip and ankle) using the "ippon-seoi-nage" judo technique. The accelerometer and cables were settled with elastic ribbons to enable the natural execution of the techniques avoiding the accelerometer and cables oscillation. The athletes were instructed to start the movement simultaneously with data acquisition. The electrical charge generated by piezoelectric transducer (accelerometer) during the fall, in the three directions (x, y and z) was transmitted through cables to the respective pre-amplifiers, adjusted for values of acceleration (m/s^2). After that, the signals were converted to digital form and acquired by the software AqDados 7.02 at a frequency of 4000 Hz in order to preserve signal integrity, according to the Nyquist theorem which states that the sampling frequency of an analog signal must be equal to or greater than twice the highest frequency spectrum of signal ($Fa \geq 2F$), so it can later be reconstituted with a minimal loss of information.

The motion axes orientation (x, y and z) of acceleration followed the ISO 2631-1 (1997) standardization, designated in the standing position on the longitudinal axis (± z), anterior-posterior axis (± x), and transverse axle (± ay). When falling on the mat (ukemi), the judoka assumes the supine position. So, the axes orientation during the impacts were arranged according to Figure 2. Signals were analyzed by the AqDAnalysis 7.0 software. After the signal baseline off-set adjustment, the peak values of signals in time domain (m/s^2) were taken and corrected by the amplification factor. These values were divided by 9.81 to be transformed into gravitational units (g). The impact duration (milliseconds) were determined by the difference between the final time and initial time of the event (Figure 3). Data were analyzed by the SPSS 15.0 statistical program. The results were descriptive represented by mean and standard deviation values. The normal distribution of data was checked by Kolmogorov-Smirnov ($n \geq 50$) normality test, and then, ANOVA One Way was applied in order to compare the values between the movement axes, body regions and athletes. Since significant differences were found, the Tukey HSD multiple comparison test was applied. For all tests a significance level of 95% was adopted.

RESULTS

The descriptive values of impacts magnitude and duration generated on the judokas wrist, hip and ankle, in each motion axis, are shown in Figure 4 A, B and C

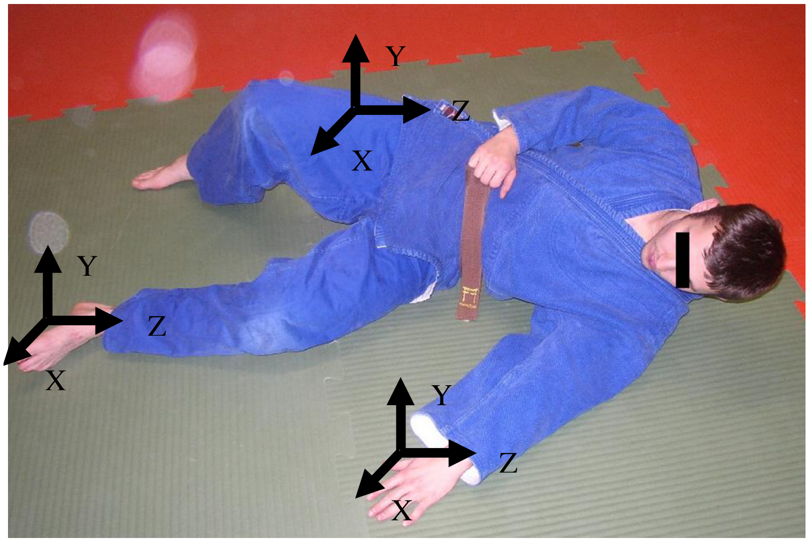

Figure 2. Axes orientation during judokas body impact.

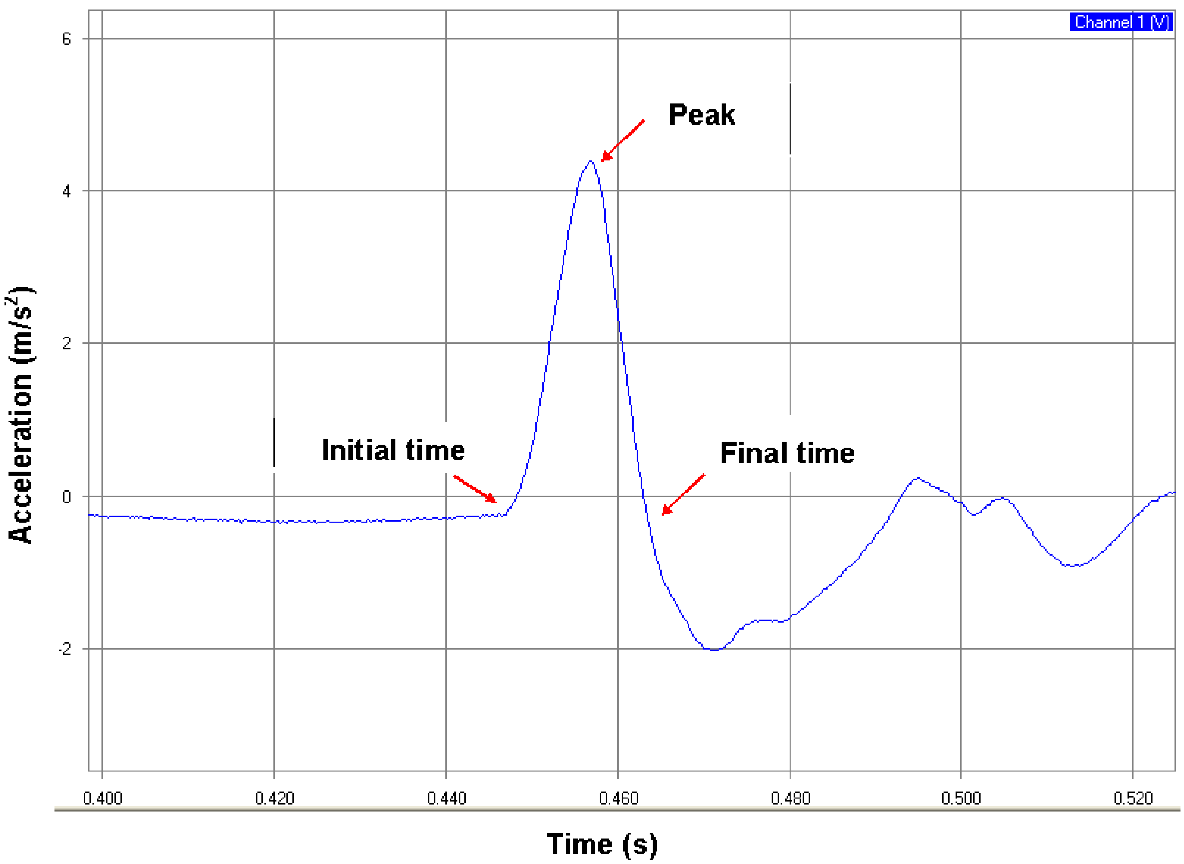

Figure 3. Criteria used to determinate the peak and the duration of each impact.

respectively. It is observed in Figure 4 that the half middleweight athlete had the highest impact magnitude average on the wrist, reaching 351.94 g in the y-axis. The longest impact duration occurred on the y-axis for the half heavyweight athlete. Figure 4B shows that the half heavyweight athlete had lower impact magnitude on the

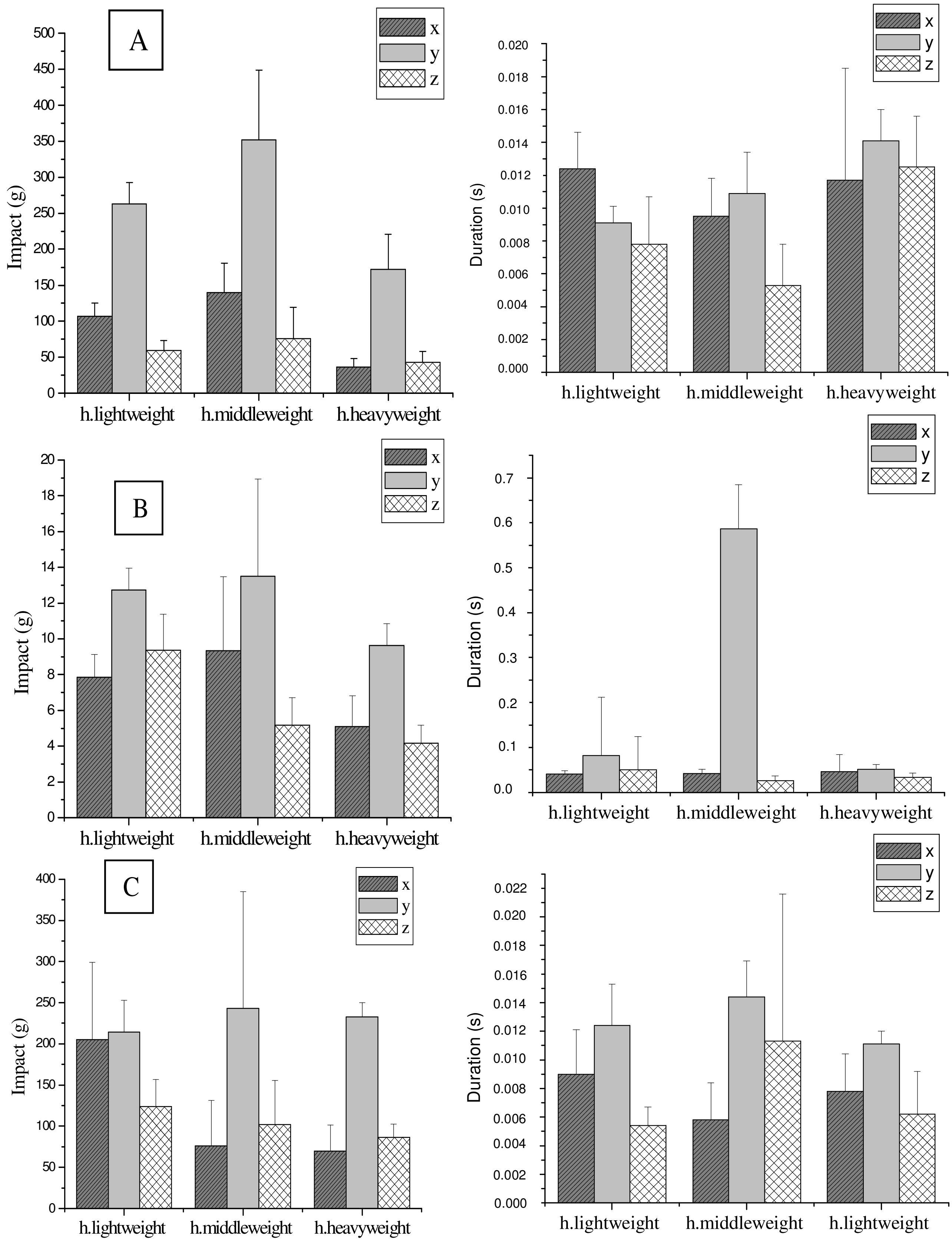

Figure 4. Mean and SD of magnitude (g) and duration time (s) of impact measured on the judokas wrist (A), hip (B) and ankle (C), in x, y and z axes.

Table 1. Comparison of impact magnitude (g) between the axes (x, y and z), joints (wrist, hip and ankle) and judokas (half lightweight, half middleweight, half heavyweight).

	Categories	*X*	*Y*	*z*
Wrist	H. Lightweight	106,96* $^{\Psi \xi}$	263,110* $^{\Psi \xi}$	59,023$^{\Psi}$
	H. Middleweight	140,212* $^{\xi}$	351,947* $^{\Psi}$	75,994*
	H. Heavyweight	36,364* $^{\xi}$	171,836* $^{\Psi \xi}$	42,701* $^{\xi}$
Hip	H. Lightweight	7,865$^{\xi}$	12,730 $^{\Psi \xi}$	9,367* $^{\xi}$
	H. Middleweight	9,326* $^{\xi}$	13,506 *$^{\Psi \xi}$	5,180 $^{\xi}$
	H. Heavyweight	5,081* $^{\xi}$	9,631* $^{\Psi \xi}$	4,474 $^{\xi}$
Ankle	H. Lightweight	204,886* $^{\xi}$	214,483 $^{\xi}$	123,583 $^{\Psi \xi}$
	H. Middleweight	76,090 $^{\xi}$	242,888 $^{\Psi}$	101,974
	H. Heavyweight	69,815 $^{\xi}$	232,741 $^{\Psi \xi}$	86,642 $^{\xi}$

Where: *differences between categories; $^{\Psi}$ differences between axis; $^{\xi}$ differences between joints. $p \leq 0.0$.

hip, and the higher value occurred in the y-axis for the half middleweight athlete. The duration of impacts on the hip was greater in the y-axis for the half middleweight athlete. In Figure 4C it is observed that the magnitude of impacts on the ankle were similar between athletes, being more evident for the half lightweight athlete in the x-axis. The duration of impacts on the ankle was greater in the y-axis for the half middleweight athlete.

It is also noted in Figure 4 (A, B, C) that for all athletes and in all regions investigated, the highest values of impact magnitude and duration occurred in the y-axis, except for the half lightweight athlete's wrist. The result of comparing the magnitude of impacts between the axes (x, y and z), joints (wrist, hip and ankle) and judokas (half lightweight, half middleweight, half heavyweight), and the post-hoc test are presented in Table 1. It is observed in Table 1 that there were significant differences between the joints investigated, except between the wrist and ankle to the half middleweight athlete in y and z axes.

The hip region had the lowest magnitude of impact, and the ankle suffered greater magnitude of impact than the wrist, except the y-axis for the half lightweight athlete and the x-axis for the half middleweight athlete. Regarding differences between the motion axes, the magnitude of impact on the y axis was significantly higher compared to the other axes for all joints and all the athletes investigated. Among the weight categories, the half heavyweight athlete suffered the lower magnitude of impact on the wrist and hip in all axes. The half lightweight athlete showed higher magnitude of impact than the other athletes in the x and z axis at the ankle joint.

DISCUSSION

The magnitude of impacts founded in the different motion axes and body regions of judokas during falls are similar to the values founded by Santos (2003) and Piucco and Santos (2010). The increase of vertical impact strength when collision occurs is attributed, among other factors, to the action of gravitational force, the height and speed with which athletes are projected (Santos and Melo, 2001). The increase of impact values of y to z axis can be explained by the characteristics of the "ukemi" technique used by athletes, called "zempo-kaiten-ukemi". According to Santos (2003), during the "zempo-kaiten-ukemi", the hit on the mat occur with combined displacement of the vertical and medial-lateral direction, providing an approach from the inside out, justifying the incremental values in vertical, lateral and longitudinal direction. The lowest impact values found in judokas hip as well as the high values found in the wrist and ankle during the fall, were also confirmed by Santos (2003) and Piucco and Santos (2010). This distribution of impact forces occurs because of the first hand beat on the mat, followed by the support of shoulder which acts as the hip axis rotation, dissipating the greater impact forces of this region (Santos and Melo, 2001). By the other hand, the ankle accomplishes the biggest trajectory during the throwing due to the length of the radius formed by the distance between hip and foot, creating a large tangential velocity, and therefore a great impact value (Santos, 2003).

The high magnitudes of impact generated at the judokas wrist and ankle can be explained by the relatively small mass of these segments/limbs when compared with the region of the trunk and pelvis. Nussenzveig (1996) explains that body mass provides variations in time of contact between bodies, that is the greater the mass, the greater the deformation of bodies and the greater the contact time between them, which reduces the magnitude of impact forces generated. The lower magnitudes of impact suffered by the half heavyweight judoka category may be justified basically by three factors: the inverse relationship between the magnitude of impact and the mass of bodies involved in the collision; the decrease of throwing speed due to the large mass; the difference between fat-free mass and fat mass relationship in body composition of athletes, since the increase in % G facilitates the nonlinear damping of the shocks (Jarrah et al., 1997). Despite the magnitude of impacts were lower in the higher weight category judoka, the nonlinear impact attenuation effect promoted by adipose tissue does not necessarily means a positive factor, since, according to Jarrah et al. (1997), the vibration energy generated during these impacts starts to be dissipated in the joints and ligaments, causing damages over the years of exposure.

Another factor to consider is that heavier categories athletes are subject to larger forces and surcharges during falls, considering that the ground reaction force increases directly with the mass of the bodies involved in the collision, according to Nussenzveig (1996). The higher is the overload the higher is the injury risk, specially the acute ones, as bone fracture, damage to the ligaments, tendons and muscles (Nigg et al., 1995). All these factors relate to the importance of judokas physical readyness, training not only to improve performance, but also to prevent injuries resulting from impacts between the athlete and the mat. Overall, in all body regions the impacts attenuation is influenced by intrinsic and extrinsic factors, as the viscoelastic properties of muscles and bones, the degree of joints stiffness, the angular movement and positioning of body segments, the muscle contractions during the impact, as well as the type of floor where the impact occurs (Nigg et al., 1995). So, to be able to correctly analyze the relationship between body mass and the impact forces, is important to consider the participation of all dissipative elements at the time of the collision, as deformation of body tissues and mat.

Even though researchers suggest that the submission of the body to repeated impact forces can cause injuries (Voloshin et al., 1998; Voloshin et al., 1982; Voloshin and Wosk, 1982), there is no criterion to limit athlete's exposure to sports impacts. For this type of event (short term), the criterion developed by Macaulay (1987) can be used, which relates graphically the lengths of impacts (0.001 to 0.1 s) with the magnitudes of impacts (g). According to this criterion, the shorter the duration of impact, the higher acceleration body can stand. Therefore, considering that the greatest magnitude and duration time of impacts in judokas body occurred in the vertical direction, it can be stated that the impacts in this direction are the mainly responsible for the possible injuries that occur during falls in judo. The lowest values of impacts duration founded on the wrist and ankle occurred probably due to the great speed that the hand and foot hit the ground, resulting in a high separation speed between these limbs and the mat and, consequently, shorter impact duration. The highest values of impacts duration in the hip occurred probably because to the hip location, near to the body center of mass. According to Piucco and Santos (2010), the body mass increases the mat deformation during the collision of judoka, and therefore the contact time.

The results of this study indicate an increasing trend in the time duration of the impacts on the wrist according to the weight increase of the athletes. This result is justified by the increase in the duration of the impact according to the increase in body mass involved during the collision, as previously mentioned. In the hip this feature was observed only for the impacts on the x axis. In the ankle no trend was observed. It is likely that the small differences between the values of impact time (milliseconds) and the athlete's particularities during the "ukemi" accomplishment have influenced these results. Analyzing the results founded on the judokas wrist, according to the Macaulay (1987) criterion, for the half lightweight athlete, the values of the time duration of the impacts in the y and z-axes are within the short duration region (<0.01 s), and the x-axis in the intermediate duration region (between 0.01 and 0.1 s). Associated with the impact magnitudes, in the x-axis (106.96 g) and the y-axis (263.11 g), these values are in the severe injury risk area, and in the z-axis (59.02 g) these values are in the moderate injury risk area of the criterion. For the half middleweight athlete's category, the duration times of impacts in the x and z axes of the wrist were within the short duration region, and in the intermediate region in the y-axis. Considering the impacts magnitudes in the axis x (140.21 g) and the y-axis (351.94 g), these values are in the severe injury risk area, and the z-axis (75.99 g) in the moderate injury risk area.

For the half heavyweight category athlete, the impacts time duration on the wrist in all axes investigated are in the region of intermediate duration. Considering the magnitude of impacts, these values in the x-axis (36.36 g) and z-axis (42.70 g) represent risk of moderate injury, and in the y-axis (171.83 g) risk of severe injury. On the wrist, although the characteristics of impact support the increase of the injury risk in this region, there is no report about the shocks numbers and the time of rest necessary to avoid injuries. Some studies have reported some medical conditions such as hand-arm vibration syndrome, the carpal tunnel syndrome and tendinitis with exposure to periodic high-frequency vibrations (Starck and Pyykkö, 1986). Moreover, considerable amount of vibration energy generated in the hands can be transmitted by the arm to the head (Denisov and Sergeev, 1968; Dupuis and Zerlett, 1986), which increases the difficulty to understand the body damages resulting from a particular vibration, as well as to determine limits of tolerance. Other factors such as the upper limb tissue characteristics, the position adopted and the degree of muscle tension during the fall also influence the level of damage caused by transient vibrations (Mansfield, 2005; Griffin, 1998), and so, these factors should also be considered. In the hip region, for the half lightweight category athlete, the duration times of the impacts in all axes are in the region of intermediate duration, but the impact magnitudes are less than 13 g, meaning no injury risk according to the Macaulay criterion. For the half middleweight athlete, the duration of impact on the hip x and z-axes are in the chart intermediate-term region, while the y-axis values are in the region of long duration (> 0.1 s).

The magnitude of impacts in x and z-axes, associated with the impacts duration does not represent hip injury risk. However, in the y-axis, the values of impacts (13.5 g) and duration (0.58 s) represent moderate risk of injury in this region. For the half heavyweight athlete, the impacts time duration on the hip in all axes are in the region of intermediate duration, and the magnitude of impact varied from 5 to 13.5 g, which represents no injuries risk in this region. Although the Macaulay criterion indicates a lower risk of injury in the pelvic region resulting from the impacts generated during judo falls, Mertz (1993) argues that due to the high concentration of internal organs in this region, the tolerance rate of force application on the pelvis to cause injury is more sensitive to short impacts pulses. Santos et al. (2005) indicate that the ground reaction forces (N) are higher in the hip during the judokas fall, reaching 6.9 times their body weight. Data founded in the literature showed that the 10th percentile for moderate injury in the pelvis is 0.22 kN, the 50th percentile is 2.6 kN and the 90th percentile is 6.7 kN (Zong and Lam, 2002). Considering that the judoka investigated by Santos et al. (2005) weighed 647.46 N, and that the athlete's center of mass is located on the hip at the fall moment, this athlete suffered 4.46 kN of force in the pelvis region during the impact with the mat, exceeding the values that represent the 50th percentile of moderate injuries risks for this region.

In the ankle region, the half lightweight athlete category had values of the impacts time duration referent to the short term Macaulay chart region on the x and z-axes, and for the y-axis these values are in the region of intermediate duration. Linking these values to impact magnitudes values, these numbers indicate risk of severe injury on the x axis (204.88 g) and the y-axis (214.48 g), and risk of moderate injury for the z-axis (123.58 g). For the half middleweight athlete, the impacts time duration on the ankle on the x-axis are in a short duration region, and the y and z-axes in the intermediate duration region. Magnitudes of impacts associated with these values in the x-axis (76.09 g) represent moderate risk of injury and in the y-axis (242.88 g) and z-axis (101.97 g) risk of severe injury. The half heavyweight athlete had values of impact duration in the ankle classified as short duration/term to the axes x and z and medium duration to the axis y. These values, associated with the magnitude of impacts in the x axis (69.81 g) and z axis (86.64 g) are in the moderate injury risk area, whereas the values in y-axis (232.74 g) represent severe injury risk. As in wrist, although the characteristics of the impacts generated in the judokas ankle represent a high risk of injury, no other factors likely to influence the involvement of injury resulting from impact loads was found in the literature, for example the impacts number and the time between them, the body position adopted on impact and the distribution of tissues in the region of impact.

In judo, the correct final position adopted during the “ukemi” is with the knees bent about 90°, as shown in Figure 2. The dangerous frequency range for this joint decreases from 20 Hz for extended knee to 2 Hz for the bent knee (Rasmussen, 1982), which shows the influence of body position adopted during the fall in the increase of judo injuries risk. It is therefore important that teachers emphasize the proper execution of “ukemi”, especially for amateur judokas, in order to mitigate the damage caused by transitory vibrations in the judoka body.

Despite Macaulay criterion being the only one that can be used to refer the transitory vibrations, characteristics of the impact in sports, this criterion does not cite the number of impacts, the exposure time or the interval between repetitions of the same which are minima for no injuries. According to Radin et al. (1998), the smaller the duration of impacts, the greater are the magnitudes that the body can bear, and that only the random impacts are not sufficient for the onset of damage, but the continuous application of these impacts in the body. Therefore, without the control of these variables it is not possible to infer about the biomaterials self-healing capacity considering the load characteristics and the fatigue process, arising from falls in judo. The onset of fatigue and the application of excessive loads decrease the cellular synthesis in joint cartilage and increase the tissues degradation, causing common deterioration due to overuse that follow the accentuate practice of exercise (Vazan, 1983). Therefore, the deleterious effects to the judokas body caused by impact loads over time practice are evident, considering the high number of falls that athletes perform in competitions and especially training. While there are no satisfactory answers and further study to formulate a limit criterion of transient vibration body exposure, Mansfield and Griffin (2000) reaffirm that the reduction of deleterious effects caused by the human body vibration can be obtained by reducing the movement magnitude that causes the vibration.

In judo, despite being impracticable to reduce the magnitude of the motion projection during training and competitions, the correct execution of the art projection and damping of fall and the use of properly prepared site (flexible base under the mat) may reduce the magnitudes of impacts and vibrations caused by the body of judo, mitigating the adverse effects on the body of judokas.

Conclusions

Considering the results found in this study and understanding the limitations, as well as answering the problems subject, it can be stated that judokas of different categories are often exposed to impact of high magnitude and short in time duration. The impacts characteristics, especially in vertical axis represent a severe injury risk in the judokas wrist and ankle, and moderate injury risk in the hip of the athletes. Since the high concentration of internal organs in the hip increases the risk of damage to this site, and those impacts generated in the body of judokas over years of practice can cause serious damage to the body, it is recommended to the sport practitioners to apply some preventative initiatives in terms of training intensity, number and technical quality of the falls taken and the type of mat used.

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