IMPROVEMENT OF EARLY RECOGNITION OF ATTACKS IN KARATE KUMITE DUE TO TRAINING IN VIRTUAL REALITY

Katharina Petri[*1], Nicole Bandow[2], Steffen Masik[3], Kerstin Witte[4]
Otto-von-Guericke-University Magdeburg, Institute III: Sports Science,
Department of Sports Engineering and Movement Science, Germany[1,2,4]
Fraunhofer Institute for Factory Operation and Automation IFF, Germany[3]
Email: katharina.petri@ovgu.de[*1], nicole.bandow@ovgu.de[2], steffen.masik@iff.fraunhofer.de[3],
kerstin.witte@ovgu.de[4]

ABSTRACT

In a Virtual Reality training, young karate athletes divided in two groups (intervention vs. control group) responded to attacks of a virtual opponent. For the analysis, the first reaction of the responding karate athletes was detected. From that point three reaction times were subtracted to analyze the attack of the virtual opponent at the time of the recognition of the real athlete. The attacks were divided into four movement stages. Analysis of Variance (ANOVAs) with repeated measures and estimation of effect sizes as well as Bonferroni post-hoc tests were applied to calculate interactions between time (PRE to POST), group (intervention vs. control) and reaction time (150 ms vs. 255 ms vs. 370 ms). We found significant effects for time and time x group interactions for the attacks Gyaku-Zuki and Kizami-Zuki as well as an effect for time x reaction time in Gyaku-Zuki (all p < 0.001), but no significant effects for time x group x reaction time in both attacks (p > 0.05). Paired t-tests showed significant improvements in attack recognition from PRE to POST for the intervention group, but not for the control group. At the pretest all athletes responded to late movement stages (extension of the pushing arm) while the intervention group responded to early movement stages (preparing steps and reduction of distance before the attack) at the posttest due to the Virtual Reality training. Early steps for the preparation of the attack and the reduction of distance seem to be important signals for attack recognition.

Keywords: VR Training; Classification of Movement Stages; Perception; Anticipation; Head Mounted Display

How To Cite: Petri, K., Bandow, N., Masik, S., & Witte, K. (2019). Improvement of Early Recognition of Attacks in Karate Kumite Due to Training in Virtual Reality. *Journal Sport Area*, *4* (2), 294-308.

INTRODUCTION

There are several possibilities to analyze perception and anticipatory signals in sports: eyetracking to investigate the foveal vision, usage of occlusions in film material (spatial or temporal removal of information), and in-situ studies (Müller & Abernethy, 2012). A further possibility to analyze perception-action coupling is the application of Virtual Reality (VR) (Craig, 2013).

VR is an artificial environment created by hardware and software. By recording of the user, the virtual scene can adapt accordingly to the user's view (Rebenitsch & Owen, 2016; Lin & Woldegeorgis, 2015). With using VR, realistic (sports) scenarios and virtual characters as opponents, teammates or audience can be created with which the real user can interact either for training or competition preparation (Petri et al., 2018b) or to analyze human behavior (Craig, 2013, Ida, 2015). VR, which can be

applied in sports science research and training, provides many advantages: standardized and controllable conditions with manipulations, which are not possible in reality, and no dependence on other training partners, coaches or gyms exist (Miles et al., 2012). Since Head Mounted Displays (HMDs) reached commercial viability, they are small and lightweight and do not disturb the user. As long as the technological equipment is available, VR can be used in every space, which is big enough to allow sports specific movements.

The technological development has proceeded very fast in the last couple of years. Rebenitsch and Owen (2016) stated that HMDs cause more symptoms of cybersickness (discomfort due to VR) than screen-based VRs, such as CAVEs (Cave Automatic Virtual Environment) or powerwalls. However, Petri et al. (2017) found that karate athletes preferred HMDs over a CAVE and Hartnagel, Taffou and Sandor (2017) proved that a duration of ten to fifteen minutes in VR using an HMD did not cause cybersickness at all.

A detailed presentation of today's often-used virtual environments in sports is given in Petri, Bandow and Witte (2018). That review shows that many VR systems were created in several sports, but most systems were developed in ball sports. It also demonstrates that more studies analyzing perception and anticipation are needed as well as intervention studies, especially perceptual training, with high-skilled athletes and sports specific tasks (Petri et al., 2018b).

VR can be used to analyze anticipatory cues, as it is described in Bandow (2016). In that work, real karate athletes responded to temporally and spatially occluded attacks of a virtual opponent. From the time of the first reaction of the real athlete 150 ms as estimated reaction time were subtracted to analyze the movement of the attack at that point. It was assumed that the identified movement phase of the attack contains relevant cues. Based on that analysis, Bandow (2016) was able to identify some relevant signals, such as hip and punching arm of a karate opponent. However, these results are not validated yet.

Anticipation is defined as the mental presumption of future events or movements. Adequate forecasting of intentions of opponents or teammates can result into having more time for the preparation of the own motor response (Müller & Abernethy, 2012). Cognitive skills, such as adequate perception and anticipation of relevant information, are performance limiting factors in karate (Mori & Shimada, 2013). Karate kumite is a type of martial arts, where two opponents fight against each other for two to three minutes in an area of 8 x 8 m. According to the official rules, many karate styles are contactless. Thus, the opposing athlete has to stop the attack before actual body contact. For application in VR, karate is therefore perfect because no tactile feedback has to occur; the visual scene with only one virtual opponent is quite easy to create.

Although several studies were conducted in this field, the anticipatory cues, to which athletes respond, are not clarified in many sports, neither in karate kumite. An in-situ study with parallel motion capturing of two karate athletes (Petri et al., 2016) and the following in-situ study with parallel video analysis of two athletes (Petri et al., 2018a) implied that the reduction of distance before the attack might be an anticipatory cue. In that studies, according to the method described above in Bandow (2016), 150 ms were subtracted from the first reaction of the reacting athlete to analyze the movement of the attacking athlete at that time. According to Gardner, Mitchell and Russo (1978) reaction behavior contains neural and cognitive processes, and reaction times can be

used to measure information processing. The findings from Petri et al. (2016) confirm results of previous studies from Hristovski, Davids, Araújo and Button (2006), Okumura et al. (2012) and Okumura, Kijima and Yamamoto (2017), where the perception of interpersonal distance was found to be important in martial arts. Experienced athletes were able to switch preferred distances to either prepare or execute attacks.

There is a lack in tools for analysis of karate specific reaction times. The 150 ms in Petri et al. (2016) and Bandow (2016) as assumed reaction times were taken from the literature (Zaciorskij, 1971). Von Oehsen (1984) tried to analyze karate specific reaction times in an almost realistic setting. She obtained several reaction times from three expert athletes responding to light signals on a karate dummy and executing given and free karate attacks: 255 ms and 370 ms. 255 ms was the reaction time for a simple visual choice reaction task and 370 ms the reaction time for a complex visual recognition reaction. Because the sports specific reaction times are not clear in karate kumite, the current study used all three times (150 ms, 255 ms and 370 ms) to subtract these from the first reaction of the responding athlete to analyze relevant cues in the movement of an attacking virtual opponent. Hence, the analysis of anticipatory cues in the movement of the attacker bases on the method described in Bandow (2016) and Petri et al. (2016).

Farrow and Raab (2008) stated that cognitive elements are underrepresented in sports training and Milazzo, Farrow and Fournier (2016) observed that cognitive training (in this case a training to improve the response behavior) improved the gaze behavior, so that athletes were able to better concentrate and perceive relevant information. Thus, gaze behavior became more efficient. Vignais et al. (2015) demonstrated that for perception tasks VR is more suitable than 2D film material due to the depth information. However, for natural motor behavior of the real athletes, the graphical implementation of the VR has to be realistic (Vignais et al., 2009). Therefore, Petri et al. (2019) performed a reaction training in VR, where karate athletes responded to attacks of a virtual opponent and improved their sports specific response behavior. They were able to respond faster and better due to VR training. Müller et al. (2017) conducted an anticipation training in reality with video material and also found improvements in perception and anticipation. Thus, perception and anticipation are trainable and benefit from targeted intervention.

Most studies analyzing perception and anticipation in karate kumite used cross-sectional designs in reality, while the present study is an intervention study to improve attack recognition and anticipation using immersive VR. The current study aims to investigate if a reaction training towards virtual attacks improves the early recognition and anticipation of karate attacks in young karate athletes.

Our study is quite similar to the VR training in Petri et al. (2019), where athletes improved their sports specific response behavior. Because it was shown that athletes initiated their reactions earlier, we expect that a sports specific reaction training using immersive VR will lead to improvements in the attack recognition. Thus, the intervention group will learn to respond to early movement stages due to improvements in their perception and anticipation while the control group will react to later movement stages.

METHODS

We used two groups of participants: one group to build the avatar and another group in the intervention. The virtual opponent was created on the basis of a first group of five (n=5) male and international successful karate kumite athletes at the age of 24 - 56 years. All of them had the black belt degree (1st - 4th Dan).

Afterwards, fifteen (n=15) young karate athletes at the age of 13 - 17 years (five women and ten men, 3rd – 1st Kyu) with at least five years of karate experience and participation in national competitions (e. g. German championships and national cups) served as participants in the intervention study, where they had to respond to attacks of the virtual character. These young athletes were chosen because they had enough experience to recognize and respond to several karate attacks. Higher skilled athletes (longer or even international karate experience) could be demanded too little from our developed VR training because we implemented only seven different type of attacks in the virtual opponents.

All participants came from the German karate federation and the Japan karate association in Germany and practiced the Shotokan style (no body contact). They (and in case of underage their parents) were informed about the procedure of the study and gave their written consent. The study was conducted in accordance to the declaration of Helsinki and had obtained the approval of the ethic committee of the first author's University.

Creation of the virtual character and the virtual environment

The five karate experts conducted several attacks: the arm attacks Gyaku-Zuki jodan (GZj), Gyaku-Zuki chudan, Gyaku-Zuki overrun, Kizami-Zuki (KZ), Uraken, the leg technique Mawashi-Geri as well as two attack-combinations. All attacks were performed from a realistic distance towards a target. Each attack was recorded twice and the better one was used for the creation of the virtual attacker. For the creation of the VR training all attacks were necessary, but for analysis in pre- and posttest, we only used GZj and KZ, because these attacks belong to the most used karate attacks in high-class international karate kumite competitions (Petri et al., 2017). GZj is an attack with the rear hand towards the head of the opponent, while KZ is performed with the front hand towards the head.

The virtual attacker was animated by motion capturing data which were recorded using Vicon Tracker (Vicon, Oxford, UK, version 2.2), twelve cameras (MX-13, Vicon, Oxford, UK) and a full-body target set (A.R.T., Weilheim, Germany). After processing and filtering the raw data using linear interpolation, LULU-filtering and SG-filtering these data were mapped onto the skeleton of the used avatar, a male and a female character. The virtual character was visualized as a karate fighter wearing a karate gi. The virtual environment depicted a sports hall with a karate specific fighting area (Fig.1 A,B). In the end, we had five different virtual characters based on the five real experts. Each avatar contained the recorded movements of one real athlete. However, each of the five avatars had the same look – either a male or a female look to avoid that real athletes would recognize upcoming attacks according to the appearance. So, while we created five datasets of five male expert athletes, the participants of the intervention study only saw one virtual opponent. However, we did not average our motion data to ensure that each avatar exhibits natural movements like a person.

Our created character was a passive one, thus, this sort of virtual character cannot take the positions or the movements of the real athlete into account. Therefore, our character was only able to attack to a fixed point and could not react to the athlete directly. Finally, all recorded movements and distances of the recorded attacks were checked by a karate expert because it is well known that distances can be underestimated in VR (Renner, Velichkovsy & Helmert, 2013).
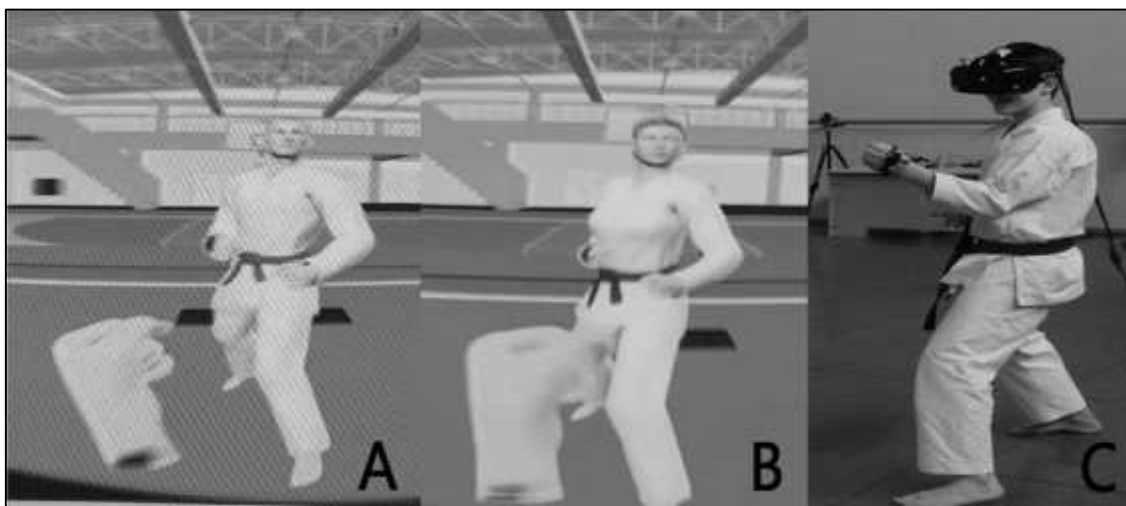

Figure 1. A karate athlete (C) responds to upcoming attacks of virtual characters (A+B). Each athlete had to fight against a virtual character of the same sex to increase the degree of reality. A: male version of the character. B: female version of the character.

VR training procedure

The five karate experts conducted several attacks: the arm attacks Gyaku-Zuki jodan (GZj), Gyaku-Zuki chudan, Gyaku-Zuki overrun, Kizami-Zuki (KZ), Uraken, the leg technique Mawashi-Geri as well as two attack-combinations. All attacks were performed from a realistic distance towards a target. Each attack was recorded twice and the better one was used for the creation of the virtual attacker. For the creation of the VR training all attacks were necessary, but for analysis in pre- and posttest, we only used GZj and KZ, because these attacks belong to the most used karate attacks in high-class international karate kumite competitions (Petri et al., 2017). GZj is an attack with the rear hand towards the head of the opponent, while KZ is performed with the front hand towards the head.

The virtual attacker was animated by motion capturing data which were recorded using Vicon Tracker (Vicon, Oxford, UK, version 2.2), twelve cameras (MX-13, Vicon, Oxford, UK) and a full-body target set (A.R.T., Weilheim, Germany). After processing and filtering the raw data using linear interpolation, LULU-filtering and SG-filtering these data were mapped onto the skeleton of the used avatar, a male and a female character. The virtual character was visualized as a karate fighter wearing a karate gi. The virtual environment depicted a sports hall with a karate specific fighting area (Fig.1 A,B). In the end, we had five different virtual characters based on the five real experts. Each avatar contained the recorded movements of one real athlete. However, each of the five avatars had the same look – either a male or a female look to avoid that real athletes would recognize upcoming attacks according to the appearance. So, while we created five datasets of five male expert athletes, the participants of the intervention study only

saw one virtual opponent. However, we did not average our motion data to ensure that each avatar exhibits natural movements like a person.

Our created character was a passive one, thus, this sort of virtual character cannot take the positions or the movements of the real athlete into account. Therefore, our character was only able to attack to a fixed point and could not react to the athlete directly. Finally, all recorded movements and distances of the recorded attacks were checked by a karate expert because it is well known that distances can be underestimated in VR (Renner, Velichkovsy & Helmert, 2013).All fifteen participants were randomly assigned according to gender, age and expertise (Kyu) into the intervention group (IG) and control group (CG). The intervention study lasted eight weeks. In the first and in the last week, pre- and posttests were carried out. The VR intervention itself was performed ten times with ten minutes each session over six weeks and was integrated in the course of the conventional karate training. The IG completed the VR training using an HMD (Oculus Rift DK2, Oculus VR, USA with a resolution of 969 x 1080 pixels per eye) and two hand targets (A.R.T., Weilheim, Germany, Fig. 2) for their orientation (the rest of the body was not visualized). Vicon Tracker calculated the position data of the HMD and the hands on a PC. The position and the rotation of these objects were updated at every displayed frame by the rendering software. The CG continued with the normal karate training which was conducted by the normal karate coach. In that normal training, they performed endurance and resistance training, technique training and specific competition preparation.

Since concrete training recommendations are still lacking (Miles et al., 2012, Petri, Bandow & Witte, 2018), we developed a karate specific training routine with the help of a karate expert. In each session the athletes had to respond to four sets with each six to eight different attacks and attack combinations, which were a mix from all attacks, which we recorded using motion capturing with the five karate experts. Between the attacks within the sets a pause of three seconds was given, and between each set there was a pause of two minutes to ensure full concentration. The routine was developed on the basis of scientific principles: from easy to difficult to increase the degree of complexity by different type of attacks, number of attacks and several individual executions of the same attack. The real karate athletes had to step in place and should respond to the upcoming attacks as they would do in a natural competition (Fig. 1).

Pre- and posttests procedure

At pretest (PRE) and posttest (POST) a movement analysis with regard to the attacks of the virtual opponent was captured by the use of two synchronized cameras (Contemplas, Kempten, Germany, 100 Hz). Therefore, the virtual opponent was projected on a large canvas applying a rear projection beamer. Hence, attacks and responses were recorded synchronously. At pre- and posttest, each athlete had to respond to 22 attacks from the virtual character (either the male or the female version) with a break of 30 – 45 seconds between each attack according to the processing of the recorded videos. These 22 attacks were eight GZj, eight KZ, three Gxaku-Zuki chudan and three Mawashi-Geri in a randomized order, but we only included GZj and KZ in our analysis due to the previous competition analysis. Thus, 16 responses from each athlete were analyzed.

Subtraction of reaction times and movement classification for analysis of relevant cues

According to the method presented in Bandow (2016), where anticipatory signals can be analyzed by subtracting the reaction time from the first reaction, the first measurable reaction of the real athlete was examined. From that point several reaction times were subtracted to analyze the movement of the attacker to the time of the recognition by the reacting athlete to find out relevant movement stages which contain anticipatory cues. The reaction times were 150 ms (Petri et al., 2016, based on Zaciorskij, 1971), 255 ms and 370 ms (von Oehsen, 1984). Since, tools for the measurement of sports specific reaction times in karate kumite are lacking, we took all three values.

At each pre- and posttests eight responses to the attacks GZj and KZ were analyzed from each participant. To investigate to which signals the real athletes responded to, the movements of the attacks were divided into four movement stages according to Petri et al. (2018a), which are defined as follows: Movement stage 1: early steps during the preparation of the attack, Movement stage 2: the last step before the execution of the actual attack starts. Reduction in distance by a flight phase towards the opponent, Movement stage 3: Ground contact of the feet after the previous flight phase, Phase between the contact of the toes on the ground and the contact of the heel on the ground, Movement stage 4: Main phase of the attack: the front foot moves forward and the pushing arm moves also forward until the arm is extended.

The classification described above is also shown in Fig.2. This classification was made on the basis of all analyzed attacks, and is therefore valid for natural performed GZj and KZ without the comprehension of a deceptive motion. Our classification is further derived from Bandow (2016).
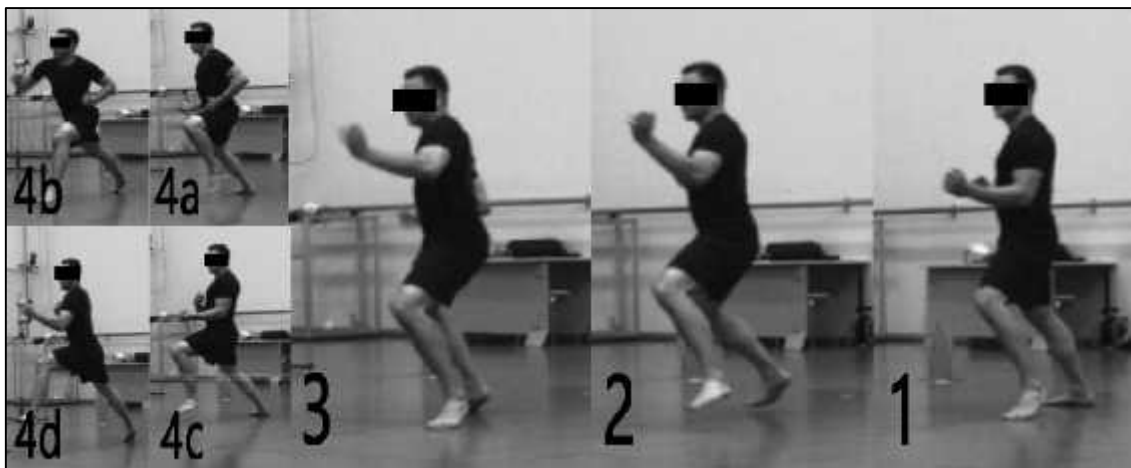

Figure 2. Visualization of the movement stages. 1: early steps. 2: reduction of distance due to the last step forward. 3: landing with the rear foot on the ground after the flight phase of 2. 4: movement forward of front leg (4a+4c) and pushing arm (4b+4d). 4a+b: movement stage 4 of GZ. 4c+d: movement stage 4 of KZ.

Data processing

All recorded movements (parallel recording of virtual opponent and real responding athlete) were analyzed using the software Kinovea. For the IG (n=8) 64 responses towards the attack GZj and 64 responses towards the attack KZ were analyzed each time

at PRE and POST. For the CG (n=7) 56 responses, each for GZj and KZ, were analyzed at PRE and POST. In each video, the movement stages were analyzed according to the three reaction times. Thus, we had three results for each video. Two videos from GZ and nine videos from KZ had to be excluded due to technical problems.

For all statistical analysis SPSS version 25 (IBM, Germany) was used. The level of significance for all tests was set at <0.05. To detect differences in anticipation between IG and CG at PRE, unpaired t-tests were performed for each attack and each reaction time. No significant differences (all p>0.05) were found, thus, the performance level of both groups was quite similar at PRE.

To determine whether anticipation differed between two groups we conducted repeated-measures two-factorial analysis of variance (ANOVA), with time (PRE / POST) as within-subjects factor and group (IG / CG) and reaction time (150 ms / 255 ms / 370 ms) as between-subject's factors. Such an ANOVA was performed separately for each attack (GZj and KZ) to analyze time effects and group effects of the relevant movement stages over the time, to which the athletes responded to. Eta squares (2) being classified as 2 < 0.06 small effect, 0.06 < 2 < 0.12 moderate effect and 2 > 0.14 large effect were also analyzed to examine effect sizes.

To examine differences between the used reaction times (150 ms / 255 ms / 370 ms) one-factorial variance analyses with Bonferroni-post-hoc-tests were made for each attack, group and time. Paired t-tests were carried out to detect differences from PRE to POST for each group and each attack.

RESULTS AND DISCUSSION
Two-factorial analysis of variance (ANOVA) – GZj
Two-factorial analysis of variance for the attack GZj showed significant interactions for time (PRE to POST) with F = 67.110, p < 0.001 and 2 = 0.162, large effect. Time (PRE to POST) x group (IG vs. CG) showed a significant interaction with F = 91.766, p < 0.001 and 2 = 0.209, large effect. Time (PRE to POST) x reaction time (150 ms, 255 ms, 370 ms) revealed a significant interaction with F = 8.039, p < 0.001 and 2 = 0.044, small effect. However, no interaction was found between all factors (time x group x reaction time) with F= 2.823 and p = 0.61.

Two-factorial analysis of variance (ANOVA) – KZ
Two-factorial analysis of variance for the attack KZ showed significant interactions for time (PRE to POST) with F = 77.470, p < 0.001 and 2 = 0.183, large effect. Time (PRE to POST) x group (IG vs. CG) showed a significant interaction with F = 21.503, p < 0.001 and 2 = 0.059, small effect. No significant interactions were found for time (PRE to POST) x reaction time (150 ms, 255 ms, 370 ms) with F = 2.492 and p = 0.084 as well as for time x group x reaction time with F = 0.017 and p = 0.984.

One-factorial variance analyses with Bonferroni-post-hoc-tests at PRE and POST - GZj
At PRE, one factorial analysis of variance of attack GZj for IG showed significant differences between the three reaction times 150 ms, 255 ms and 370 ms with p < 0.001. Post-hoc-tests showed significant differences between all reaction times with each p < 0.001. At POST, one factorial analysis of variance also showed significant differences between all three reaction times with p < 0.001. Post-hoc tests revealed significant

differences between 150 ms and 255 ms as well as 150 ms and 370 ms with $p < 0.001$. Between 255 ms and 370 ms a significant difference with $p = 0.008$ was found.

At PRE, one factorial analysis of variance of the attack GZj for CG also showed significant differences between all three reaction times at PRE with $p < 0.001$. Post-hoc tests showed significant differences between 150 ms and 255 ms as well as between 150 ms and 370 ms with $p < 0.001$. Between 255ms and 370 ms also a significant difference was found with $p = 0.014$. At POST, one factorial analysis of variance showed a significant difference between all three attacks with $p < 0.001$, but post-hoc tests showed only a significant difference between 255 ms and 370 ms ($p = 0.002$). No significant difference was found between 150 ms and 255 ms, as well as between 150 ms and 370 ms (both $p>0.05$).

One-factorial variance analyses with Bonferroni-post-hoc-tests at PRE and POST - KZ

At PRE, one factorial analysis of variance of the attack KZ for IG showed significant differences between all three reaction times ($p < 0.001$). Also, all post-hoc tests showed significant differences with $p < 0.001$. At POST, there one-factorial analysis showed significant differences between all reaction times ($p < 0.001$). The post-hoc tests revealed significant differences between 150 ms and 255 ms as well as 150 ms and 370 ms with $p < 0.001$. Between 255ms and 370 ms a significant difference was found with $p = 0.001$.

At PRE, one factorial of variance for CG showed significant differences between all three reaction times with $p < 0.001$. The post-hoc tests also showed significant differences between all reaction times with each $p < 0.001$. At POST, one–factorial analysis of variance showed a significant difference between all reaction times, and also the post-hoc tests carried out significant differences with each $p < 0.001$.

Paired t-tests– GZj and KZ

Paired t-tests were performed to analyze differences from PRE to POST. For GZj, significant differences were found from PRE to POST in IG with 150 ms, 255ms and 370 ms (all $p < 0.001$). In CG, also significant differences were found with 255 ms ($p= 0.019$), but not with150 ms and 370 ms (both $p > 0.05$).

For KZ significant differences were found from PRE to POST in IG with 150 ms (p 0 0.021), 255 ms ($p = 0.007$) and 370 ms ($p = 0.018$). In CG, there was only a significant difference from PRE to POST with 255 ms ($p = 0.002$), but not with 150 ms and 370 ms (both $p > 0.05$).

For graphical information see also Figure 3, where we show mean and standard deviations of the used movement stages at PRE and POST of IG and CG according to the subtracted reaction time 150 ms, 255 ms and 370 ms from the first detected reaction. At PRE both groups responded to the movement stages 3 and 4, and there was no difference between IG and CG. While for CG, no differences in attack recognition were shown from PRE to POST (except of 255 ms: in KZ CG improved attack recognition, but in GZj CG worsened anticipation), there were improvements in attack recognition for IG in both attacks. At POST IG was able to respond more often to the movement stages 1 and 2.
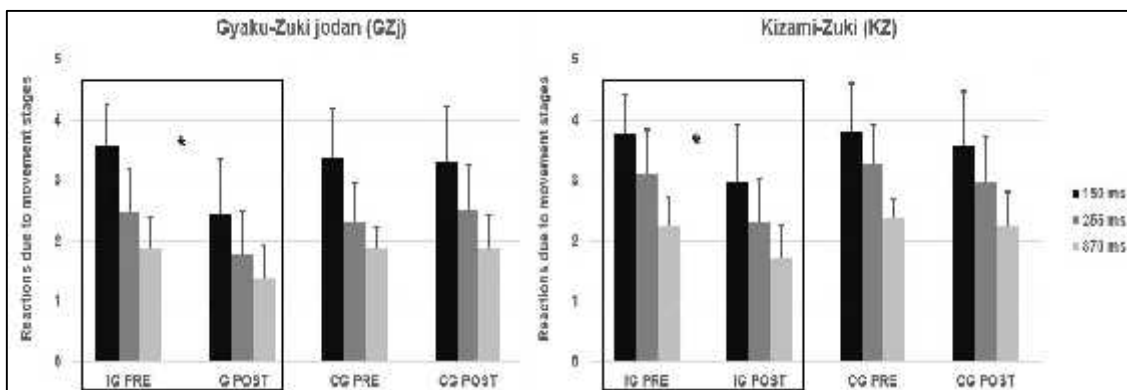
Figure 3. Mean and SD of the reactions due to the movement stages (1 - 4). Frames and *: significant differences in attack recognition of the intervention group from PRE to POST in both attacks.

A VR training was performed where young karate athletes responded sports specifically in ten sessions à 10 – 15 minutes to attacks of a virtual character. We expected improvements in attack recognition for the intervention group to recognize attacks at early movement stages in order to the VR training. This expectation was confirmed. In the current study we could show that VR training integrated in the conventional training leads to significant improvements in the early recognition of the attacks GZj and KZ in VR compared to conventional training only. The improvements were highly significant for the intervention group compared to the control group, where no significant differences were found (except of the changes from PRE to POST with 255 ms). However, no significant interactions between the factors group, time and reaction time were found in neither of the attacks.

VR training improved participants' anticipation. This was evident in the pre- and posttest results. AT PRE the most frequent movement stages, to which the athletes responded, were 3 (ground contact after flight phase) and 4 (main phase of the attack by extension of the punching arm). At POST especially IG was able to recognize attacks in movement stage 2, which contains the last step and the reduction in distance, and movement stage 1 (early steps, preparation phase). Thus, the athletes were able to recognize the upcoming attacks earlier and therefore had more time for their own motor response.

These results are in line with the results of a cross-sectional in-situ study from Petri et al. (2018a), who also found movement stage 2 being the most important stage. Furthermore, it could already be shown in Petri et al. (2016) that the reduction in distance was an important anticipatory cue. However, it is possible that our athletes recognized the attacks at an even earlier time. Dicks, Button and Davids (2010) observed that athletes responded dependent on their motor skills. Highly-skilled athletes often have fast motor times and thus, have more time in their information intake and can wait a little longer with their motor response compared to less experienced athletes who often have low motor skills, and hence, have to respond to earlier information to have enough time to start and complete their reaction. Therefore, expert athletes with fast motor skills are more robust against deceptive movements because they can wait longer and watch later movements where it is unlikely that feints occur (Güldenpenning, Kunde & Weigelt, 2017). Furthermore, it is possible that skilled athletes not only use one anticipatory cue, but several cues as a meaningful interplay of the whole body

(Dicks, Button & Davids, 2010). Or highly skilled athletes watch different relevant signals at different times in the movement (Jackson & Mogan, 2007). Loffing and Hagemann (2014) as well as Smeeton and Huys (2011) are of the opinion that expert athletes use global signals from the whole body to be less prone to deceptive movements and that they also take the dynamic of the movement into account. Hence, it is possible that not only the reduction of distance between both athletes, but also the fast reduction are anticipatory cues in the present study.

We conducted an intervention study as demanded by Farrow and Raab (2008) to investigate the improvements in early attack recognition. This is one of the first intervention studies which proved the benefits of VR on perception and reaction skills. Such an intervention using standardized VR could also be used for running an experiment to assess the effect of the found anticipatory cues.

VR is a quite new technology and thus, many open questions remain, such as concrete training recommendations in VR or positive transfer from VR training into reality (Petri, Bandow & Witte, 2018, Petri et al., 2018b). VR can be a suitable tool to improve the athletes' performances as it was also shown in our study. Gray (2017) used VR to improve performance in baseball and found better effects of VR training compared to conventional training and also positive transfer from VR training into reality. Furthermore, Rauter et al. (2013) and Varlet et al. (2014) found that VR training can improve performance in reality. On the other hand, Tirp et al. (2015) showed that VR training leads to the same performance in VR and reality, but there was a difference in the motion execution and gaze behavior. Thus, more studies with high-skilled athletes are necessary to further conduct interventions using VR.

In a critical analysis, Düking, Holmberg and Sperlich (2018) state that VR can be a useful tool in sports science with several advantages, such as implementation of feedback, standardized conditions, and individual training independent of location, time and other people. However, there is a dependence on technologies and a huge amount of data recording for the creation of realistic avatars what produces high costs. Furthermore, there exists the threat that VR can lead to excessive or too little demand due to the lack of concrete training recommendations for different sports and athlete types. Future studies are needed that compare movement execution, gaze behavior and decision making in VR and in reality with sports specific tasks. Our developed training schedule can be seen as a first step to create such training recommendations. With that training schedule, we were able to induce improvements in the perception of anticipatory cues. Thus, we invite other researchers or coaches to also apply the developed schedule.

Limitations of the study

We have to mention critically that the current study could only show improvements in VR. We were not able to analyze the transfer into reality as demanded by Gray (2017). In future studies, transfer should be tested in pre- and posttests by use of real attackers to which the tested athletes should also respond to, or by use of interviews or questionnaire, with which athletes, and coaches could rate athletes' behavior in reality. Further analysis could also include the coupling of several methods, such as eyetracking, occlusions and virtual reality (Miles et al., 2012) or methods of data mining which could determine characteristics in these early steps on the basis of precise motion capturing data.

It was not possible for us to influence the karate training in reality. Therefore, we were unable to perform a similar reaction training in reality for the control group as it was conducted with the intervention group. This is a task for us in future studies. We could only include fifteen athletes in our study. Therefore, we could analyze only seven athletes as control group and eight athletes as intervention group. Thus, in future studies, it would be desirable to include more participants.

Since tools for the analysis of sports specific reaction times in karate kumite are still lacking, we tried to analyze anticipatory cues by subtraction of reaction times based on literature values. However, we are unable to recommend which value should be taken in future studies because improvements in anticipation in the intervention group could be detected with all reaction values. Significant differences from PRE to POST could be detected with 255 ms in the control group, thus, it is possible that 255 ms ist the best from the presented three values, but further studies are needed to confirm that idea.

CONCLUSION

In the present study we could show that the (fast) reduction of distance and early steps contain anticipatory signals. Especially the reduction of distance (movement stage 2) and early steps (movement stage 1), which was often accompanied with a lowering of the center of pressure to prepare the takeoff for the flight phase in phase 2, seem to be important anticipatory cues for attack recognition. These new findings can be used in karate training to improve motor learning in beginners to enhance performance.

After consultation of our karate expert, it could also be possible to fixate the shoulder axis for early recognition of preparing movements, such as rotations around the longitudinal axis before moving forward of the pushing arm. Subtracting reaction times from the first reaction of the responding athlete is an appropriate method to analyze changes in perception and anticipation due to training in VR. All used reaction times were suitable to detect changes in the anticipatory cues.

REFERENCES

Bandow, N. (2016). Bestimmung der Antizipationsfähigkeit im Karate-Kumite unter Nutzung der virtuellen Realität. [Analysis of anticipation in karate kumite by use of virtual reality]. *Berlin: epupli Verlag*. ISBN: 978-3-7418-0131-0.

Craig, C. (2013). Understanding perception and action in sport: how can virtual reality technology help? *Sports Technology*, 6 (4), 161-169. DOI: 10.1080/19346182.2013.855224.

Dicks, M., Button, C. & Davids, K.-W. (2010). Availability of advance visual information constrains association-football goalkeeping performance during penalty kicks. *Perception*, 39 (8), 1111 1124.

Düking, P., Holmberg, H.-C. & Sperlich, B. (2018). The potential usefulness of virtual reality systems for athletes: a short SWOT analysis. *Frontiers in Physiology*, 9: 128. DOI: 10.3389/fphys.2018.00128.

Farrow, D., & Raab, M. (2008). A recipe for expert decision making. In D. Farrow, J. Baker, & C. MacMahon (Eds.), Developing Sport Expertise: Researchers and coaches put theory into practice. (pp. 137-154). *London, New York: Routledge*.

Gardner, M.P., Mitchell, A.A. & Russo, J.E. (1978). Chronometric Analysis: An introduction and an application to low involvement perception of advertisements. *Advances in Consumer Research*, 5, 581-589.

Gray, R. (2017). Transfer of training from virtual to real baseball batting. *Frontiers in Psychology*, 8, 2183, 1-10. DOI: 10.3389/fpsyg.2017.02183.

Güldenpenning, I., Kunde, W. & Weigelt, M. (2017). How to trick your opponent: a review article on deceptive actions in interactive sports. *Frontiers in Psychology*, 8:917. DOI: 10.3389/fpyg.2017.00917.

Hartnagel, D., Taffou, M. & Sandor, P.M.B. (2017). Effects of short exposure to a simulation in a head-mounted device and the individual difference issue. In: C. Stephanidis (ed.) HCI International 2017, Part II, CCIS 714, 9-16. *Springer International Publishing*. DOI: 10.1007/978-3-319-58753-0_2.

Hristovski, R., Davids, K., Araújo, D., & Button, C. (2006). How boxers decide to punch a target: emergent behaviour in nonlinear dynamical movement systems. *Journal of Sports Science & Medicine*, 5 (CSSI), 60-73.

Ida, H. (2015). Visuomotor behavior in computer-simulated display. In: T. Heinen (ed). *Advances in Visual Perception Research*, 233-367. ISBN: 978-1-63482-455-2.

Jackson, R.C. & Mogan, P. (2007). Advance Visual Information, Awareness, and Anticipation Skill. *Journal of Motor Behavior*, 39 (5), 341–351.

Lin, C.J. & Woldegeorgis, B.H. (2015). Interaction and visual performance in stereoscopic displays: a review. *Journal of the Society for Information Display*, 23, 319-332. DOI: 10.10002/jsid.378.

Loffing, F. & Hagemann, N. (2014). Skill differences in visual anticipation of type of throw in team-handball penalties. *Psychology of Sport and Exercise*, 15, 260-267.

Milazzo, N., Farrow, D. & Fournier, J. F. (2016). Effect of implicit perceptual-motor training on decision-making skills and underpinning gaze behavior in combat athletes. *Perceptual and Motor Skills*, 123 (1), 300-323. DOI: 10.1177/0031512516656816.

Miles, H.C., Pop, S.R., Watt, S.J., Lawrence, G.P. & John, N.W. (2012). A review of virtual environments for training in ball sports. *Computer & Graphics*, 36, 714-726.

Mori, S. & Shimada (T. (2013). Expert anticipation from deceptive action. *Attention, Perception & Psychophysics*, 75, 751–770.

Müller, S. & Abernethy, B. (2012). Expert Anticipatory Skill in Striking Sports: A Review and a Model. Research Quarterly for Exercise and Sports. *Physical Education, Recreation and Dance*, 83 (2), 175-187.

Müller, S., Gurisik, Y., Hecimovich, M., Harbaugh, A.G. & Vallence, A.-M. (2017). In-dividual differences in short-term anticipation training for high-speed interceptive skill. *Journal of Motor Learning and Development*, 5, 160-176.

Okumura, M., Kijima, A., Kadota, K., Yokoyama, K., Suzuki, H., & Yamamoto, Y. (2012). A critical interpersonal distance switches between two coordination modes in kendo matches. *PloS ONE*, 7 (12): e51877.

Okumura, M., Kijima, A., & Yamamoto, Y. (2017). Perception of affordances for strik-ing regulates interpersonal distance maneuvers of intermediate and expert players in kendo matches. *Ecological Psychology*, 29 (1), 1-22. DOI: 10.1080/10407413.2017.1270147.

Petri, K., Bandow, N. & Witte, K. (2018). Using several types of virtual characters in sports - a literature survey. *International Journal of Computer Science in Sport*, 17 (1), 1-48. DOI: 10.2478/ijcss-2018-0001.

Petri, K., Bandow, N., Binder, J., Droste, M. & Witte, K. (2018a). Antizipation im Karate-Kumite [Anticipation in karate kumite]. In: I.Fichtner (Ed.), Technologien im Leistungssport 3: Schriftenreihe für Angewandte Trainingswissenschaft, 13, pp.74-88. *Aachen: Meyer und Meyer.*

Petri, K., Emmermacher, P., Danneberg, M., Masik, S., Eckardt, F., Weichelt, S., Bandow, N. & Witte, K. (2019). Training using virtual reality improves response behav-ior in karate kumite. *Sports Engineering*, 22:2. DOI: 10.1007/s12283-019-0299-0.

Petri, K., Lichtenstein, M., Bandow, N., Campe, S., Wechselberger, M., Sprenger, D., Kaczmarek, F., Emmermacher, P. & Witte, K. (2016). Analysis of Anticipation by 3D motion capturing – a new method presented in karate kumite. *Journal of Sport Science*, 35 (2): 130-135. DOI: 10.1080/02640414.2016.1158851.

Petri, K., Ohl, C.-D., Danneberg, M., Emmermacher, P., Masik, S. & Witte, K. (2018b). Towards the usage of virtual reality for training in sports. *Biomedical Journal of Scientific & Technical Research*, 7 (1), 1-3. DOI: 10.26717/BJSTR.2018.07.001453

Petri, K., Witte, K., Bandow, N., Emmermacher, P., Masik, S., Danneberg, M., Salb, S., Zhang, L.& Brunnett, G. (2017). Development of an autonomous character in karate kumite. Proceedings of the 11th International Symposium on Computer Science in Sport (IACSS 2017), Advances in Intelligent Systems and Computing 663. *Springer International Publishing*. DOI: 10.1007/978-3-319-67846-1_13.

Rauter, G., Sigrist, R., Koch, C., Crivelli, F., vaan Raai, M., Reiner, R. et al. (2013). Transfer of complex skill learning from virtual to real rowing. *PLoS ONE*, 8: e82145. DOI: 10.1371/journal.pone.0082145

Rebenitsch, L. & Owen, C. (2016). Review on cybersickness in applications and visual displays. *Virtual Reality*, 20: 101-125. DOI: 10.1007/s10055-016-0285-9

Renner, R.S., Velichkovsky, B.M. & Helmert, J.R. (2013). The perception of egocentric distances in Virtual Environments a Review. *ACM Computing Surveys*, 42 (2), Article No. 23. DOI: 10.1145/2543581.2543590.

Smeeton, N.J. & Huys, R. (2011). Anticipation of tennis-shot direction from whole-body movement: the role of movement amplitude and dynamics. *Human Movement Science*, 30, 957-965. DOI: 10.1016/j.humov.2010.07.012.

Tirp, J., Steingrover, C., Wattie, N., Baker, J. & Schorer, J. (2015). Virtual realities as optimal learning environment in sport-A transfer study of virtual and real dart throwing. *Psychological Test and Assessment Modeling*, 57, 57-69.

Varlet, M., Filippeschi, A., Ben-sadun, G., Ratto, M., Marin, L., Ruffaldi, E. & Bardy, B.G. (2013). Virtual Reality as a Tool to Learn Interpersonal Coordination: Example of Team Rowing. *Presence: Teleoperators and Virtual Environments*, 22 (3), 202-215. DOI: 10.1162/PRES_a_00151.

Vignais, N., Bideau, B., Craig, C., Brault, S., Multon, F., Delamarche, P. & Kulpa, R. (2009). Does the level of graphical detail of a virtual handball thrower influence goalkeeper's motor response? *Journal of Sports Science and Medicine*, 8, 501-508.

Vignais, N., Kulpa, R., Brault, S., Presse, D. & Bideau, B. (2015). Which technology to investigate visual perception in sport: video vs. virtual reality. *Human Movement Science*, 39, 12-26. DOI: 10.1016/j.humov.2014.10.006.

Von, O. E. (1984). *Aufnahme und Verarbeitung bewegungsinitiierender Information für situations-und zeitgerechtes Verhalten-Angriff und Konter im Karate [Perception and Processing of movement initiating information for adequate reaction-attack and counterattack in karate]*. Bremen: University Erfurt, Germany.

Zaciorskij, V. M. (1971). Theorie und Praxis der Körperkultur-Die körperlichen Eigenschaften des Sportlers [Theory and praxis of body culture-physical characteristics of athletes]. *Sportverlag*, 2, 1-119.