Preprint of:
Soltoggio, Andrea, et al. "The Aikido inspiration to safety and efficiency: an investigation on forward roll impact forces." Proceedings of the 10th International Symposium on Computer Science in Sports (ISCSS). Springer International Publishing, 2016.

The Aikido inspiration to safety and efficiency: an investigation on forward roll impact forces

Andrea Soltoggio[1], Bettina Bläsing[2], Alessandro Moscatelli[3], and Thomas Schack[2]

[1] Computer Science Department, Loughborough University, Loughborough, UK
[2] Neurocognition and Action Research Group, Bielefeld University, Bielefeld, Germany
[3] Cognitive Neuroscience, Bielefeld University, Bielefeld, Germany

Abstract. Aikido is a Japanese martial art inspired by harmony and intelligent exploitation of human body movements, a consequence of which is believed to be a minimisation of impacts. This study measures the effectiveness of aikido-specific movements to minimise impact forces, and arguably the risk of injuries, in person-to-floor contact. In one experiment, we measured a significant reduction of impact forces with the ground for aikido experts during a forward roll in comparison to untrained participants. This first initial result encourages further studies of aikido techniques in areas such as safety and efficacy in sport exercise, safety during full body motion involving falls and impacts, transfer to human-robot interaction and training of elderly people.

1 Introduction

The aikido philosophy and practice teach harmony and the understanding of human movements to induce unity and agreement between the practitioner and his/her surroundings, including a partner [13, 10, 11]. The techniques studied in aikido allow for an intelligent reaction to the different attacks performed by the partner. Aikido techniques aim not only to neutralise the attack, but also to restore equilibrium and harmony between the athlete attacking (*uke*) and the one reacting (*tori*). As described in [6], aikido "transforms aggression into cooperation": an idea that has seen aikido being the subject of a number of sociological studies [7, 4] looking at mediation and conflict resolution.

Aikido concepts like *harmony*, *unity*, and *agreement*, in the sense of a continuous dialog with the movement of the partner to manage his/her action force, suggest a collaborative and intelligent attitude in the resolution of potentially dangerous dynamic movements. Frequent approaches to resolve impact conditions are based on strength, a way to further disrupt harmony and unity, and thus are to be avoided in aikido. An intelligent resolution of dynamic conflictual conditions, on the other hand, involves early understanding of the nature of the movement, and the application of techniques that mitigate the risk or intensity of the impact. This "intelligent attitude" is often refined to the highest technical and philosophical standards by the highest ranking aikido masters. The

effectiveness of a large spectrum of ideas, philosophy and practice, when they converge to result in the minimisation of impact forces, could be evaluated in relatively narrow but measurable way, i.e. by means of precise measurements of impact forces, which is what we aim in this study.

In aikido, when a person experiences a fall, the ground is seen as a partner, not to be avoided or aggressively confronted, but rather to be met with what can be defined as "friendly" reactions and movements. The initial conditions that determine a fall have to be detected as early as possible to prepare for an appropriate response. Such a response involves the execution of precise and technical movements by the aikido practitioners, resulting in a well executed *ukemi*. In most cases, a fall can be converted into a low-impact sequence of movements resulting in a forward or backwards roll.

Most aikido schools put considerable emphasis and technical detail in the execution of *ukemi*. In this study, we refer to the school of Katsuaki Asai Sensei, a Japanise aikidoka who trained directly with the founder of aikido, Morihei Ueshiba between 1955 and 1965 [2]. Figure 1 is a sequence of photos taken from a video of Asai Sensei performing a forward roll. It can be noticed that the contour

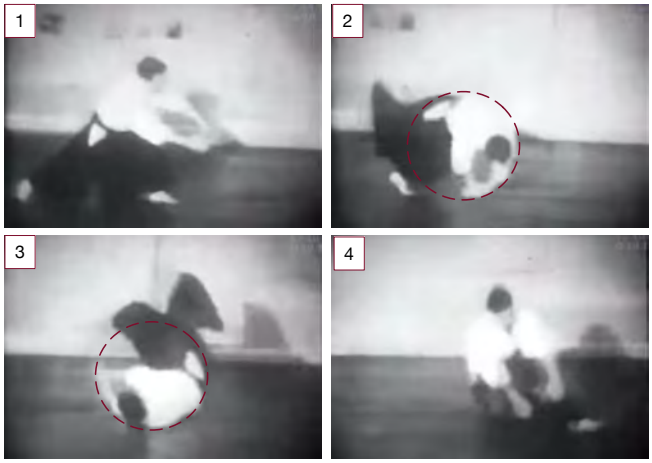

Fig. 1. Katsuaki Asai Sensei performing a forward roll [1]. In the snapshot 2 and 3, a dashed circle is added to indicate the circular shape of the body that facilitates smooth low-impact ground contact.

of the body assumes a circular form during the execution of the roll (sequence 2 and 3), as outlined by the overlying dashed circle. The full sequence in the video conveys a natural, smooth and low-impact sequence of movements. Asai Sensei, who founded Aikikai Deutschland when he moved to Germany in 1965, taught instructor Thomas Gertz, third Dan, who provided technical support and demonstrations to conduct this study.

2 Method

A force sensor integrated with the floor, measuring 90x90cm, was used to measure horizontal and vertical forces that participants exerted on the ground when performing a forward roll. Additionally, video cameras and a Vicon system of 12 infrared cameras (for tracking position of body parts in 3D space) were employed to capture additional data for a subset of participants. Figure 2 illustrates the setup.

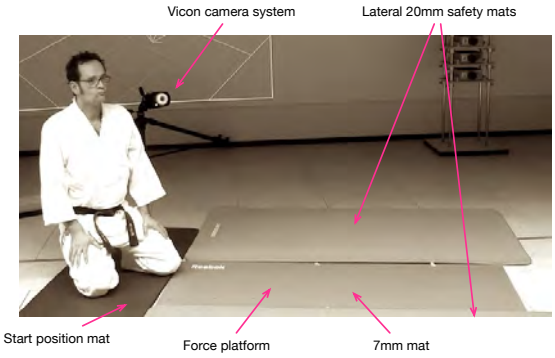

Fig. 2. Experimental setup. A force platform is incorporated at floor level (here hidden under a protective foam mat of 7mm). Thicker safety mats (2cm) are placed around the platform to protect participants. The Vicon system was used to track positions of some key body elements, but due to occlusions and unreliability of the tracking was not used for the analysis. Instructor Thomas Gertz is showing the initial position of the movement.

The forward roll is a dynamic body-to-floor contact movement that may approximate a gentle type of fall. A realistic type of fall would involve an initial standing position, although not necessary completely upright, as in the example of Figure 1. Unfortunately, this movement, although it appears natural and simple when performed by an expert, cannot be safely tested on untrained participants without risking injuries. For both pedagogic and safety reasons, instructor Gertz teaches a range of increasingly challenging rolling movements, involving starting positions from completely crouched on the ground, to kneeling and half standing. In this way, beginners can start practicing rolls from a low and safe position. Experts may also perform rolls from low positions to refine their technique with slow and precise movements. Preliminary tests revealed that rolling from a kneeling position (starting position as in Figure 2), and using a 7mm foam mat to cover the force sensor on the ground, was a sufficiently safe movement if performed under the supervision of an expert.

The precise movement, performed by instructor Gertz, was video recorded and demonstrated to participants who were asked to perform the same move-

ment. Figure 3 shows a sequence of photos during the demonstrated forward roll. Interestingly, rolling froward from a kneeling position can be hardly seen as an

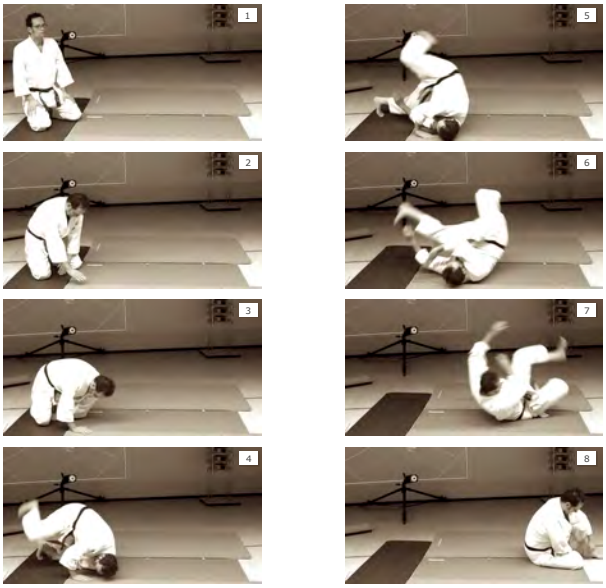

Fig. 3. Instructor Thomas Gertz, third Dan Aikikai Deutschland, demonstrates a forward roll from a low kneeling position. The movement starts from a static position with both feet and knees on the ground. The movement can be performed in two symmetrically equivalent variations: lowering at first either the left or the right arm/shoulder. Impact forces are registered and measured during phases 4 to 7.

impact-inducing movement. However, as the results will reveal, even such a low height movement can be challenging for untrained participants.

Participants. The experiment involved N=7 trained participants with 6 months to 10+ years of regular aikido training. Additionally, untrained participants (N=11, 6 males, 5 females) with no previous experience in aikido were tested. Nine out of the 11 untrained subjects performed regularly other sports, and all were selected among healthy subjects capable of performing basic physical exercise.

Procedure. Each participant was demonstrated the movement in Figure 3 and invited to observe it in order to reproduce it. In particular, the participants were instructed to following these steps: 1) assume the correct initial position; 2) lower one shoulder (either left or right) towards the ground to prepare the roll; 3) engage in the dynamic movement trying to reach a static position as in phase 8 of

Figure 3. After the explanation, the participants had the opportunity to practice a few times, under the supervision of one expert, until he or she felt comfortable and capable of executing the sequence of movements correctly. Because the goal of the movement was that of performing a roll within the measuring area (Figure 2) and of ending the roll as in Figure 3 (phase 8), participants practiced until they could reach that objective, taking between 2 to 6 preparatory rolls.

Measurements. After the practice rolls, each participant had four rolls recorded, two starting by lowering the left shoulder, and two starting with lowering the right shoulder. Finally, the static vertical force (i.e. equivalent to the weight) was measured for each participant in order to compute the ratio of dynamic over static vertical forces.

3 Results

Figure 4 shows the impact forces recorded by the force platform during rolls performed by two participants with 3 and 10 years of aikido experience (panels A and C respectively), and two participants with no previous training (panels B and D). There appears to be little difference between trained subjects (panels A and C) despite difference in history and years of training. Untrained subjects instead appear to have high peaks of vertical forces. We applied a Linear Mixed Model (LMM) [3] to test for the difference in the force ratio between trained and untrained participants (Figure 5). Mixed models distinguishes between *fixed-effect* predictors accounting for the effect of the experimental variable (i.e., years or practice) and *random-effect* predictors accounting for idiosyncratic differences between participants. We applied the following model:

$$\boldsymbol{y}|\boldsymbol{b} = b \sim \boldsymbol{X}\beta + \boldsymbol{Z}\boldsymbol{b} + \boldsymbol{\epsilon}, \tag{1}$$

Where $\boldsymbol{y}|\boldsymbol{b} = b$ is the force ratio in participant b, $\boldsymbol{X}$ is the years of aikido practice, $\boldsymbol{Z}\boldsymbol{b}$ is the random-effect predictor and ϵ is the error term. The estimated coefficient β was -0.1 ± 0.01 ($\beta\pm$ Standard Error), which means that the force ratio decreases on average of 0.1 unit per year of practice. The effect of year of practice was statistically significant (Likelihood Ratio Test, $p < 0.001$).

We also tested an alternative LMM where the level of expertise was coded as a categorical predictor. Participants were divided into two groups, non-expert (less than two years of practice) and expert (two years of practice or more). The effect of group was statistically significant ($p < 0.001$) confirming that practice of aikido significantly reduce the contact force during rolling.

In two cases, untrained subjects recorded forces higher than 3.5 times their body weights, a surprising factor considering that the movement starting position (Figure 3) is at a low height, with both knees on the ground. Given such high impact forces registered by untrained subjects, it was decided that a roll starting from a higher position of the body centre of mass could not be safely performed by untrained subjects. Nevertheless, it was deemed interesting to compare the

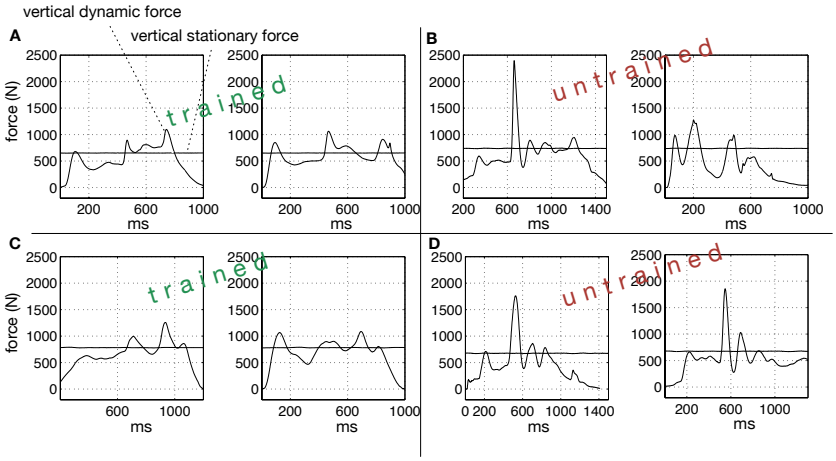

Fig. 4. Impact forces measured during rolls performed by two trained participants (one expert, one intermediate), and two untrained participants. The vertical force is reported on the vertical axis, time in ms is on the horizontal axis. Each panel (ABCD) shows two rolls for one participant initiating the roll with the left arm (left graph) and with the right arm (right graph). (A) Expert participant's rolls (3 years of aikido practice). (B) Untrained participant's roll. (C) Expert participant's roll (10 years of aikido practice). (D) Untrained participant's roll.

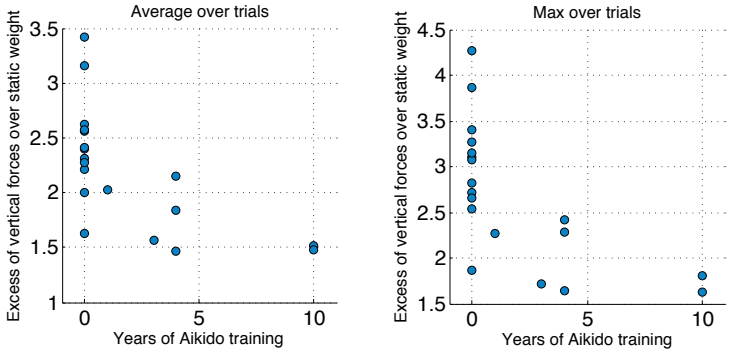

Fig. 5. Ratio of dynamic forces over stationary forces for all subjects taking part in the experiment plotted against the aikido experience (in number of years).

previous data with a sample of measurements involving a roll movement from a standing position, i.e. reproducing the movement in Figure 1, performed exclusively by trained subjects. Figure 6 shows two rolls from a standing position

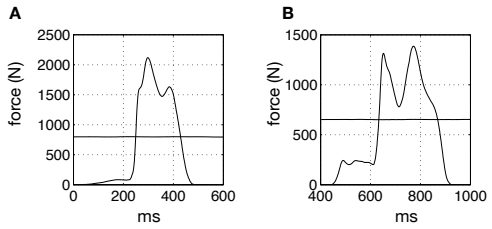

Fig. 6. Vertical forces during two rolls (performed by two different subjects) from a standing starting position. Compared to rolls from a low height (Figure 4, which had a duration of approximately 800ms, these movements from standing have a duration of 200 to 300ms, i.e. there are executed at approximately 3 times the speed of the low-height rolls. Trained subjects are nevertheless capable of minimising impact forces in this case as well, resulting in impact forces to weight ratio that are still lower than those recorded by untrained subjects starting from a ground position.

performed by experts with 3 and 4 years of aikido practice. The peaks of forces are in these cases lower than those registered by untrained subjects when rolling from a kneeling position. In other words, for a trained subject, falling from a standing position, and transforming the fall into a roll, measures less impact forces than for the average person rolling over starting already from the ground.

4 Discussion

In this study, we measured ground impact forces during forward rolls performed by aikido experts and amateurs as well as novices. We found that peak impact forces in the group of novices was higher than in the group of aikido-experienced participants. Furthermore, the variance of peak vertical forces was smaller in the group of aikido practitioners, suggesting that the movement was performed more homogeneously over trials by this group than by the novice participants.

It has to be stated that this pilot study with seven aikido practitioners of different expertise level (two experts with 10 years of training, five amateurs practicing on intermediate level, 1 to 4 years) and eleven novices does not have the potential to provide a full picture regarding force compliance in aikido rolling techniques. However, as this is the first study of this kind, we are presenting substantial evidence that aikido techniques seem to reduce impact forces during a simple roll movement. The results of this preliminary study need further substan-

tiation on the basis of measuring impact forces from participants of different expertise level performing different rolling techniques (e.g., from different starting positions). Looking at individual participants' data, large differences, particular among untrained participants, were observed. A venue of future research should be to improve our understanding on why some participants recorded very high impact forces (thereby being more likely to be injured) while others recorded rather low impact forces.

In this study, the use of the Vicon system was intended to further analyse the precise dynamics of each roll, which is instrumental to gather more insights on the precise techniques and differences among participants. As markers were often occluded or lost during the rolls, future studies should employ flatter or softer markers, securely attached, and with a high number of cameras. This will enable a technical or pedagogical description of the movement, e.g. as 3D reconstruction of the rolls that minimise impact forces.

Results of our study clearly point at the potential of aikido training to reduce ground impact forces during rolling, a topic that certainly deserves further investigation. Our findings promise to be relevant not only for martial arts training, they also bear high relevance for sports training in general and for all contexts in which the reduction of ground impact forces is desirable and important for reasons of security, to reduce injury and damage. Learning to fall or roll smoothly with low impact can be a protective measure in many sports (e.g., [8]) as well as in everyday situations, particularly for the elderly. [12] showed that even after a short martial arts fall training of 30 minutes, young adults without experience of martial arts training were able to reduce hip impact forces and velocities in martial arts falls from a reduced height (kneeling), and [5] achieved comparable results with elder adults (60-80 years) after five training sessions. Finally, similar strategies are relevant to bipedal humanoid robotics, particularly in robot soccer or other real-world applications, as minimizing impact forces from falls is crucial to maintain the robots functional in situations in which falls cannot be avoided [9].

4.1 Conclusion

This study analyses one particular full body rolling movement performed by both aikido experts and untrained participants. Employing a force platform that measures impact forces with the ground, it was possible to measure a significant difference of impact forces between aikido experts and untrained participants. The study contributes to validate the hypothesis that aikido movements seek low impact dynamics. Not only are impact forces reduced when aikido techniques are applied, but arguably, the movement is performed in a more efficient way, reducing the energy dissipated on the ground by impact forces. The results also suggest that aikido techniques to control falls could be beneficial to reduce the risk of injury for particular participants, e.g. in particular sports, or for elderly people that are more prone to falls.

References

1. Asai, K.: Youtube: Katsuaki Asai Allemagne [last checked june 2015] (1970), https://youtu.be/r8OCfEn77Ts
2. Asai, K.: Interview with Katsuaki Asai [last checked june 2015] (1993), http://www.aikidojournal.com/article?articleID=309
3. Bates, D., Mächler, M., Bolker, B., Walker, S.: Fitting linear mixed-effects models using lme4. arXiv preprint arXiv:1406.5823 pp. 1–51 (2014)
4. Edelman, A.J.: The implementation of a video-enhanced aikido-based school violence prevention training program to reduce disruptive and assaultive behaviors among severely emotionally disturbed adolescents. (1994)
5. 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), 215–221 (2010)
6. Kroll, B.: Arguing with adversaries: Aikido, rhetoric, and the art of peace. College Composition and Communication pp. 451–472 (2008)
7. Saposnek, D.T.: Aikido: A systems model for maneuvering in mediation. Mediation Quarterly 1987(14-15), 119–136 (1986)
8. Shuman, K.M., Meyers, M.C.: Skateboarding injuries: An updated review. The Physician and Sportsmedicine (0), 1–7 (2015)
9. Ruiz-del Solar, J., Moya, J., Parra-Tsunekawa, I.: Fall detection and management in biped humanoid robots. In: Robotics and Automation (ICRA), 2010 IEEE International Conference on. pp. 3323–3328. IEEE (2010)
10. Ueshiba, K., Ueshiba, M., Stevens, J.: Best aikido: the fundamentals. Kodansha (2002)
11. Ueshiba, M.: The art of peace. Shambhala Publications (2002)
12. Weerdesteyn, V., Groen, B., van Swigchem, R., Duysens, J.: Martial arts fall techniques reduce hip impact forces in naive subjects after a brief period of training. Journal of Electromyography and Kinesiology 18(2), 235–242 (2008)
13. Westbrook, A., Ratti, O.: Aikido and the dynamic sphere: An illustrated introduction. Tuttle Publishing (2001)