ORIGINAL ARTICLE

The use of augmented-reality technology to improve judo techniques. Premises, assumptions, methodology, research tools, preliminary scenarios – the first stage of the study

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 02 October 2016; **Accepted:** 07 November 2016; **Published online:** 31 December 2016

AoBID: 11351

Abstract

Background & Study Aim: Sport, professionally and for all, is an area of both the application of modern technology, and to create new ones. The premises of such a statement is to protect health (all practitioners sport) and to achieve optimal sport results first of all by top athletes. In judo, like in each combat sports, motoric actions are cumulative directly on the body of an athlete during a specific exercise (*kata*, *uchi komi* etc.), training fights (*randori*) and the tournaments ones. The aim of this work are the most important premises based on the analysis of the available technology, augmented reality (AR) in relation to the expectations of adaptive judo athletes (under the scientific knowledge about the determinants of success) and assumptions construction of research tools and training, including initial scenarios.

Material & Methods: We use the design method and the Delphi method involving the science of martial arts experts' (2 professors sport science and at the same time judo coaches master class, 1 professor management science and judo coach first class, 1 PhD and three times of Judo Word Champion, 1 PhD and Karate World Champion). In our opinion, an essential value of the project are not only the methods but also the selection of experts (all of the scientific qualifications and experience of the practice of combat sports). The selection of only those people who possess abilities to perform scientific analysis of a studied phenomenon has been a very essential criterion from methodological perspective.

Results: All the experts agreed that the essence of judo sport is to maintain a vertical posture and break the balance competitor. Only such a result makes it possible to continue the fight in the horizontal posture. However, these two general principles does not mean that they are fighting techniques of judo to ensure reliability.

Conclusion: Therefore design methodology of teaching and perfecting judo techniques using AR cannot ignore these rules.

Key words: Delphi method • design method • randori • tachi waza • tandoku rensiu

Conflict of interest: The authors of this study declare that they have no conflicts of interest

Ethical approval: Not required

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: This paper was supported by the Ministry of Science and Higher Education, and 2015-2017 at the AZS-AWF Wroclaw Sports Club and applications related to Augmented Reality in judo (prototyping an educational trainer), grant numbers: 0011/RS3/2015/53.

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Introduction

Sport, professionally and for all, is an area of both the application of modern technology, and to create new ones. The premises of such a statement is to protect health (all practitioners sport) and to achieve optimal sport results first of all by top athletes. In judo, like in each combat sports, motoric actions are cumulative directly on the body of an athlete during a specific exercise (*kata*, *uchi komi* etc.), training fights (*randori*) and the tournaments ones [1-6].

The innovative nature of this issue encourages us to overcome formal rules for editing original articles in the field of empirical science. In this article there are no boundaries between formal sections "Results" and "Discussion". Because of the innovation of the subject matter, there is no place in this article for perceptual sentences, which should form the "Results" section (obviously along with tables, figures and other graphical forms showing empirical data). Therefore, an elementary and strictly methodological question emerges – what should be discussed?

No measurements have been taken at this stage of our research project. On the other hand, references and comments to previous study results corresponding with issues discussed here are completely different in purely methodological sense. The results of our theoretical studies include in particular: premises, assumptions, basic methodology (specifics of study design), models of research tools and preliminary scenarios. Thus, the rationale for each of these results stems from synthesis of previous theoretical and empirical knowledge of even most distant fields. Such cognitive effects and innovative application opportunities open secondary complementary studies still underestimated in scientific methodology which are associated with designing new applications of general importance, that is for the common good. While taking such approach, it is obvious that synthesis of results of carefully performed secondary studies serves methodological functions of arguments provided in *Discussion* section in original articles (and partially in *Introduction* as well).

Such approach is promoted in methodological articles whose authors have already overcome these barriers [7-10] and, above all, opened new perspective on the applications of methods from various fields of knowledge and practice related to broadly understood health science and security science. This wide cognitive and application perspective highlights the fact that sport science as a whole and science of martial arts as new subdiscipline very close to sport science as well as a number of other specialized sciences, even from most distant fields of study, and practical experience obtained in numerous branches of activity are necessary "tools" (in a very broad, methodological understanding of this term) used to carry out the mission of sport in the field of health and security – both individual and human *an bloc* one.

The overall aim of this article is implicated by this most general, preliminary synthesis of knowledge about relationship between judo and mission of sport as a whole with health and with security (from the perspective of the need for survival of both individuals and the entire human population) and the fact that modern technology is expanding. In spite of appearances, sport success is a secondary issue. Sports career at the highest level (Olympic, World Cup and continental championship) is limited individually to a few or several years. Judo as a "sport of life" is one of the few methods and at the same time an attractive offer to optimally develop and maintain health in all its dimensions (somatic, mental, social), along with survival ability. In this broad perspective related to health and survival ability, judo can be perceived as general good which does not prevent anyone from achieving sport successes at certain stage of life which correspond to their own talent.

The aim of this article are the most important premises based on analysis of the available technology, augmented reality (AR) in relation to

Atemi-waza – striking techniques: u**de-waza (arm strikes):** *ago-oshi* (jaw push); *ryogan-tsuki* (strike to both eyes); *suri-age* (forehead thrust); tsuki-kake (punch); *tsukiage* (uppercut); *yoko-uchi* (side blow); name-uchi (slanting strike); *kirioroshi* (downward cut); *ushiro-dori* (hold from behind); *ushiro-ate* (rear strike) and **ashi-ate (leg strikes)**: *ryote-dori* (two hand hold); *gyakute-dori* (reverse two hand hold); *keage* (kick); *mae-geri* (front kick); *ushiro-geri* (rear kick); *yoko-geri* (side kick); *ashi-fumi* (foot stamp).

Dan (dan'i) – a term used to denote one's technical level or grade. In *jūdō*, the "*dan*" ranks start at shodan (1- *dan*) and go up to the highest grade of *jūdan* (10- *dan*) [5].

The Delphi method (Delphi technique) – a method of group decision-making and forecasting that involves successively collating the judgments of experts [11].

Frame rate – also known as **frame frequency**, is the frequency (rate) at which an imaging device displays consecutive images called frames. Frame rate is usually expressed in *frames per second* (FPS) or *hertz*.

Gokyo – **t**he collective name for the officially recognised throwing techniques of the Kodokan [34].

Imitation training consists of three parts: (1) the teacher demonstrates what behaviour the learner is to engage in (called the imitative stimulus; (2) the learner is called on to produce a similar behaviour Called the imitative behaviours; and (3) the teacher arranges for some type of reinforcement for the imitative behaviour. The imitative stimulus is an SD for the imitative behaviour [72].

"Innovative throws" – are all throwing techniques that keep alive the formal aspect of classic judo throws, and differ in terms of grips and final direction of applied forces only [72].

Judo ichidai – a judo life (spending one's life in the diligent pursuit of judo) [34].

Jū-no-kata – This *kata* is studied by *jūdō* practitioners, and is designed to teach fundamental principles of attack and defence [5].

Kake – **c**ompletion or execution of technique [34].

the expectations of adaptive judo athletes (on the basis of the scientific knowledge about the determinants of success) and assumptions related to establishment of research tools and training, including initial scenarios.

The cognitive aim of the entire project is to verify the hypothesis that application of AR in relevant period (stage) and training cycle may improve the effectiveness of improving judo techniques, whereas the application goal focuses on the prototype of educational judo trainer (with possible extension of implementations) with the use of AR.

Material and methods

Participants and Delphi method

The Delphi method [8, 11] involving the science of martial arts experts' (2 professors sport science and at the same time judo coaches master class, 1 professor management science and judo coach first class, 1 PhD and three times of Judo Word Champion, 1 PhD and Karate World Champion). In our opinion, an essential value of the project are not only the methods but also the selection of experts (all of the scientific qualifications and experience of the practice of combat sports). The selection of only those people who possess abilities to perform scientific analysis of a studied phenomenon has been a very essential criterion from methodological perspective.

Components of designing method

The specificity of the issue is reflected in the structure of the paper the designing methods are discussed in all parts of the paper (and project). In the *Introduction* some space has been given to the main information enabling '(a) reconstruction of the practical situation [12]', whereas the *Results* and *Conclusion* provide some complementary statements. The *Results* discusses the subsequent part of the designing procedure i.e.'(b) the formulation of the hypotheses to overcome this situation [12]'. In other words, it provides the description of methodology (main premises, assumption, operational objectives, detailed scenarios) and pre-testing during the second stage of this project. The final part of designing procedure i.e. '(c) the verification of the hypothesis' [12] is a subject of research during the third and fourth stages of this project.

Design of four-stage studies

The first stage was determined as the aim of this article, while the interference of augmented reality (AR) was limited to judo techniques in vertical position (*tachi waza*). The second stage involved designing and developing a software used to pre-testing of the reference values adopted within detailed methodologies and scenarios. The third stage included testing of the prototype software for selected sports groups (beginners, advanced, masters, etc.). The fourth stage, in turn, consisted in the performance of an experiment (according to the principle of separation of "twin pairs") with participation of judo athletes whose training is supported by the AR and the "twins" whose trainings involve traditional methods.

Results

Main premises: the term "techniques" in praxeology, agonology, sport science, judo

The term "techniques" is ambiguous. In praxeology (science about good work), general definition of techniques is as follows: "temporal (t), local (r) and material (x, y) transformation of something (x) into something (y), in general: $x(t_1, r_1) \rightarrow y(t_2, r_2)$, whereas: $x = y$, $t_1 \geq t_2$, $r_1 = r_2$ are acceptable". J. Zieleniewski in general believes that these are "ways more detailed than methods", whereas definition provided by E. Girardou in 1955 is as follows: "techniques are methods which consist of a set of rules and procedures established in a rational manner and confirmed empirically, whose aim is to achieve the goal" [13, p.245]. According to J. Groszkowski (in one of three meanings of the term "techniques", being most related to praxeology), techniques "involve the entirety of resources and skills which allow us to perform one of the actions falling within the scope of human activity" [14].

In agonology (science about struggle), technique of struggle in a broad sense is a set of rules, directives, tricks, grasps, principles, postulates and methods applicable during a fight [15].

According to Z. Ważny, sports technique is a method of performing a motor task specified in the rules of given sports discipline which depends on particular athletes' somatic, motor and psychic properties [16]. The term technique is shortly defined also in the popular *Dictionary of Sport and Exercise Science*: "*noun* a way of performing an action" [17 p. 206]. Broader definition is provided by R. Martens: "specific procedures to move one›s body to perform the task that needs to be accomplished" [18].

Kakkari-geiko – attack practice in which the attacker unleashes a barrage of techniques to develop technical skill, stamina, and fighting spirit [5].

Kata – predetermined and choreographed physical exercises, which together with free exercises (randori), lectures (kōgi) and discussions (mondō) form the four critical pillars of Kōdōkan jūdō educatinn [36].

Katsu – the art of resuscitation used in *jūdō* [5].

Koshiki-no-kata – "Antique forms". *Jūjitsu* techniques from thr Kitō-ryū were incorporated into the *koshiki-nokata* by Kanō Jigorō to preserve the essence of classical schools [5].

Kuzushi – unbalancing the opponent judo's "softness subdues hardness" creed is demonstrated in the act of a small-statured contestant using a larger opponent's own power to throw him. This is one of judo's attractions, and is no small feat. The execution of such a manoeuvre relies on "kuzushi" (balance breaking) [34].

Link trainer of judo – first part of the term "link trainer" is borrowed from the vocabulary of the airline industry, but in this application it means a special device which enables learning and training of skills (particular judo techniques) in artificial conditions.

Motor safety is consciousness of the person undertaking to solve a motor task or consciousness the subject who has the right to encourage and even enforce from this person that would perform the motor activity, who is able to do it without the risk of the loss of life, injuries or other adverse health effects [71].

Nage no kata – forms of throwing [34].

Ne-waza (prone techniques), a related concept is that of **katame-waza** (grappling techniques) – judo techniques executed from a horizontal posture: *osaekomi-waza* (pinning techniques), *shime-waza* (strangle technique), *kansetsu-waza* (joint holds).

Perceptual sentence – in the methodological meaning is constative utterance the result of some observation (result of the measurement) [9].

Randori – sparring in judo in which both participants practice attacking and defending [5].

Safe fall technique – a method to control the body while it is losing the balance to provide effective shock absorption during collision with the ground or maximal minimization of potential injuries [54].

Shadow boxing – *noun* a form of training for boxing in which there is no opponent, with the boxer's own shadow on the wall used for reference [17].

Tachi-waza – judo throwing techniques executed from a standing position. These include *te-waza* (hand techniques), *koshi-waza* (hip techniques), and *ashi-waza* (foot and leg techniques) [23], including also sub classification *sutemi-waza* (rear-fall and side-fall judo throws; synonym – "dedication throws").

Tai-sabaki – (body shifting/body control) refers to the manner in which a contestant changes his body position and orientation when executing or receiving a waza: **mae-sabaki**" (front movement control), in which the contestant steps forward to place one foot immediately in front of the opponent's foot, with body at right angles to the opponent; **ushiro-sabaki** (back movement control), in which the contestant steps back with one foot, distancing it from the opponent's foot, with body at right angles to the opponent; **mae-mawari-sabaki** (front turn movement control), in which the contestant steps forward with one foot and spins around in front of the opponent with back to the opponent; **ushiro-mawari-sabaki** (back turn movement control), in which the contestant pulls the opponent forward while stepping back with one foot, then spins around in front of the opponent with back to the opponent [34].

Tandoku renshu – is the official name of the Kodokan for practicing movements without a partner, these method was developed by Jigoro Kano.

Tokui waza – favourite or best technique [34].

Tsukuri – **e**ntry into a technique, positioning [34].

In Japanese the word "*waza*" means "technique" [5]. In the terminology of judo, *waza* in numerous expressions informs mainly about the particular group of sports techniques typical for the practice of judo. However, from the perspective of the science about struggle (agonology), the term *waza* may be understood in a broad sense. For example, *kaeshi waza* (counter techniques – see glossary) involves not only repeating "motor responses" to a particular offensive techniques of the opponent. A cognitive aspect, i.e. the need to activate intellectual and emotional sphere (gaining confidence and reducing anxiety) becomes also important here. It is no wonder that coaching practice and scientific publications refer to terms such as "technical-tactical preparation" [19], "technical-tactical profile" [20] or "technical-tactical behaviour" [21].

Main premises: multi-dimensional judo motor activity in basic relation to intellectual, ethical and health development

In common global perception, judo is associated with the Olympic sports discipline and with the first Olympic combat sport of Asian origin (1964, officially from 1972). In symbolic dimension, the term "judo" is most recognisable (Figure 1) [22]. Whereas judo established in the nineteenth century by Jigoro Kano meant mainly a coherent system of physical, moral and health education [1].

In physical (motor) aspect, judo is a set of techniques of hand-to-hand fighting based on soft and relatively soft means divided according to the position in which they are used, namely vertical posture (*tachi waza*) [23] and horizontal posture (*ne waza*) [24]. Motor safety (health aspect) of judo practitioners during formal exercises (*kata*) and fighting's (*randori*) are to be ensured by safe fall techniques (*ukemi waza*) supported by specific preparative body movement (*tai sabaki*) – especially turnover of the body.

Judo fight (as a particular example of combat sports) begins in vertical position (*tachi waza*), and may end before the fight time in vertical position, if one of judo athletes performs throw in a manner classified by at least two of three referees as *ippon*. If a throw (particular nage *waza*) is not classified as *ippon*, the fight may be continued and completed in horizontal position (*ne waza*).

Judo competition shares a dimension of a martial art. Its essence is to present judo techniques (*kata)* and as befits the art both the roles (in this case who is *tori* and who is uke) and the programme of motor actions along with the ceremony are known "before the spectacle". The quality in which this programme will be performed remains the unknown. Visual effect is the primary criterion for expert judgment.

Contemporary judo therefore includes two categories of sports competition: combat sport and shows. These two categories are distinguished in five-element adequate division of sports disciplines of Z. Naglak [25, p. 11]: games (e.g. chess); games with a ball or a puck, etc. (e.g. soccer); shows (e.g. figure skating); direct confrontation (combat sports); races (e.g. giant slalom). According to this distinction, "direct confrontation" is in fact a synonym of "combat sports". Its author determined the relationship (their hierarchy) between elements of acting skills in respect to the specificity of sports discipline. In the case of direct confrontation (combat sports), this hierarchy is as follows: perceptive, cognitive, motor, open motor habit. In turn, in the case of shows it

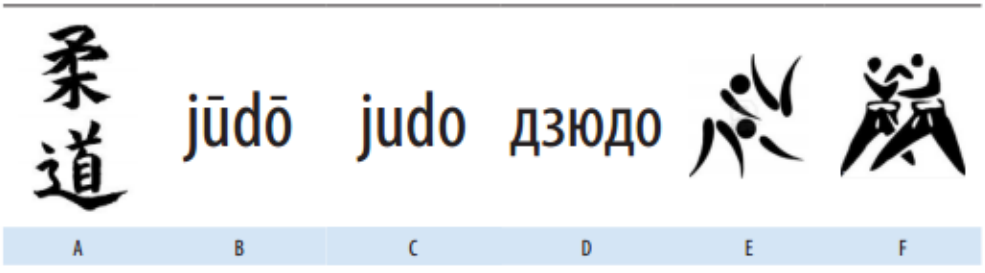

Figure 1. "Judo" symbols used in social communication – *"Symbol C is the most popular, but people (outside Japanese society) associate judo primarily with one of the many sport disciplines that have Olympic status"* [22, p. 3].

looks as follows: motor, cognitive, closed motor habit.

The third dimension of judo includes self-defence and it is applicable in a fight "one against one" or "one against group", whereas in motor sense a defence may be carried out in three forms: judo in distance [26]; judo in close contact; alternating application of both forms (in particular if a situation involves defence "one against group"). Defensive measures are extended by *atemi-waza* (striking techniques) which are used in close contact. A utilitarian value of *tai sabaki* is revealed during defence carried out in accordance with the principles of judo in distance. This technique combines the systems of hand-to-hand fighting, which in methodological sense cannot be classified as martial arts but meet the criteria of the art of self-defence (*goshin jutsu*). *Aiki do* is perhaps the most representative form, common throughout the world [27]. *Aiki do* fits most fully the concept of honourable self-defence [28, 29] and meets all motor and mental criteria of a defensive fight at the micro level or only superficially at the micro level [30, p. 333, 334].

The fourth dimension includes judo for health ("judo as a sport of life" – *judo ichidai*). Practice of judo in such this sense may include all dimensions specified above (and thus the period of sports career [4, 31]) or from its beginnings it oriented at optimal development of health (somatic, mental and social one) and survival abilities [32]. There are no formal limitations (pertaining to sex, age, health, etc. [1, 5, 33]) in the practice of "judo as a sport of life". There is a space e.g. for *ju-no-kata* (forms of gentleness [34]; some sources stage that these are "gentle" forms, supposedly established for women [5, 35]); *koshiki-no-kata* (archaic forms [5, 36, 37]). This dimension remains perhaps the closest to the concept of judo according to Jigoro Kano [1, 38]. Strictly intellectual (mental) aspect, briefly referred to as *judo in mind* stems from implementation of two general judo principles, which were formulated by Jigoro Kano, who was 63 years old at the time: *seryioku-zenyo* ("maximum efficient use of energy") and *jita-kyoei* ("mutual prosperity for self and others") [38].

Judo practice which combines moral education with intellectual (mental) and physical development is evidenced by: the ceremony at the training room (*dojo*); the ceremony during sports competitions; the rules of judo fight which set forth prohibited acts. Although the principles of *seryioku-zenyo* and *jita-kyoei* are exhibited on the front walls of Japanese *dojo* along with the image of Prof. Jigoro Kano, they are rarely respected by referees in other countries. Only 14.3% of the coaches (n = 21) from military judo clubs from Europe, Asia and America, the participants the Judo Military Word Championships (CISM) in Beijing (China) in 2002 and Catania (Italy) in 2003 state that they have sufficient knowledge of the philosophy and ethics of judo. Only 25% of 40 judo coaches from 19 countries made such declaration. Incidentally, 16% of 135 combat sports and martial arts educators surveyed declared to have sufficient knowledge of their philosophy and ethics [29, 39].

Motor evidence of moral and health education of people by formal exercises and judo fights includes the following ones: elementary education which starts with exercises, such as *kumi kata* (grip), *kamae* (an on-guard or fighting stance), *kuzushi* (to break down the opponent's *kamae,* or to unbalance him), *tai sabaki* and *ukemi waza*; systematised catalogue of *tachi waza* and *ne waza* permitted during a fight; *kinshi waza* (techniques prohibited in competition); the need to repeat forms such as *nage no kata* (throws), *katame no kata* (immobilisation in horizontal posture)*; goshin jitsu no kata* (self-defence) as a prerequisite to be promoted to the next master levels (*dan*); *katsu* (the art of resuscitation [40]) at the master level, as a significant part of judo therapy.

Judo which is deeply rooted in *bushido* tradition offers traditional methods and forms of motor training with the partner *uchi komi* (repetition training); *yakusoku geiko* – or *renshu* (pre-arranged free practice); *randori* (a match controlled by judo rules), also specific attack practice *kakkari-geiko*. The method without partner *tandoku renshu* (solo exercise or practice) is close to "shadow boxing" (see glossary) or the forms of imitation training, during which a learner repeats the action that is performed by a model (activity showed by a coach or a master or monitored with the use of video technology, or even a motor activity previously perpetuated in a student's mind, which is often repeated with eyes closed).

The practice, however, shows limited effectiveness of these traditional training methods and forms in vertical position with partner. This is proven by

fatal accidents and permanent disability [41-44] due to errors committed by both parties – the one who performs the throw (*tori*) and the falling one (*uke*), or are cumulated [45, 46]. While studying available judo textbook, no extensive methodology of belaying the falling person by the one who caused this fall was encountered. The authors usually refer to general principles.

Main premises: augmented reality technology in the implementation of „link trainer of judo"

Scientific literature discusses augmented reality (AR) in two aspects: ideological and technological one. The ideological aspect is included in the question about how to expand the organisational space. It is therefore an object-type question and dynamics of well justified answers is closely related to innovation and technological progress.

Technological aspect has for many years been represented by widely available *virtual reality* (VR). VR is defined as some mean of visualisation, manipulation and interaction between a person, a computer and complex data. VR utilizes a certain set of technologies: *head-mounted display* or *helmet-mounted display (HMD*), interactive gloves or even the entire interactive suit and devices which generate spatial sound. VR is originally used to describe immersive sensory experience with artificially created world [47]. The following question constitutes a challenge for modernity [48]: how to configure these spaces in order to effectively carry out convergence processes which take place in real and virtual organisational space?

Over 20 years ago, Milligram [49] used the term *virtuality continuum*, which refers to a certain set of object classes – in real environments, the real ones are on one side and virtual environments are on the other (opposite) one. Apart from purely real and virtual environments, this continuum consists also of the so-called *mixed reality* (MR). MR comprises: AR and AV (*augmented virtuality*). Real environments enriched with certain virtual elements are referred to as AR. For example, in architectural applications, the actual surroundings of particular places may be enhanced with views of the structures planned (buildings, roads, bridges, etc.). On the other hand, we deal with AV when e.g. the virtual world of 3D games [50] is extended with certain elements of reality, e.g. forms with human appearance or at least human faces.

Currently, AR is also defined as a variant of VR [51], in which digital information in form of images, audio, video or sensations (*haptic* or *kinesthetic communications*) is overlaid on real world surrounding the recipient. Although AR may be used to influence all five senses (sight or vision; hearing or audition; taste or gustation; smell or olfaction; touch or somatosensation), it usually allows the users for seeing real world with virtual graphical objects overlaid on it.

Invariably, one of the first applications of AR consists in the use of special *heads-up display* (HUD) to present information about the status of avionics and weapons systems for fighter pilots. Tablets and mobile phones are one of the most popular hardware platforms commonly used by AR systems. Their screens display an image from a camera mounted in this device which is enriched with certain graphical visual elements.

The following devices are used in pilot AR application to the implementation of "link trainer of judo" at the LSOA-HCI Laboratory of the Technical University in Wrocław (Poland): see-through eyewear system Vuzix Star 1200 XLD, MS Kinect sensor and interactive floor and whiteboard MultiTap.

See-through eyewear system

See-through eyewear system Vuzix Star 1200 X is AR system which supports audio, 2D and 3D video for most devices with HDMI output (e.g. desktop computers, laptops, tablets, smartphones, DVD or 3D Blu-ray). They allow for the presentation of AR system in the so-called "first-person view" which is more realistic than watching virtual objects placed in real world by 2D displays (e.g. a tablet or a smartphone), complemented by a opportunity of the recipient to free move and watch virtual objects in a view determined by positioning of person's head.

Vuzix Star 1200 XLD eyewear system is equipped with two twin displays which allows for displaying virtual image with a diagonal of 75" seen from 3 m. It is also equipped with 1080p HD camera mounted between the display (Figure 2). Camera uses a separate USB connector that can be connected to the controlling computer similarly to a typical web camera in MS Windows. Camera provides possibility of recording video up to 60 fps (frames per second) and is compatible with most leading programs for creating AR operating under

Figure 2. See-through eyewear system Vuzix Star 1200 XLD (source: http://www.vuzix.com/augmented-reality/products_star1200xld/)

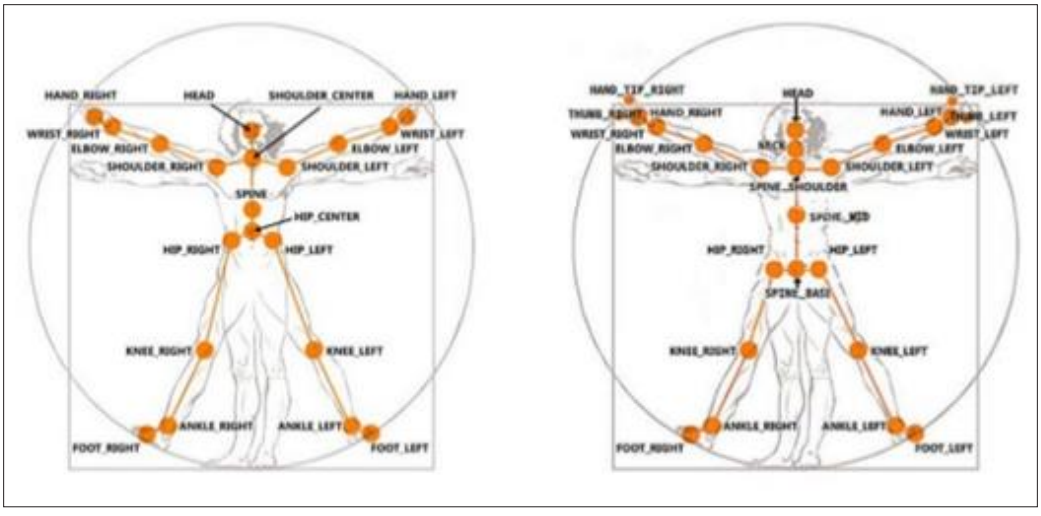

Figure 3. Joints identified by Kinect for Xbox 360 (left) and Kinect for Xbox One (right) (source: http://www.slideshare.net/MatteoValoriani/programming-with-kinect-v2).

Windows. Eyewear system is also equipped with a controller (located on the right, which functions as an interface between the system, device which tracks head movements and computer). Controller HDMI 1.4 also powers the eyewear system by means of rechargeable lithium-ion battery. The so-called wrap tracker is another important piece of equipment (this device is used to track head movements in all three planes). These movements can be controlled through application operating under MS Windows which is supplied along with the device.

Sensor Kinect

Kinect sensor enables the implementation of new ways of human-computer interactions [52]. It combines camera, directional microphone and depth sensor in a mas-range integrated product which allows software developers to create interactive systems with all kind of kinetic interaction, e.g. complex arm manipulations which in judo are strongly reflected by the variety of techniques used. Currently, the following versions are used: Kinect for Xbox 360, Kinect for Windows and Kinect for Xbox One Depth sensor is the most important and innovative element. It used infrared light projector and a camera, which is able to see small points displayed by this projector. Unfortunately, this process requires a fairly complex calculation time, because it involves thousands of points on an image, which should be performed for each frame [52].

Kinect for Xbox 360 allows for i.a. tracking of movements made by a person who is in the visual field

of the sensor by recognizing the characteristic elements of the human body (20 in total) on the torso, head, arms and legs. Additionally, also major joints are identified as part of these body parts (Figure 3).

Since 2013, the market has been offering newer, improved version of Kinect for Xbox One, which has 1080p camera, identified more characteristic points on the human body (25, including the distinctive elements of a hand, thumb and others – Figure 3, on the right). Depth sensor operates in the range of 0.4 to 4.5 meters. This sensor along with the software supplied allows for identification of an open and closed hand.

The issues related to this sensor include even greater hardware requirements (e.g. the need of connecting by through USB 3.0) and compute requirements than its older version, which result from i.e. higher resolution of a camera, and thereby the need of transmitting and processing larger volumes of data.

Figure 4. Interactive floor and whiteboard MultiTap in the LSOA-HCI Laboratory of the Technical University in Wrocław (Poland).

Interactive floor and whiteboard

Interactive floor (Figure 4) is an integrated device combining a PC (personal computer) and a high-power video projector in one casing, which due to its mirror surface displays image on a substrate, and Kinect sensor (on an extension arm). This system allows for developing modern multimedia applications which display image on the floor and for natural interaction between users and the system by movements of the body and its particular parts, e.g. legs and/or arms [53]. It is usually used in marketing and digital signage through the use of games and activities that attract large crowds, usually a younger audience (e.g. installed in shopping centres or during occasional events).

Main assumptions

Only three elements related to judo techniques may be repeated individually, without the need for a partner (*tori/uke* or opponent during *randori*, alternately). *Tai sabaki* and *ukemi waza* are elementary techniques which are related to motor safety and health related training. *Tai sabaki* – when it is necessary to avoid collision with a moving object (e.g. an object thrown, aggressor's hits, a biker). *Ukemi waza* – not only in situations involving sudden balance loss and collision with the ground [54], but also during collisions with vertical obstacles [55] or avoiding collision by means of preceding controlled fall – safe fall technique [54]. *Tandoku renshu*, as a motor training method is based on great involvement of one's own imagination, intuition and creative thinking, is available for everyone who has a possibility of activating the system of motor control at any specified time and intensity of physical effort. *Tandoku renshu* may constitute one of elementary methods applied in health related training based on judo techniques which are performed individually.

Years of sports and coaching experience of the members of the research team (the result of Delphi method) as well as the results of long-term empirical studies [10, 31, 56–58] justify the main assumption that it is talent and not specific judo technique that determine sport success in judo (and self-defence). Although rankings of the preferred throwing techniques (i.e. effectively used) by top judo athletes favour for years rather a small group (approx. throws during the World Championships from 1981 to 2001, and similarly in 2009 and 2010 [60]), the entire *gokyo* set (see glossary) is filled by a continuum of these

rankings. There is also another category "innovative throws" [61]. These are important proofs that there is a relationship between preferred throwing techniques and predispositions of particular judo athlete which are difficult to identify even by experienced coaches. Important non-published observations of A. Kruszewski and W. Wałachowski (Poland) confirm that is no relationship (it is rather opposite) between throwing techniques preferred (recommended) by the coach during training and the ones used by experienced wrestlers during tournaments fights.

Therefore, especially during preliminary training (1 to 3 years of long-term training cycle [62, 63]), it would be justified to teach the entire *gokyo*, set so that: movement possibilities of judo trainees are not limited by early specialisation in throwing techniques; no one would be guided by a naive principle that effectiveness of throwing techniques (this is only a mental shortcut – jargon) is determined in the aforesaid rankings, but to assume that effectiveness (or its lack) is an immanent trait of an acting person (any techniques *a priori* will not ensure anticipated effectiveness but may significantly increase the probability of achieving success); an athlete would have a possibility of developing *tokui waza* (see glossary), with necessary intervention of a coach and other advisors (a biomechanic, psychologist, etc.).

Recent research confirms that rapid learning of particular judo techniques does not require an excessive number of repetitions [64], which is particularly advantageous for health reasons.

Each of the displays (Kinect sensor for Xbox One, tablet/smartphone operating with Android, see-through eyewear system Vuzix Star 1200 XLD or interactive floor) enables visualisation of virtual models overlaid on actual image of an athlete performing a throw or other judo technique.

Reference models of implemented judo techniques must be adapted to the basic indicators of the trainee learning (body weight and height, age, training experience, etc.). However, due to training objectives set it is possible (and required in justified cases – a feedback of a coach, psychologist, biomechanic, pedagogue, etc.) to appropriately manipulate the variables (differentiation of the level of technical advancement, repeating selected movement sequences, response to fakes, etc.).

A prerequisite is that an athlete (or judo adept) stands in front of the Kinect sensor so that he or she will find oneself in the field of view of the depth sensor (0.4-4.5 m). It records a reference judo throw based on information on information on spatial location of featured joints determined for each video frame recording the throw. A mathematical model of a "reference" judo throw is created. This model takes into account the location of particular joints in specified quanta of time (1/30 second).

Additionally, this model may be created on the basis of several intersubjective recommendations of experts or averaged measurements of throws performed as fast as possible in actual conditions involving championship competitions – creating "optimal models" (according to the sports level of given person).

During a throw, one may optionally provide information by means of displayed icon (eyeglasses) or background colour displayed on the floor whether in given moment an athlete performs a motor activity in a correct manner (green – in accordance with the model adopted) or in an incorrect manner (red), or an intermediate colour (between green and red), depending on the deviation from the model adopted.

Technological limitations will be gradually compensated based on the synthesis of the experience of all subjects participating in research with particular emphasis on the comments and suggestions of trainees (persons who are learning) and modification of methodology.

Methodological criteria of training with the use of AR

Training sessions with the use of AR should be individual and not last longer than 60 minutes. Training tasks must mainly consist of motor exercises and may incorporate means appropriate for mental training or combine both forms (as a variant of intellectualization of training).

The intervals between individual training tasks with the use of AR should be carefully recorded. Secondary multifaceted analysis of observation results in longer cycles of training may turn out to be a significant element while creating individual training session programmes, in which the time interval between specific exercises (and the number of repetitions) can be essential for improving the adaptive effects.

A coach observes a throw performed by an athlete (or any other motor activity) with the use of appropriate device, which optionally provides the following information: it displays the skeleton (avatar) on an actual athlete image (it is necessary to determine athlete's position and to overlay the image of skeleton at a specific angle); parallel display of an animation of model performance of given activity by the skeleton (avatar); monitoring of information about mistakes committed during exercises (live), e.g. by changing the colour of the skeleton.

Feedback for an athlete:

- having performed a motor task, an athlete received the following information depending on the device used (on eyeglasses or on the floor): video of performed motor task; video of performed motor task with a skeleton overlaid on the athlete image (avatar); about correct or incorrect performance of the task (deviations from the model are displayed, e.g. animated avatar and simultaneously a skeleton of exercising person);

- additionally, deviations from the model are explained using a "coach's voice" or a text displayed on a suitable device;

- the commands to correct given motor activity are provided in an analogous manner (in a version for less advanced ones, specific instructions to perform a throw may consist in displaying areas in which feet were placed on the floor and taking specific position and key movement elements may be presented in form of a picture or in an interactive manner, i.e. by verifying the location of the skeleton read by Kinect).

Scenarios (examples)

Creating optimal model of a throw seoi nage for the novice judo athlete

Prerequisites and assumptions: determination of the dominant side on the basis of "Rotational Test (RT)" [9] (flawless performance of three jumps with a rotation of 360° or lower number of errors than in the opposite direction, in accordance with RT criteria); *seoi nage* rate in variant 1 should allow exposing most important elements (*kuzushi – tsukuri – kake*); the "optimal model" should be used in variant 2.

Variant 1: a) observe a five-time performance of *seoi nage* throw to the side previously determined for you as "dominant" by model skeleton (avatar); b) short break; c) perform *seoi nage* throw at the model rate; d) short break; e) do the same in the opposite direction; f) short break; g) perform *seoi nage* throw three times at the same rate towards dominant side (2 second break between the repetitions); f) short break; g) do the same in the opposite direction.

Variant 2: a) perform *seoi nage* throw to the right as fast as you can; b) short break; c) perform three times *seoi nage* throw to the right as fast and accurate as you can; d) short break; e) perform *seoi nage* throw three times to the left as fast and accurate as you can; f) short break; g) perform *seoi nage* throw to the left as fast and accurate as you can.

Seoi nage as the second throw of the first group (te waza) *nage no kata*

Task 1: a) observe a five-time performance of *seoi nage* throw by model skeleton (avatar) at first to the right, then to the left in accordance with examination criteria of *nage no kata*; b) short break and listen to the coach's instructions about elements (or element) on which you are supposed to be focused; c) perform the task on your own; d) short break and listen to the coach's remarks; d) repeat the task so many times (however no more than 8) until you decide that you come close to the performance of a champion (coach discussed only the repetitions performed in the best manner and uses relevant visualisation).

Task 2: a) observe the performance of the entire group of *te waza* (*uki otoshi – seoi nage –kata guruma*) as part of *nage no kata* by two masters (but no one informs the athlete that these are recordings from championship competitions and that knows assessments of the referees); b) assess everyone on your own according to the criteria for sports competition; c) justify you assessment; d) perform all *te waza* throws in accordance with *nage no kata;* e) break, coach uses the entire visualisation, discusses the mistakes but focuses on the best-performed elements.

Seoi nage in self-defence

Task 1: a) an athlete does not know that all simulated attacks will be performed with right hand (strike from the top as in *kata*) and does not know the number of attacks, has no idea from

which side the attack will take place and at what rate (coach tells the athlete from which side the "aggressor" will attack); b) one-minute break (an athlete has the time for individual analysis without coach's remark); c) two first simulated attacks with left hand (strike from the top as in *kata*), the following ones performed randomly with right or left hand, but still by the same "aggressor" (strike from the top as in *kata*); d) break, coach uses the entire visualisation and listens to a critical self-assessment of the athlete (but does not make any assessments).

Task 2: a) repeat programme "c" in an identical manner; b) break, coach uses the entire visualisation and listens to a critical self-assessment of the athlete, and afterwards makes assessments and provides remarks.

Conclusions

The broad application possibilities of AR are indicated by the fact that the entire issue no. 103 of the *European Research Consortium for Informatics and Mathematics – ERCIM News* (October 2015) was devoted to this subject. The following applications have been listed: art, museology, exhibitions, architecture, maintenance of infrastructure, information exchange in teams, railways, education, publishing, security, psychology, support in browsing and searching for information.

According to Stephanidis and Kaasinen [65], AR may be defined as direct or indirect view on actual world watched in a real time, enriched with virtual elements generated by a computer. The following elements are indicated: actual and virtual objects displayed in the real environment; their mutual arrangement (which allows an observer for watching them in a natural manner from various perspectives); acts interactively in real time and in three dimensions.

Delphi method and design method applied allowed us to determine that all the experts agreed that the essence of judo sport is to maintain a vertical position and break the competitor's balance. Only such a result makes it possible to continue the fight in the horizontal position. However, these two general principles do not mean that they are fighting techniques of judo that ensure reliability.

Preliminary results of unique studies using virtual reality technology reveal that accumulated motor experience (fixed movement habits) in long-term judo training (*judo ichidai*) provide surprising adaptive effects. Although judo trainee 41 years old younger usually faster reacts in situations involving simulated frontal collision with an object in motion, but this person is not superior compared to a "judo veteran" aged 68 as far as quality of tai *sabaki* is concerned [66]. Thus, our project fits well into this optimistic perspective, not only as a technological attraction [48, 67-70]. It promotes judo in a sustainable manner – in four dimensions defined in the introduction (two sports ones as self-defence and an attractive method of health related training).

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Cite this article as: Witkowski K, Sobecki J, Maśliński J et al. The use of augmented-reality technology to improve judo techniques. Premises, assumptions, methodology, research tools, preliminary scenarios – the first stage of the study. Arch Budo 2016; 12: 355-367