Possibilities To Use A Virtual Opponent For Enhancements Of Reactions And Perception Of Young Karate Athletes

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Abstract

We conducted a virtual reality (VR) training with ten sessions, performed by fifteen young karate athletes, who responded to attacks of a virtual opponent to improve their response behavior and their decision-making. The control groups continued with their normal training. Results of the Friedman tests with subsequent Dunn-Bonferroni post-hoc-tests and estimation of effect sizes showed that the karate specific response behavior (measured by a movement analysis) improved significantly due to the training. The parameters time for response (as the time for the attack initiation) and response quality improved with large effect sizes for the intervention groups, whereas the control groups demonstrated improvements with only small effect sizes. The unspecific response behavior (analyzed by two forms of the reaction test of the Vienna test system) did not show any significant changes. Paired t-tests revealed an improvement in attack recognition. While in the pretests, the intervention groups responded to late movement stages of the attack (execution of the main phase), they responded to early movement stages (reduction of distance and preparing steps) in the posttests. Furthermore, Friedman-tests and bivariate correlation analysis showed that the intervention groups were highly motivated to perform the VR training because of the new and safe learning conditions.

KEYWORDS: VIRTUAL REALITY, VR TRAINING, RESPONSE BEHAVIOR, ATTACK RECOGNITION, ANTICIPATION

Introduction

Virtual Reality (VR) is an often-used tool in sports (Petri, Bandow & Witte, 2018) to analyze perception-action-coupling and decision making (Craig, 2013) and to improve performance due to training (Gray 2017). However, there is a lack in training studies using immersive VR with experienced athletes (Donath, Rössler & Faude, 2016, Petri et al., 2018).

VR provides many advantages, such as standardized and controllable conditions with depth information and realistic environments, where sports specific behavior can be performed (Petri, Bandow & Witte, 2018). Three types of virtual environments (VE) exist: VE without a virtual character, VE with a passive character, and VE with an autonomous character. Autonomous characters, which can adapt their reactions to the positions and movements of the user are rare in sports (for further detail see Petri et al., 2017, Zhang et al., 2018). Passive characters, which cannot take the positions and movements of the user into account, exist more frequently in sport related VEs. The majority of such passive characters are acting as an opponent (Petri, Bandow & Witte, 2018). Most studies in the past used a CAVE (CAVE Automatic Virtual Environment) or a Powerwall as output devices (Miles et al., 2012), but nowadays, HMDs (Head Mounted Displays) are more common, as they became very cheap, light weighted and small since they reached market readiness. Furthermore, they offer more room for sports specific movements than CAVEs or Powerwalls (Petri et al., 2017). Additionally, symptoms of cybersickness (discomfort due to immersing in VE) decreased in the last few years due to technical improvements in HMDs (Rebenitsch & Owen, 2016).

There are several training studies in karate kumite, which showed improvements in the response behavior in reality (e.g. Milazzo, Farrow & Fournier, 2016, 2014). Especially the study of Milazzo, Farrow and Fournier (2016) showed that the response behavior and the gaze behavior of karate athletes could be improved due to the training of reactions towards attacks in video footage. However, no study has investigated the response behavior, the decision making and the subjective feeling of experienced athletes due to training in immersive VR.

Therefore, we conducted a study similar to the study from Milazzo, Farrow and Fournier (2014), in which karate athletes responded to attacks of a virtual passive opponent in a VR training. Please note that the passive attacker performed attacks, but the character was not able to take the position or the movements of the athlete into account. Our aim was to improve the unspecific and the sports specific response behavior and the recognition of attacks in young karate athletes during training in VR and to further analyze the motivation of these athletes during the course of the training.

Because of the benefits in response behavior and gaze behavior during the training in reality (Milazzo, Farrow & Fournier, 2016), we also expected improvements in the reactions of young karate athletes as well as enhancements in the recognition of karate attacks in VR training.

Methods

Participants and study design

The participants were divided into three groups: five athletes for the creation of the virtual opponent, 32 athletes for the evaluation of the VR and the opponent, and 15 athletes, who performed the VR training.

We recorded relevant karate movements of five male karate kumite athletes (age 24-56 years) who had long-term international success (1st to 4th Dan). For the evaluation of the VR and the created opponent, 32 karate athletes (age 14-64 years, recreational level and high-performance

level, but at least three years of karate kumite experience) tested the VR and gave feedback. Twelve athletes (5 women and 7 men) were expert athletes (1st to 4th Dan) with international competition experience, eleven athletes (3 women and 8 men) were advanced (5th Kyu to 1st Kyu) with national competition experience and nine athletes (1 woman and 8 men) practiced only at recreational level without any competition experiences.

Fifteen karate kumite athletes (five women and ten men, 4th Kyu to 1st Kyu) at the age of 13-18 years took part in the intervention study. They practiced the Shotokan style and had at least five years of competition experience at national level. The athletes were randomly assigned into two groups: A and B. According to our cross-over-design, we had two intervention phases with the VR training. In phase 1 (PRE1 to POST1), group A underwent the VR intervention and group B served as the control group, while in phase 2 (PRE2 to POST2), both groups interchanged their trainings (Fig.1). The control groups (group B in phase 1 and group A in phase 2) received only their regular karate training with 90 minutes (twice a week for six weeks). The intervention groups (group A in phase 1 and group B in phase 2) received VR training integrated in the course of the regular training with 10-15 minutes VR training per session and participant. In the end, we could perform ten sessions with VR training over six weeks in each phase.

All athletes were informed about the procedure, took part on a voluntary basis and gave their written consent. The ethical approval was obtained by the first author's university.

Fig. 1: Study design: cross-over study with fifteen karate kumite athletes.

Procedure

Creation of the virtual opponent

The virtual opponent was created based on motion capture data of five male karate kumite experts with long-term international competition experience. According to previous competition analysis in karate kumite (Petri et al., 2017) and in consultation with an expert coach, we decided to integrate two attack combinations and several single attacks into the virtual character: Gyaku-Zuki, Gyaku-Zuki overrun, Kizami-Zuki, Uraken (all arm techniques), and Mawashi-Geri (foot technique). All attacks were performed with both arms and legs and towards several attack areas. A sport hall with a combat area served as the virtual environment. For further information concerning the creation of the used VR, we refer to Petri et al. (2017). We only created a visual stimulus in our VR without further auditory or tactile feedback because Gierczuk, Lyakh, Sadowski and Bujak (2017) stated that the visual sensor is the most important one in martial arts.

Evaluation of the VR

The created virtual environment and the virtual opponent were evaluated with thirty-two karate athletes, who had all at least three years of karate experience. The athletes wore a HMD (Oculus Rift DK2, Oculus VR, USA) and two hand targets (A.R.T., Weilheim, Germany) for

better orientation and tested the VR for 10 to 15 minutes. Afterwards, they filled out two questionnaires: Simulator Sickness Questionnaire (SSQ) and Igroup Presence Questionnaire (IPQ, Schubert, Friedmann & Regenbrecht, 1999). SSQ was analyzed according to the guidelines in Kennedy, Lane, Berbaum and Lilienthal (1993). The total score for our VR was 0.18 while the score for nausea was 0.08, the score for oculomotor was 0.19 and the score for disorientation was 0.21. Thus, we had a D>O>N-profile and only negligible symptoms of cybersickness. Mean $\pm$ SD values for the items of the IPQ are given in Table 1. Cronbach's alpha of the IPQ was 0.766, thus acceptable. The participants rated the VR and the virtual opponent to be realistic. They felt present and involved in the VR. However, they were aware that the virtual environment was not reality.

Tab. 1: Results of the items of the IPQ.

Item	Mean $\pm$ SD
	0: fully disagree
	3: fully agree
I did not feel like I was just perceiving pictures.	2.63 $\pm$ 0.71
I felt present in the virtual space.	2.6 $\pm$ 0.56
I did not feel that I was not present in the virtual space.	2.44 $\pm$ 0.62
I had a sense of acting in the virtual spacer, rather than operating something from outside.	2.44 $\pm$ 0.62
I was completely captivated by the virtual world.	2.31 $\pm$ 0.82
Somehow I felt that the virtual world surrounded me.	2.13 $\pm$ 0.9
In the computer generated world I had the sense of "being there".	2.09 $\pm$ 0.82
I was not aware of my real environment.	1.91 $\pm$ 0.89
The virtual world seemed real to me.	1.88 $\pm$ 0.66
I was not aware of the real world surrounding while navigating in the virtual world.	1.84 $\pm$ 0.81
I did not pay attention to the real world.	1.78 $\pm$ 1.04
My experience in the virtual environment seemed consistent with my real world experiences.	1.72 $\pm$ 0.63
The virtual environment seemed real to me.	1.38 $\pm$ 0.61
The virtual world seemed more realistic than the real world.	0.5 $\pm$ 0.72

VR training

In the VR training the fifteen karate athletes responded karate specifically to attacks of a virtual character, which was displayed in an HMD (Fig.2). The athlete's hands were visualized by two hand targets while the rest of the body was not visualized.

In consultation with our expert coach, we developed a schedule for our VR training. In each session, four sets à 6-8 attacks were performed to which the athletes responded. Between each attack, a pause of three seconds was maintained and between the sets the athletes could relax for two to three minutes. For further detail, see Table 2.

Fig. 2: An athlete (B) steps in place, waiting for an attack of the virtual opponent (A), and is instructed to react to the attack as he would do to an attack of a real opponent.

Tab. 2: Training schedule for the single sessions. GZ: Gyaku-Zuki, GZo: Gyaku-Zuki overrun, KZ: Kizami-Zuki, U: Uraken, MG: Mawashi-Geri. Chudan: attack towards the chest. Jodan: attack towards the head. VC: virtual character. VC 1-5: motion data sets 1-5 of the five karate experts, who embody the virtual opponent. Attack combinations: 1 = Gyaku-Zuki-Mawashi-Geri, 2= Kizami-Zuki-Gyaku-Zuki.

Training session	contents
1	<ul style="list-style-type: none"> only GZ chudan / jodan with right arm, VC 1-5 display of attack
2	<ul style="list-style-type: none"> repetition of GZ KZ with left arm, VC 1-5
3	<ul style="list-style-type: none"> repetition of KZ with left arm GZ with right and left arm, VC 1-5
4	<ul style="list-style-type: none"> GZ jodan with left arm of VC 5 GZ chudan / jodan, VC 1-5 KZ with right arm, VC 1,2
5	<ul style="list-style-type: none"> KZ with right arm, VC 1,2 MG jodan / chudan with left leg, VC 2
6	<ul style="list-style-type: none"> MG chudan rear leg, VC 1 MG jodan / chudan with front and rear leg, VC 1,2
7	<ul style="list-style-type: none"> MG jodan / chudan with right rear leg, VC 2 GZo, VC 3,4 MG jodan / chudan, VC 1,4
8	<ul style="list-style-type: none"> MG jodan / chudan with right rear leg, VC 1, GZo, VC 3+4 attack combination 1 and 2, VC 2 Uraken, VC 5
9	<ul style="list-style-type: none"> attack combination 1 and 2, VC 1 GZ chudan / jodan with left and right arm, VC 1-5 KZ with left and right arm, VC 1-5
10	<ul style="list-style-type: none"> randomized attacks of all VCs

In the pre- and posttests, we analyzed the unspecific and the karate specific response behavior. To measure the unspecific response behavior, we used two subtypes of the reaction test of the Vienna test system (Schuhfried, Vienna, Austria): S1 (simple reaction test) and S4 (recognition reaction test). In both tests, the parameters reaction time (RT, time between the onset of the visual stimulus and the release of the start button) and motor response time (MT, time between the release of the start button and the pushing of the destination button) were measured at 1000 Hz.

In order to analyze the karate specific response behavior, we conducted a movement analysis applying two synchronized high-speed cameras (Contemplas, Kempten, Germany, 100 Hz) and recorded the attack of the virtual character and the reaction of the real athlete synchronously. We projected the virtual opponent on a large screen using a rear projection beamer, and the virtual opponent performed 22 single attacks: 8 Gyaku-Zuki jodan (target area head), 3 Gyaku-Zuki chudan (target area chest) 8 Kizami-Zuki (target area head), and 3 Mawashi-Geri with the rear leg chudan (target area chest). We analyzed the parameters time for response as the time between the beginning of the virtual attack (the beginning of the extension of the punching arm or the forward movement of the kicking leg) and the beginning of the reaction of the karate athlete (either the movement of the blocking hand, the beginning of the forward movement of the punching arm or preparing movements in the legs), and response quality, which was assessed by a scoring system. 0 points were given if the athlete could not prevent the upcoming attack, 1 point if the athlete prevented the attack by a block or an evasive movement and 2 points if the athlete performed a direct and successful attack without a previous block. Inter-rater reliability was analyzed with Cohen's kappa (k) and good reliability between two raters was achieved for time for response and response quality (both $k > 0.81$).

By the use of a short feedback questionnaire, which the athletes filled out after each VR training session, we examined the subjective estimation of the athletes. On a scale from 1 (does not apply for me at all) to 10 (fully applies to me), the athletes should rate the following statements: "The fight against the virtual character makes fun". "The VR training is exhausting". "My responsiveness improves in order to the VR training". "I can react to the attacks of the virtual character as I do to attacks of a real athlete".

Furthermore, we analyzed if the VR training led to improvements in the recognition of the upcoming attacks. Therefore, we divided the attacks in four movement stages (Tab. 3). We examined if the recognition of the attacks Gyaku-Zuki jodan (GZj, $n=8$) and Kizami-Zuki (KZ, $n=8$) (both target area head) improved for both intervention groups (group A in phase 1 and group B in phase 2, $n=15$) from the pre- to the posttests. The movement classification applies for both attacks and is based on the work of Bandow (2016). We chose these two attacks because they belong to the most frequently and most successfully performed attacks in international karate kumite competitions (Petri et al., 2017).

According to the method already described in Petri et al. (2016), 150 ms as assumed reaction times (bases on literature values from Zaciorskij, 1971) were subtracted from the time of the first reaction of the karate athlete to analyze the attack motion at the time of the recognition. Already Bandow (2016) had shown that the subtraction of reaction times from the first reaction of the responding athletes can be used to analyze relevant signals which are used to recognize an upcoming attack. With that method we aimed to examine if relevant signals changed according to the VR training. We used that value from the literature but we are aware that it is likely that this single value would not be valid for each athlete.

Tab. 3: Classification of the movement stages of Gyaku-Zuki jodan and Kizami-Zuki.

Movement stage	Description
1	Early steps
2	Last step before the attack started. Reduction in distance by a flight phase towards the opponent
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.
4	Main phase of the attack: the front foot moves forward and the pushing arm moves also forward until the arm is extended.

However, there is a lack in instruments with which it is possible to measure sports specific reaction times in karate and therefore, we decided to use the literature value to compare perception between pre- and posttests.

Analysis of data

All videos from the movement analysis (1,320 videos from both groups) and from the analysis of the attack recognition (480 videos (Kizami-Zuki and Gyaku-Zuki jodan from the intervention groups)) were analyzed with the open source software Kinovea.

The unspecific parameters reaction times and motor response times of S1 and S4 and the karate specific parameters time for response and response quality were analyzed within each group (group A and group B) at the four times PRE1, POST1, PRE2 and POST2 using the Friedman test with subsequent Dunn-Bonferroni post-hoc tests. For the detection of effect sizes Pearson's ratio was applied with the following classifications $r < 0.3$ small, $r = 0.3-0.5$ moderate and $r > 0.5$ large effect size. Furthermore, group comparisons were calculated at the four times PRE1, POST1, PRE2 and POST2 using one-factorial analysis of variances for each parameter. Effect sizes were also analyzed with Pearson ratio and the given classification.

The feedback questionnaires at all ten training sessions were examined applying the Friedman tests and subsequent Dunn-Bonferroni post-hoc-tests and estimation of effect sizes (Pearsons r) to analyzes differences over time for each item. Furthermore, bivariate correlations with spearman-rho-coefficient (r) and the before mentioned classification were carried out to analyze correlations between the items.

The attack recognition from pretests to posttests for the VR trainings groups (group A in phase 1 and group B in phase 2) was analyzed by paired t-tests for GZ and KZ.

The level of significance of all tests was set at $\alpha < 0.05$. All statistics were performed with the software SPSS (IBM, Germany, version 25).

Results

Unspecific response behavior

There were no significant changes in the reaction time and the motor response time within the groups over time and between the groups at PRE 1, POST1, PRE2 and POST2 (all $p > 0.05$). The values of the reaction times of S1 were around 200-230 ms and of S4 around 300-350 ms at all times. The values of the motor response times of S1 and S4 were around 85-100 ms at all times.

Karate specific response behavior – time for response

One factorial analysis of variance showed significant group differences at POST1, PRE2 and POST2 (all $p < 0.05$), but not at PRE1, indicating that both groups had the same performance level at PRE1. At POST1, PRE2 and POST2 the groups, which had received the VR training, always had a shorter time for response. Friedman-tests for group A (intervention group in phase 1) showed significant reductions for all attacks and for several single attacks with large effect sizes ($r > 0.5$). The same reduction was seen for group B (intervention group in phase 2, $p < 0.05$, $r > 0.5$). In phase 1, group B, serving as the control group, also showed significant improvements in time for response ($p < 0.05$), but these improvements had only a moderate effect for all attacks ($r > 0.3$) and small effects for several single attacks ($r > 0.1$) (see also Fig.3).

For group A, which was the intervention group in phase 1, we found at PRE1 values of 162.18 ± 90.77 ms for all attacks. According to the VR training, we detected a significant decrease in time for response at POST1 with 73.26 ± 114.51 ms. That result was similar for several single attacks: GZj (PRE1: 166 ± 91.84 ms, POST1: 44 ± 122.76 ms), KZ (PRE1: 160.95 ± 94.95 ms, POST1: 79.63 ± 104.44 ms), and MG (PRE1: 81.25 ± 60.74 ms, POST1: 24.35 ± 60.35 ms).

For group B, which was the intervention group in phase 2, we found the same improvements as described in group A. At PRE2, we observed 119.86 ± 94.83 ms for time for response for all attacks, and a significant reduction at POST2 with -8.57 ± 140.84 ms. Furthermore, we found the same improvements for the single attacks: GZj (PRE2: 93.04 ± 94.83 ms, POST2: -40.4 ± 122.27 ms), GZc (PRE2: 229.05 ± 51.37 ms, POST2: 160.48 ± 54.54 ms), KZ (PRE2: 118 ± 122.65 ms, POST2: -35.69 ± 150.3 ms), and MG (PRE2: 45.24 ± 78.52 ms, POST2: -51.5 ± 91.95 ms). Group B was often able to respond to early signals being located in movement phases which occurred before the main phase (extension of the punching arm or kicking leg). Here, we assume that group B not only showed fast specific reaction times, but also an efficient anticipation based on the perception of early anticipatory signals. Therefore, we also conducted an analysis of attack recognition (Tab. 6).

We also found a significant increase in time for response (decreased times) for group B, which was the control group in phase 1, for all attacks (PRE1: 178.14 ± 90.47 ms, POST1: 131.68 ± 86.93 ms), GZj (PRE1: 183.57 ± 80.64 ms, POST1: 128 ± 82.76 ms), GZc (PRE1: 239.52 ± 53.15 ms, POST1: 193.33 ± 61.02 ms), and KZ (PRE1: 185.45 ± 93.27 ms, POST1: 129.73 ± 94.46 ms). However, no significant differences (all $p > 0.05$) were found for group A, which was the control group in phase 2. The levels of group A at POST1 remained stable at PRE2 and POST2. Therefore, the benefits persisted over several months.

Karate specific response behavior – response quality

One-factorial analysis of variance showed significant group differences between the groups at POST1, PRE2 and POST2 (all $p < 0.05$), but not at PRE1, indicating that both groups had the same performance level at PRE1. At POST1, PRE2 and POST2 the groups, which had received the VR training, always had a better response quality. Friedman-tests for group A (intervention group in phase 1) showed significant improvements for all attacks and for several single attacks with large effect sizes. The same improvement was seen for group B (intervention group in phase 2). However, none of the control groups showed significant improvements in response quality (see also Fig.4).

Fig. 3: Time for response. Framed: phases of VR training for the groups. $r > 0.05$: significant reduction in time of response with large effect sizes for the VR training groups. $r < 0.05$: significant reduction in time for response for the control group in phase 1 with moderate effect size.

For group A, which was the intervention group in phase 1, we found a significant increase in response quality (higher scores) for all attacks (PRE1: 0.37 ± 0.66 , POST1: 0.92 ± 0.09), GZj (PRE1: 0.47 ± 0.69 , POST1: 1.25 ± 0.84), and MG (PRE1: 0.79 ± 0.98 , POST1: 1.52 ± 0.85).

For group B, which was the intervention group in phase 2, we also observed a significant increase in response quality for all attacks (PRE2: 0.55 ± 0.78 , POST2: 1.49 ± 0.87), GZj (PRE2: 0.84 ± 0.78 , POST2: 1.84 ± 0.55), GZc (PRE2: 0.05 ± 0.22 , POST2: 0.62 ± 0.92), KZ (PRE2: 0.29 ± 0.68 , POST2: 1.33 ± 0.95), and MG (PRE2: 1.4 ± 0.85 , POST2: 2 ± 0).

No significant differences were found for the control groups. However, the benefits of the VR training remained stable in group A over several months.

Fig. 4: The scores as response quality. 0: athlete did not prevent the attack. 1: athlete prevented the attack by a block or evasive movement. 2: athlete performed a direct and successful attack. Framed: phases of VR training for the groups. $r > 0.05$: significant improvements in response quality with large effect sizes due to VR training.

VR training – feedback questionnaires

Concerning the statements “The VR training is exhausting.”, “My responsiveness improves in order to the VR training.”, and “I can react to the attacks of the virtual character as I do to attacks of a real athlete.” no significant differences were found over time (all $p > 0.05$). However, a significant difference was detected for the statement “The fight against the virtual character makes fun.” ($p = 0.045$). In the post-hoc-analysis, significant improvements were only seen between T3 and T7 ($p = 0.056$, $r = 0.6$) and between T3 and T8 ($p = 0.014$, $r > 0.7$). Mean $\pm$ SD values for all training sessions are given in Table 4.

Furthermore, we found positive correlations between all statements (all, $r > 0.3$, $p < 0.001$). For further detail see Table 5.

Tab. 4: Answers in the feedback questionnaires at the ten training sessions of all intervention groups as mean $\pm$ SD. T: training session. The answers were scaled from 1 (does not apply for me at all) to 10 (does fully apply to me).

Statement	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Friedman tests
The fight against the virtual character makes fun.	7.07 $\pm$ 1.64	6.83 $\pm$ 1.90	6.77 $\pm$ 2.09	6.57 $\pm$ 1.95	7.23 $\pm$ 2.05	6.77 $\pm$ 2.17	7.25 $\pm$ 1.96	7.43 $\pm$ 1.95	7.55 $\pm$ 1.75	7.71 $\pm$ 1.38	$X^2(9) = 18.031$, $p = 0.045$
The VR training is exhausting.	5.07 $\pm$ 1.64	5.25 $\pm$ 1.76	5.54 $\pm$ 1.45	5.93 $\pm$ 1.54	5.92 $\pm$ 1.75	6.60 $\pm$ 1.84	5.90 $\pm$ 1.66	6.38 $\pm$ 1.85	5.91 $\pm$ 1.76	5.70 $\pm$ 1.2	$X^2(9) = 11.981$, $p = 0.214$
My responsiveness improves in order to the VR training.	5.00 $\pm$ 2.32	5.50 $\pm$ 1.98	5.46 $\pm$ 2.03	6.14 $\pm$ 1.92	6.38 $\pm$ 1.71	6.70 $\pm$ 1.88	6.40 $\pm$ 1.77	6.20 $\pm$ 1.94	6.64 $\pm$ 1.56	7.00 $\pm$ 1.4	$X^2(9) = 15.923$, $p = 0.069$
I can react to the attacks of the virtual character as I do to attacks of a real athlete.	4.57 $\pm$ 2.3	5.58 $\pm$ 1.83	4.7 $\pm$ 2.36	4.71 $\pm$ 2.27	5.00 $\pm$ 1.47	4.90 $\pm$ 2.33	5.30 $\pm$ 2.6	4.85 $\pm$ 2.12	5.18 $\pm$ 2.14	5.10 $\pm$ 2.71	$X^2(9) = 9.000$, $p = 0.437$

Attack recognition

Results of the paired t-tests showed that both intervention groups significantly improved in the recognition of Gyaku-Zuki jodan and Kizami-Zuki from pre- to posttests. While in the pretests the later movement stages 3 and 4 were used for recognition, at the posttests, the attacks were recognized in the earlier movement stages 1 and 2. For further information see Table 6.

Tab. 5: Results of the bivariate correlations

Item correlation	Spearman Rho
The fight against the virtual character makes fun. x The VR training is exhausting.	$r=0.341$, $p<0.001$
The fight against the virtual character makes fun. x My responsiveness improves in order to the VR training.	$r=0.507$, $p<0.001$
The fight against the virtual character makes fun. x I can react to the attacks of the virtual character as I do to attacks of a real athlete.	$r=0.461$, $p<0.001$
The VR training is exhausting. x My responsiveness improves in order to the VR training.	$r=0.475$, $p<0.001$
The VR training is exhausting. x I can react to the attacks of the virtual character as I do to attacks of a real athlete.	$r=0.475$, $p<0.001$
My responsiveness improves in order to the VR training. x I can react to the attacks of the virtual character as I do to attacks of a real athlete.	$r=0.396$, $p<0.001$

Tab. 6: Recognition of the attacks according to the four movement stages. GZj: Gyaku-Zuki jodan. KZ: Kizami-Zuki.

GZ	movement stage	PRE [%]	POST [%]	paired t-test	KZ	movement stage	PRE [%]	POST [%]	paired t-test
	1	0	25.6	T(116)=15.108, $p<0.001$		1	0	21.7	T(117)=10.899, $p<0.001$
	2	13.3	47			2	7.6	33.3	
	3	22.5	18			3	7.6	10.8	
	4	64.2	9.4			4	84.8	34.2	

Discussion and future directions

Virtual environments with a passive opponent are quite easy to create (in comparison to an autonomous character) and are useful to improve the sports specific response behavior and perception in form of attack recognition in karate. We showed that the sports specific response behavior improved significantly with large effects for the parameters time for response and response quality due to VR training, while the unspecific response behavior did not show any significant differences. These results of the benefits in the sports specific parameters are in line with those of Milazzo, Farrow and Fournier (2014). For further information concerning the aspect of the response behavior we refer to Petri et al. (2019). While Petri et al. (2019) focused on the response behavior only, in the current study also the subjective evaluation of the participants during the VR intervention was analyzed as well as their changes in perception from pretests to posttests. Furthermore, it is important to note that we could show significant improvements for the intervention group in phase 1, and these positive effects remained stable about several month. That result is in line with the results of Gray (2017) who also carried out a retention test.

The results of the feedback questionnaire showed that the karate athletes had fun using VR for training and that their motivation remained quite stable. At the end of the intervention, the motivation was even slightly higher than at the beginning. We found a significant increase

from session three to session seven and eight. The reason for the great motivation was that VR provided a new training tool for our athletes and they could try new movements and reactions in a safe environment. This result is in line with previous statements of Cheung, Tunik, Adamomich and Boyd (2014) who reported that the application of VR in training can lead to greater motivation than conventional training only. While previous literature often assumed that VR can be used to increase participants' motivation, the current study can prove it statistically.

The level of subjective physical exhaustion for the athletes also remained stable but it was only moderate. Therefore, it would be appropriate to increase the difficulty of the VR training in future training studies. Thus, a greater number of attacks could be included per set or the pauses between the single attacks could be reduced from three seconds to one or two seconds. The athletes stated that their responsiveness improved because of VR training although this statement failed the level of significance. It is possible that with a larger sample size or with a longer training duration, significant differences over time would have been found. However, the athletes reported that they could not completely respond naturally to the attacks as they do to attacks of a real athlete. Reasons might be found in the missing tactile feedback (due to the missing touch, a blocking movement did not make sense and therefore the execution of the response had to be changed into a direct attack without a block) and the limited freedom of movement. According to the passive opponent, the athletes had to step in place and could only change their position when they reacted to the attack. It would be desirable for future training studies to perform such an intervention with an autonomous character which is able to recognize the position and the movements of the real athlete and can perform an adequate attack in order to the position and the appropriate distance between the athlete and himself self-reliantly (Petri et al., 2017, Zhang et al., 2018). Then the real athlete could step in place, as well as moving and rotating in all directions which is closer to a karate fight in reality. Furthermore, we found positive correlations between all items implying that the motivation was high when the athletes became familiar with VR training and felt that their response behavior improved. Therefore, it seems to be important to ensure enough time for familiarization and for building confidence in the new training tool. In addition, the level of physical demands should be chosen properly to the skill level for great motivation.

Furthermore, the results showed that the karate athletes improved in attack recognition. While in pretests they responded to late movement stages three and four (landing after flight phase and beginning of the main movement stage with the extension of the punching arm), in posttests, they responded to the early movement stages one and two (early steps and the reduction of distance). The current study confirmed the previous results of Petri et al. (2016), where the distance was found to be a potential anticipatory cue in karate kumite. Furthermore, early steps seem to contain relevant signals. In 2016 Bandow could already identify further anticipatory cues in the karate attacks Gyaku-Zuki, Kizami-Zuki and Mawashi-Geri. Once these relevant signals are validated, VR could also be used for anticipation training to further improve the attack recognition and the gaze behavior.

It would also be desirable to develop a low impact cognitive training, as it is already demanded by Farrow and Raab (2018). Such training could be used for perception or anticipation training, in which athletes could view different attacks or other movement executions performed by controllable virtual characters and learn to perceive relevant signals or to deepen the knowledge about correct movement executions.

VR training, either in addition to the normal training or integrated in the course of the normal training is helpful to enhance the performance of young karate athletes. The present case of ten training sessions with a maximum length of 15 minutes per participant was sufficient to induce

benefits. However, we have to mention two limitations of the study: the relatively small sample size of only fifteen athletes and the lack of the transferring the benefits into reality, as it is demanded by Gray (2017). In future studies, we plan to overcome these deficiencies by increasing the number of athletes and by conducting a transfer study, in which athletes have to react additionally to attacks of real athletes in pre- and posttests.

Furthermore, we plan to improve the virtual opponent by recording more movement and attack data from several athletes of different performance levels and gender in order to ensure a more natural interaction. Then, athletes could respond to attacks from motion data of the same gender. Additionally, athletes could fight against virtual opponents of their own performance level or at a more advanced level as it is recommended by Bandow (2016).

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