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ORIGINAL ARTICLE

Training using virtual reality improves response behavior in karate kumite

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Abstract

The aim was to study if sports-specific reaction training using immersive virtual reality improves the response behavior of karate athletes. During ten sessions, 15 experienced young karate athletes responded to upcoming attacks of a virtual opponent. On one hand, in PRE and POST tests, we examined the sports-specific response behavior using the time for response (time between a defined starting point and the first reaction), response accuracy (according to a score system), and kind of response (direct attack or a blocking movement) based on a movement analysis. On the other hand, we analyzed the unspecific response behavior using the reaction time and motor response time based on the reaction test of the Vienna test system. Friedman tests with subsequent Dunn–Bonferroni post-hoc tests and one-factorial ANOVAs showed no significant differences ($p > 0.05$) in the unspecific parameters. However, significant improvements ($p < 0.05$) of the sports-specific parameters were found, leading to a higher increase within the intervention groups (large effects) compared to the control groups (small and moderate effects in time for response, and no significant effects in response quality). It can be concluded that VR training is useful to improve response behavior in young karate athletes.

Keywords VR training · Karate kumite · Response behavior · Time for response · Response quality

1 Introduction

Technology is an often used instrument by athletes and coaches to support measurements and evaluations of athletic performance [7]. It is known that virtual reality (VR) can be an appropriate tool in sports to analyze or improve athletes' movements and performance [5]. With using VR, it is possible to create artificial, but realistic scenarios to examine and improve sports performance, due to standardized conditions and manipulations that are not possible in reality [27, 29]. Furthermore, Pan et al. [19] state the importance of the possibilities of a standalone training, especially in present-days, due to time pressure and stress. While there is no physical collision with other athletes, VR can offer much safer learning conditions [17, 19, 29]. Bideau et al. [3] proved that, while VR can provide near to reality movement patterns, it can be used for sports training and research. Furthermore, Donath et al. [6] showed that VR can be a possible tool for training, but that intervention studies using immersive VR are rare.

Looking at physical aspects, an adequate reaction behavior is a crucial aspect for success in karate kumite [15]. Several training studies in karate exist to increase muscle strength (e.g., [13, 28]), or to analyze total energy of kicks in karate [23], but they were all performed in real life settings. Milazzo et al. [16] created an intervention program to improve the reaction behavior of karate athletes to video-based attacks. They showed that it is possible to improve the reaction behavior though implicit learning, which, therefore, should be preferred as a learning method. However, Vignais et al. [26] found that perception is better in VR compared

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to video footage. To our knowledge, there is no study available to improve an athlete's reaction behavior in VR. Therefore, we performed a study similar to that of [16], but using immersive VR. We created virtual karate attackers that were used to carrying out a VR training to improve the response behavior in youth expert karate athletes later. While visual feedback is the most important information in martial arts [9], we implemented a virtual attacker in our VR without acoustic or haptic stimuli.

The aim was to study if sports-specific reaction training using immersive virtual reality improves the response behavior of young karate athletes due to attacks of the virtual character. While other intervention studies showed an improvement of reaction times due to certain interventions in reality (e.g., [2]), we expect that our intervention study will lead to better sports-specific response behavior.

2 Methods

First, we present the creation and evaluation of the virtual opponent, and afterwards, we focus on the intervention study. All studies were conducted in accordance with the declaration of Helsinki and obtained the approval of the ethic committee of the first author's university. All athletes participated on voluntary basis. They, and in case of underage their parents, were informed about the procedure prior to the study and gave their written consent.

2.1 Creation of the virtual opponent and the virtual environment

The virtual character was animated by motion capture recordings from the motion capture system Vicon tracker (Vicon, Oxford, UK, version 2.2) with 12 cameras (MX-13, Vicon, Oxford, UK) and a target set of A.R.T. (Advanced Realtime Tracking, Weilheim, Germany). Motion data of five ($n=5$) male karate kumite experts (age 24–56 years, black belt degree, 1st–4th Dan, all shotokan style) from the German Karate Federation (DKV) and the Japan Karate Association in Germany (DJKB) were recorded at 120 Hz. The karate experts executed several single attacks chosen through the previous competition analysis [21] and in collaboration with an expert coach (black belt degree, 4th Dan). Furthermore, two attack combinations (Kizami-Zuki-Gyaku-Zuki and Gyaku-Zuki-Mawashi-Geri) were recorded. For further information, see Table 1.

Gyaku-Zuki (GZ) and Gyaku-Zuki overrun (GZo) are attacks with the rear hand (contralateral side), while Kizami-Zuki (KZ) and Urake (U) are arm attacks with the front hand. Mawashi-Geri (MG) is a foot strike technique which can be conducted with the front and with the rear foot.

All attacks were performed from a defined position towards a fixed target. A karate expert (black belt degree, 4th Dan) surveyed the execution to ensure natural movements. All attacks captured with the described motion capturing system, represented target positions of each body limb and were saved as raw data files for each type of attack. All tracking raw data were filtered using linear interpolation, LULU smoothing, Savitzky-Golay-Filter, and Gaussian Smoothing. To gain best results, the parameters of the filtering process were determined separately for each attack data file. The raw tracking data were converted to a standard motion representation describing the orientations of the joints of a skeleton. These data were mapped onto the skeletons of a male and a female virtual avatar. To increase the degree of realism of the visualization for the athletes, each athlete could fight against a character of the same sex during the intervention study. The avatars and the specific karate asset were purchased from a 3D content marketplace, specialized on character animation and rendering. The virtual character was visualized as a karate fighter wearing a karate GI. The virtual environment (VE) was created using a 3D model of gym, extended by a floor mat with the typical dimensions and appearance to generate a karate fighting area. Afterwards, all processed attacks and their distances towards the responding athlete were checked again by a karate expert.

The evaluation of the virtual character and the VE was conducted by 32 karate athletes of several levels viewing the VR for 10–15 min while wearing a Head-Mounted

Table 1 Chosen attacks based on competition analysis and in consultation with an expert coach

Attack	Left side jodan	Left side chudan	Right side jodan	Right side chudan
Gyaku-Zuki (GZ)	x	x	x	x
Gyaku-Zukioverrun (GZo)			x	
Kizami-Zuki (KZ)	x		x	
Urake (U)	x		x	
Mawashi-Geri front leg (MG)	x	x	x	x
Mawashi-Geri rear leg (MG)	x	x	x	x

Chudan: attack towards the chest. Jodan: attack towards the head. For further explanation of attacks, see text

Device (HMD, Oculus Rift Rift, DK2, Oculus, VR, USA) and answering two feedback questionnaires [Simulator Sickness Questionnaire (SSQ) and Igroup Presence Questionnaire (IPQ)], subsequently. Mean and SD values for the symptoms of cybersickness (symptoms of discomfort due to VR) are given in Table 2. Mean and SD values for IPQ show that the participants rated the VR and the virtual characters to be realistic and that they felt present and involved in VR. For the complex general presence, mean, and SD values are 2.09 ± 0.82, for the complex spatial presence mean and SD values are 2.44 ± 0.71, for the factor involvement, they are 1.96 ± 0.91, and for the factor realism, they are 1.37 ± 0.84. A maximum value of 3 (as best values) could be reached.

Table 2 Results from Simulator Sickness Questionnaire with 32 participants: mean ± SD for each symptom

Symptom	Mean ± SD
Discomfort	0.19 ± 0.4
Fatigue	0.53 ± 0.62
Headache	0
Eye strain	0.38 ± 0.66
Problems due to focusing	0.5 ± 0.72
Increased salivation	0.13 ± 0.34
Sweat	1.19 ± 0.82
Nausea	0.06 ± 0.25
Concentration problems	0.38 ± 0.61
Overstimulation	0.03 ± 0.18
blurred vision	0.47 ± 0.67
Dizziness with open eyes	0.16 ± 0.4
Dizziness with closed eyes	0.06 ± 0.25
General dizziness	0.16 ± 0.4
Stomach upset	0.03 ± 0.18
Burping	0.03 ± 0.18

Maximum value (strong symptom) was 3

2.2 Intervention study

2.2.1 Participants

Fifteen ($n = 15$) youth karate athletes (age 13–17 years) were randomly assigned into group A and group B. They were in the same training group in a local club and practiced the shotokan style. All athletes had at least 5 years of experience in karate (blue and brown belt degree, 1st–4th Kyu) and participated in national competitions. They practiced two–five times for 90 min per week. All reported normal or corrected to normal vision and no impairment in spatial vision. Furthermore, we analyzed another age-matched group of 14 ($n = 14$) youth non-karatekas to compare all unspecific parameters (reaction time and motor response time) measured by the reaction test of the Vienna test system with those of the karate athletes at PRE1 (see also Fig. 1).

2.2.2 Procedure

The study was a cross-over design with two intervention phases (Fig. 1). The athletes were divided into two groups: group A and group B. Group A ($n = 8$) was the intervention

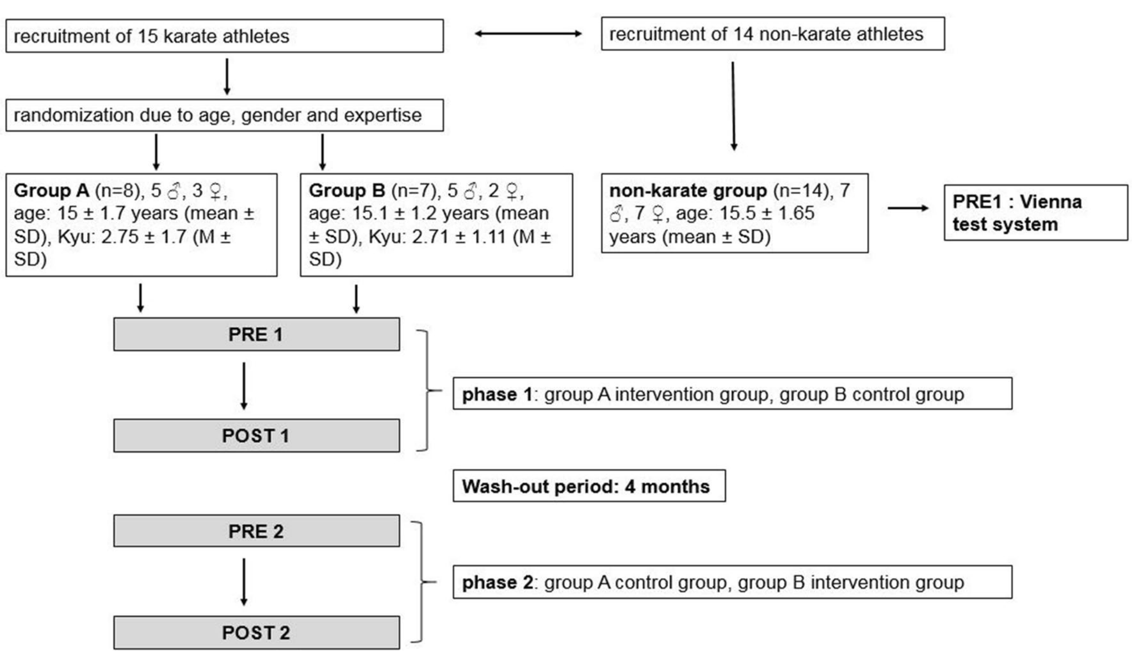

Fig. 1 Participant's assignment into group A and group B (karate athletes) and a non-karate group and the procedure of the current study

group in phase 1 and the control group in phase 2. Group B ($n = 7$) was the control group in phase 1 and the intervention group in phase 2. Each intervention group conducted the VR training in the course of their conventional training, whereas the control group had conventional training only. Each phase had a duration of 8 weeks (1st week pretest, 2nd–7th week intervention, 8th week posttest). Thus, each intervention contained ten training sessions of 10–15 min for each participant over 6 weeks. A karate expert supervised the VR training and gave additional feedback in both intervention phases.

During the training and the tests, the athletes wore an HMD [Oculus Rift DK2, Oculus VR, USA with a resolution of 1920 × 1080 pixels (960 × 1080 pixels per eye)], and two hand targets (A.R.T., Weilheim, Germany) for orientation. They were asked to position themselves on a defined mark on the floor (start position) and respond to the upcoming attacks, as they would in a real competition to score a point (Fig. 2).

The athlete's hands were visualized by use of the two hand targets, while the rest of the athlete's body was not visualized. The real athlete's virtual avatar motion visualizations were presented through the calculation of the position data of the HMD and the hands by the Vicon tracker and were retrievable through the ViconDataStream SDK. The position information was mapped onto predefined objects, such as the hands and the user's viewing direction within the VE. The position and rotation of these objects were updated according to the frame rate through the rendering software.

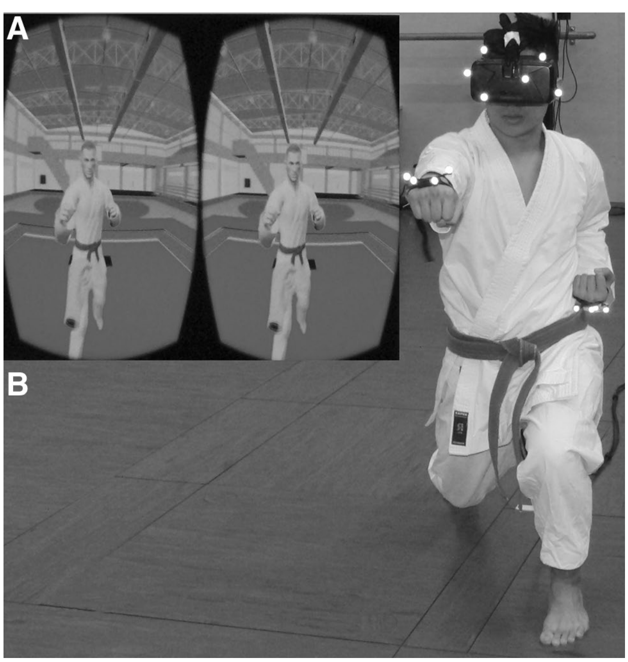

Fig. 2 Response of the real athlete (**b**) towards attacks of the virtual opponent (**a**)

In agreement with the karate coach, we developed a specific training routine containing four sets with six–eight attacks per session. Between each set, there was a 2 min break and between each attack within the sets a 3 s break. Additional breaks could be taken when desired. The training routine was created on the basis of scientific training principles (e.g., [24, 25]), from easy to difficult. The degree of complexity increased with every session: type of attacks, number of attacks, and several individual executions (up to five) of the same attack. The number of attacks per set increased with the sessions from six to eight attacks per set. The specific training routines were saved as time-based sequences of attacks being processed within the rendering software. Every set could be started individually, and at the end of every attack within the set, the virtual character was smoothly morphed into the start position of the next attack. In the first session, the upcoming attacks were inserted in written form to ensure familiarization. The name of the next attack was shown in VR, which could be read by the athletes. In the other nine sessions, these texts did not appear.

For the PRE and POST tests, two sports-unspecific tests of the reaction test (RT) of the Vienna test system (Schuhfried, Vienna, Austria) were performed, together with a karate specific movement analysis. As unspecific reaction tests S1 (simple reaction test to one visual stimulus) and S4 (recognition reaction test to one visual stimulus and visual and auditory distractors) were chosen. In both tests, the user had to move the dominant index finger from one button to another button when the relevant stimulus appeared. The reaction time (time between the appearance of the stimulus and the lifting of the finger from the first button) and the motor response time (time between the release of the first button to the pushing of the second button) were measured at 1000 Hz. All unspecific parameters of PRE1 were compared between both groups, the group of the non-karate athletes with that of the karate athletes.

The movement analysis analyzed the karate athletes' responses to the attacks of the virtual opponent. The attacks and the responses were recorded with two synchronized cameras (Contemplas, Kempten, Germany, 100 Hz). Therefore, the virtual opponent was projected on a large canvas by use of a rear projection beamer (Fig. 3). The movement analysis consisted of 22 single attacks: five Gyaku-Zuki jodan (GZj) with the right arm, afterwards five Kizami-Zuki (KZ) with the left arm (each GZj and KZ of a different attacker). Thereafter, 12 attacks followed in randomized order: three Gyaku-Zuki chudan (GZc) with the right arm, three Gyaku-Zuki jodan (GZj) with the right arm, three Kizami-Zuki (KZ) with the left arm, and three Mawashi-Geri chudan (MG) with the right rear foot (each GZc, GZj, KZ, and MG from the same attacker). After each attack, there was a short break to ensure full concentration of the athlete.

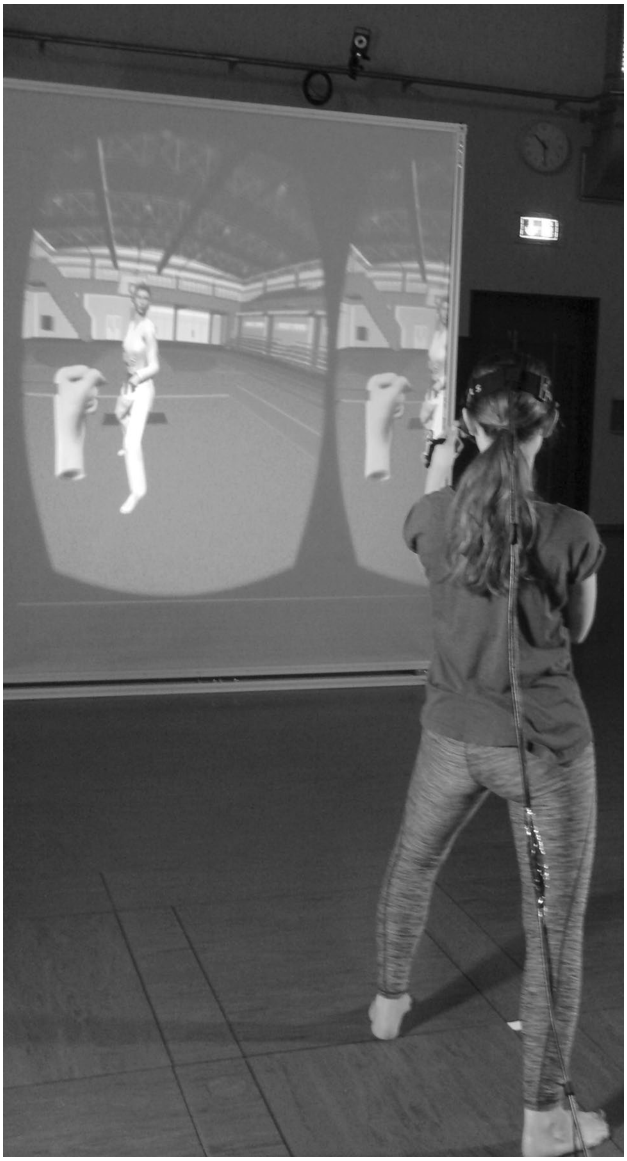

Fig. 3 Recording of the virtual opponent's attack and the athlete's response in PRE and POST tests of the movement analysis

We analyzed the following parameters: time for response, response quality, and kind of response. Time for response was defined from the beginning of the forward motion of the punching arm or kicking leg until the first measurable purposeful movement (in most cases the beginning of an evasive movement or block, or the beginning of the athlete's attack). Response quality was assessed with a score system: 0 points were given when the athlete was not able to prevent the upcoming attack. Thus, the athlete reacted either too late or in a wrong way. 1 point was given if the athlete was able to prevent the upcoming attack by a successful evasive movement or block (sometimes followed by a counterattack). 2 points, where achieved when the athlete performed a direct and successful attack themselves, either at the same time as the virtual character's attack, or earlier. We excluded the athletes' attacks that occurred more than 300 ms before the beginning of the virtual character attack. It was unlikely that the reaction occurred due to the attack, but more to another stimulus. The score system was developed in consultation with a karate expert. In high-class karate kumite more direct attacks, and not a block before a counterattack, are performed. Therefore, we analyzed the kind of response. We categorized responses to attacks either as direct attacks or evasive movements/blocking techniques that were sometimes followed by a counterattack. In the current study, the direct attack would be the desirable reaction.

2.2.3 Analysis of data

The movement analysis was conducted using the video analysis software Kinovea (version 0.8.15). 1320 videos were analyzed for response time, response quality, and kind of response. We excluded eight videos due to technical problems. 23 videos were excluded, because athletes attacked too early (more than 300 ms before the virtual character's attack).

We assessed interrater reliability using Cohen's kappa (k) coefficient using the following classification: $k<0$ no reliability, $k=0.1$–0.4 fair, $k=0.41$–0.6 substantial, $k=0.61$–0.8 good, and $k=0.81$–1 very good reliability. 20% of all data for response quality were crosschecked by a karate expert ($k=0.83$). 50% of all data for time for response and response quality were crosschecked by a third rater (both $k>0.81$). Intrarater reliability with 20% of all data for time for response and response quality revealed $k>0.91$. Thus, interrater reliability and intrarater reliability for both parameters were very good.

We analyzed reaction time (RT) and motor response time (MT) of S1 and S4 (Vienna test system) at four different timepoints: PRE1, POST1, PRE2, and POST2 of all karate athletes (120 data). In addition, the reaction and motor response time of 14 non-athletes in the age of 13–18 years at timepoint PRE1 (28 data) were analyzed. To compare the reaction and motor response times between karate athletes and non-athletes, a one-factorial analysis of variance with group, as the between-subject factor was used.

To examine differences between the sports-unspecific parameters reaction time and motor response time of S1 and S4 and the sports-specific parameters of the movement analyses, time for response, and response quality, within group A and group B between the four times PRE1, POST1, PRE2, and POST2, we used the Friedman test with subsequent Dunn–Bonferroni post-hoc tests and detection of effect sizes (Pearson's ratio, classified $r<0.3$ small, $r=0.3$–0.5 moderate, and $r>0.5$ large effect size).

A one-factorial analysis of variance was carried out for each parameter and the effect sizes were analyzed using

Pearson's r for all four timepoints between group A and group B. The level of significance for all tests was set at $\alpha < 0.05$. The parameter kind of response was analyzed descriptively. For all analysis, we used SPSS version 25 (IBM, Germany).

3 Results

3.1 Sports-unspecific responses using S1 and S4 of the RT (Vienna test system)

The results of the Friedman test showed no significant differences for reaction time and motor response time of S1 and S4 (all $p > 0.05$) between PRE1, POST 1, PRE 2, and POST 2 within group A and group B. Furthermore, the one-factorial analysis revealed no significant differences ($p > 0.05$) between group A and group B at the four points of time. The results of the four tests (RT and MT of S1 and S4) for both groups at all times are given in Table 3. Figure 4 shows the relation of the mean values at POST1, PRE2, and POST2 compared to PRE1 as 100%. One-factorial analysis of variance between the karate groups (group A and group B) and the group of the non-karate athletes at PRE1 showed no significant difference in reaction time and motor response time of S1 and reaction time of S4. However, there was a significant difference in motor response time of S4 with a moderate effect size ($p = 0.010$, $r = 0.45$).

3.2 Sports-specific response behavior based on the movement analysis

3.2.1 Time for response for the intervention groups—within-group comparisons

In group A (intervention group in phase 1), the Friedman test showed a significant difference with large effect sizes in time for response for all attacks ($p = 0.000$), GZj ($p = 0.000$), KZ ($p = 0.001$), and MG ($p = 0.001$) between the four times PRE1, POST1, PRE2, and POST2. In group B (intervention group in phase 2), the results of the Friedman test revealed a significant difference with large effect sizes in time for response for all attacks, GZj, GZc, KZ, and MG (all $p = 0.000$) between the four times PRE1, POST1, PRE2, and POST2. For further details (mean, SD, and post-hoc analysis with effect sizes) for all groups and both phases, see Table 4.

3.2.2 Response quality for the intervention groups—within-group comparisons

In group A (intervention group in phase 1), the results of the Friedman test showed a significant difference with moderate effect sizes in response quality for all attacks ($p = 0.000$), and significant differences with large effect sizes for GZj ($p = 0.000$) and for MG ($p = 0.001$) between the four times PRE1, POST1, PRE2, and POST2. In group B (intervention group in phase 2), the Friedman test revealed a significant difference in response quality with large effect sizes for all attacks ($p = 0.000$), GZj ($p = 0.000$), GZc ($p = 0.028$), KZ ($p = 0.000$), and MG ($p = 0.000$) between PRE1, POST1, PRE2, and POST2. For further details, see Table 5, showing

Table 3 Results of the Vienna test system

Group	Test	PRE1 (ms)	POST 1 (ms)	PRE2 (ms)	POST2 (ms)	p value
Group A	S1 MT	109.75 ± 27.91	91.62 ± 20.87	92.25 ± 14.82	87.5 ± 12.57	0.217
	S1 RT	234.87 ± 26.75	225.25 ± 14.03	231.87 ± 20.2	230.5 ± 33.17	0.893
	S4 MT	107.5 ± 28.52	94 ± 21.47	89.12 ± 19.27	85.25 ± 13.88	0.059
	S4 RT	349.12 ± 60.61	336.12 ± 36.06	325.37 ± 26.2	319.5 ± 47.6	0.583
Group B	S1 MT	118.43 ± 24.93	103.57 ± 23.02	115.71 ± 28.89	102.57 ± 34.86	0.341
	S1 RT	224.28 ± 18.42	222.14 ± 14.59	229.28 ± 22.63	229.85 ± 27.13	0.912
	S4 MT	123.86 ± 22.65	105.14 ± 29.62	111.57 ± 23.4	104.71 ± 36.44	0.186
	S4 RT	326.43 ± 32.63	297.57 ± 28.73	320.86 ± 45.61	307.43 ± 31.1	0.276
Non-karate group	S1 MT	133.36 ± 34				
	S1 RT	246.57 ± 30.9				
	S4 MT	149.64 ± 40.04*				
	S4 RT	351.36 ± 34.29				

S1 simple reaction time to one visual stimulus, *S4* recognition reaction choice to several visual stimuli and one auditive distractor, *MT* motor response time, *RT* reaction time

*Significant difference between group A and group B and an age-matched non-karate-group at PRE1 for S4 MT

Fig. 4 Relation of the mean values of reaction times and motor response times at POST1, PRE2, and POST2 compared to PRE1 as 100%. *S1* simple reaction time to one visual stimulus, *S4* recognition reaction choice to several visual stimuli and one auditive distractor, *MT* motor response time, *RT* reaction time

	PRE1	POST1	PRE2	POST2	
S1 MT	100%	-15%	-14%	-20%	Group A
S1 RT	100%	-4%	-1%	-2%	
S4 MT	100%	-12%	-17%	-20%	
S4 RT	100%	-3%	-6%	-8%	
	PRE1	POST1	PRE2	POST2	
S1 MT	100%	-12%	-2%	-13%	Group B
S1 RT	100%	-1%	+3%	+3%	
S4 MT	100%	-15%	-10%	-15%	
S4 RT	100%	-8%	-2%	-6%	

the means, SDs, post-hoc tests, and effect sizes for all groups in phase 1 and phase 2.

3.2.3 Time for response and response quality for the control groups—within-group comparisons

As can be seen in Tables 3 and 4, the results of the Friedman tests for group B (control group in phase 1) also showed significant improvements in time for response in phase 1 with moderate effect sizes in most cases. However, for response quality, a significant difference with a moderate effect size was only found for GZj ($p = 0.003$, $r = 0.38$), but not for the other attacks in phase 1. Furthermore, no significant differences (all $p > 0.05$) were found for group A (control group in phase 2) in time for response or response quality in phase 2.

3.2.4 ANOVAS for group comparisons

One-factorial analysis of variance analyzing differences in time for response between group A and group B revealed a significant difference for all attacks for POST 1 ($p = 0.000$, $r = 0.24$), for PRE2 ($p = 0.013$, $r = 0.14$), and for POST2 ($p = 0.000$, $r = 0.24$). Furthermore, significant group differences were found for GZj for POST1 ($p = 0.000$, $r = 0.36$), PRE2 ($p = 0.004$, $r = 0.26$), and for POST2 ($p = 0.000$, $r = 0.31$), for GZc for POST2 ($p = 0.020$, $r = 0.34$), for KZ for POST1 ($p = 0.008$, $r = 0.24$), and for POST2 ($p = 0.000$, $r = 0.4$). No significant group differences were found for PRE1, indicating that both groups had the same performance level. For further details, see Fig. 5.

One-factorial analysis of variance analyzing differences between group A and group B in response quality showed a significant difference for all attacks for POST1 ($p = 0.000$, $r = 0.24$), for PRE2 ($p = 0.000$, $r = 0.25$), and for POST2 ($p = 0.000$, $r = 0.24$). A significant difference was also found for GZj for POST1 ($p = 0.000$, $r = 0.32$), for PRE2 ($p = 0.000$, $r = 0.33$), and for POST2 ($p = 0.000$, $r = 0.33$). For GZc, we found a significant group difference for PRE2 ($p = 0.010$, $r = 0.39$). Moreover, a significant group difference for KZ was found for POST1 ($p = 0.015$, $r = 0.22$), for PRE2 ($p = 0.032$, $r = 0.2$), and for POST2 ($p = 0.001$, $r = 0.3$). For MG, we found a significant group difference for PRE2 ($p = 0.023$, $r = 0.33$). No significant differences between group A and B were found for PRE1, indicating that both groups had the same performance level. For further details, see also Fig. 6.

3.2.5 Kind of response

We analyzed the kind of response descriptively (Table 6) and we divided it in two categories: direct attack, and blocking technique or evasive movement (and counterattack). As can be seen in Table 6, the kind of response changed into the desired behavior of the direct attacks to the VR training. As direct attacks, the techniques GZ and KZ were performed.

Table 4 Time for response, comparisons within the groups

Group	Attack	PRE1 (mean ± SD) (ms)	POST1 (mean ± SD) (ms)	PRE2 (mean ± SD) (ms)	POST2 (mean ± SD) (ms)	*p* value	Post-hoc	*p* value	Effect size
A	All	162.18 ± 90.77	73.26 ± 114.51	84.73 ± 125.31	81.7 ± 129.12	0.000	PRE1–POST1	0.000	***r* = 0.59**
							PRE1–PRE2	0.000	***r* = 0.54**
							PRE1–POST2	0.000	***r* = 0.61**
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	> 0.05	
A	GZj	166 ± 91.84	44 ± 122.76	38.88 ± 105.26	51.75 ± 109.68	0.000	PRE1–POST1	0.000	***r* = 0.68**
							PRE1–PRE2	0.000	***r* = 0.73**
							PRE1–POST2	0.000	***r* = 0.73**
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	> 0.05	
A	GZc	227.92 ± 52.58	184.35 ± 82.01	205.42 ± 67.37	215.83 ± 91.5	> 0.05			
A	KZ	160.95 ± 94.95	79.63 ± 104.44	101.75 ± 137.91	83.93 ± 126.98	0.001	PRE1–POST1	0.000	***r* = 0.53**
							PRE1–PRE2	0.000	***r* = 0.85**
							PRE1–POST2	0.000	***r* = 0.85**
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	> 0.05	
A	MG	81.25 ± 60.74	24.35 ± 60.36	13.33 ± 75.8	3.33 ± 124.01	0.001	PRE1–POST1	0.001	***r* = 0.63**
							PRE1–PRE2	0.001	***r* = 0.62**
							PRE1–POST2	0.009	***r* = 0.51**
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	> 0.05	
B	All	178.14 ± 90.47	131.68 ± 86.93	119.86 ± 105.15	− 8.57 ± 140.84	0.000	PRE1–POST1	0.000	*r* = 0.36
							PRE1–PRE2	0.000	*r* = 0.43
							PRE1–POST2	0.000	***r* = 1**
							POST1–PRE2	> 0.05	
							POST1–POST2	0.000	***r* = 0.7**
							PRE2–POST2	0.000	***r* = 0.64**
B	GZj	183.57 ± 80.64	128 ± 82.76	93.04 ± 94.83	− 40.4 ± 122.27	0.000	PRE1–POST1	0.000	***r* = 0.5**
							PRE1–PRE2	0.000	***r* = 0.64**
							PRE1–POST2	0.000	***r* = 0.86**
							POST1–PRE2	0.009	*r* = 0.35
							POST1–POST2	0.000	***r* = 0.77**
							PRE2–POST2	0.000	***r* = 0.71**
B	GZc	239.52 ± 53.15	193.33 ± 61.02	229.05 ± 51.37	160.48 ± 54.54	0.000	PRE1–POST1	**0.011**	***r* = 0.6**
							PRE1–PRE2	> 0.05	
							PRE1–POST2	**0.000**	***r* = 0.83**
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	0.001	***r* = 0.67**
B	KZ	185.45 ± 93.27	129.73 ± 94.46	118 ± 122.65	− 35.69 ± 150.3	0.000	PRE1–POST1	0.001	*r* = 0.42
							PRE1–PRE2	0.000	***r* = 0.5**
							PRE1–POST2	0.000	***r* = 0.82**
							POST1–PRE2	> 0.05	
							POST1-POST2	0.000	***r* = 0.71**
							PRE2–POST2	0.000	***r* = 0.71**

Table 4 (continued)

Group	Attack	PRE1 (mean ± SD) (ms)	POST1 (mean ± SD) (ms)	PRE2 (mean ± SD) (ms)	POST2 (mean ± SD) (ms)	*p* value	Post-hoc	*p* value	Effect size
B	MG	62.86 ± 77.47	53.33 ± 54.53	45.24 ± 78.52	− 51.5 ± 91.95	0.000	PRE1–POST1	> 0.05	
							PRE1–PRE2	> 0.05	
							PRE1–POST2	0.000	***r* = 0.73**
							POST1–PRE2	> 0.05	
							POST1–POST2	0.000	***r* = 0.79**
							PRE2–POST2	0.000	***r* = 0.74**

Mean and SD, *p* values and post-hoc analysis are shown for group A and group B at the four times PRE1, POST1, PRE2, and POST2. Large effect sizes are printed in bold

4 Discussion

We found no significant differences in sports-unspecific reaction time and motor response time of the reaction tests S1 and S4 of the Vienna test system over the four times PRE1, POST1, PRE2, and POST2. Our values for reaction time and motor response time are in line with the results of [9] (Table 2). One reason for the absence of significant differences might be that the Vienna test system is not a sports-specific reaction measurement, and therefore, not sensitive enough to detect changes in response behavior of karate kumite. However, as can be seen in Table 3, the karate athletes' reaction and motor response times decreased, but these improvements failed the level of significance. In addition, Florkiewicz et al. [8] also used the reaction test of the Vienna test system to analyze effects of an intervention study, and found no significant differences in simple reaction time, but significant differences in more complex reaction times, such as recognition reaction times and choice reaction times. Thus, it is possible that our sample size was too small. Another reason could be the already existing fast response behavior of karate athletes. Therefore, we compared our karate athletes (group A + group B, $n = 15$) with a group of 14 non-karatekas, but found no significant differences between the karate athletes and the non-athletes. The only exception was the significant faster motor response time of the karate athletes in S4 compared to the non-karate group. This may be due to the fast execution of arm movements which is specific for karate [22].

The movement analysis of group A (intervention group in phase 1 and control group in phase 2) showed significant improvements with large and moderate effect sizes for all attacks in time for response ($r = 0.59$) and response quality ($r = 0.37$) in phase 1, but not in phase 2 ($p > 0.05$). Group B being the control group in phase 1, also improved in time for response for all attacks ($r = 0.36$), but not in response quality ($p > 0.05$) in phase 1. In general, the effects were smaller compared to group A (see Tables 4, 5). The improvements of group B can be explained by the ongoing conventional karate training. In phase 2, group B showed significant improvements with large effect sizes for all attacks in time for response ($r = 0.64$) and in response quality ($p = 0.63$), while group A (control group in phase 2) showed no significant differences in these parameters (both $p > 0.05$). Significant group differences for POST1, PRE2, and POST2 can be explained by the VR training intervention. The group obtaining the VR training program had larger improvements than the respective control group; thus, the VR training intervention was more effective than the conventional training program to improve response behavior. The greatest effects were found in the attacks GZ and KZ (and MG, group B). Furthermore, we detected a change in the kind of reaction during the two intervention phases. At PRE1 and PRE2, the respective training groups showed a block or an evasive movement before counterattack, while at POST1 and POST2, most athletes changed to a direct attack. This change in response execution is a success of the VR intervention, because the direct attack is faster than a time consuming blocking technique. A further result of the present study is that group A maintained their performance over a longer period of time (several months). In all analyzed sports, unspecific parameters of the Vienna test system, and in all sports-specific parameters of the movement analysis, the values of POST1 reached the values of PRE2 and POST2. In general, our results are in line with the results of [16] who also reported improvements in the response time and accuracy (quality) due to an intervention with video material.

Our VR training intervention, integrated into the conventional training, is a suitable tool to improve response behavior in young athletes. Balkó et al. [2] declared that this time span is a highly sensitive phase for improvements of response behavior. Müller et al. [18] executed an intervention study to improve anticipation in hockey by use of video. The authors found that sufficient intervention sessions must be given, due to the lack of linearity in the learning process. At the beginning of an intervention, the athlete's performance often gets worse before they benefit and their performance improves. Our ten training sessions per intervention

Table 5 Response quality, comparison within the groups

Group	Attack	PRE1 (mean ± SD)	POST1 (mean ± SD)	PRE2 (mean ± SD)	POST2 (mean ± SD)	*p* value	Post-hoc	*p* value	Effect size
A	All	0.37 ± 0.66	0.92 ± 0.09	1 ± 0.93	1.01 ± 0.96	0.000	PRE1–POST1	0.000	*r* = 0.37
							PRE1–PRE2	0.000	*r* = 0.4
							PRE1–POST2	0.000	*r* = 0.42
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	> 0.05	
A	GZj	0.47 ± 0.69	1.25 ± 0.84	1.4 ± 0.83	1.3 ± 0.9	0.000	PRE1–POST1	0.000	***r* = 0.68**
							PRE1–PRE2	0.000	***r* = 0.72**
							PRE1–POST2	0.000	***r* = 0.63**
							POST1–PRE2	> 0.05	
							POST1–POST2	> 0.05	
							PRE2–POST2	> 0.05	
A	GZc	0.12 ± 0.45	0.35 ± 0.65	0.58 ± 0.88	0.37 ± 0.77	> 0.05			
A	KZ	0.24 ± 0.53	0.58 ± 0.81	0.6 ± 0.85	0.74 ± 0.91	> 0.05			
A	MG	0.79 ± 0.98	1.52 ± 0.85	1.67 ± 0.64	1.67 ± 0.76	0.001	PRE1–POST1	0.003	***r* = 0.56**
							PRE1–PRE2	0.001	***r* = 0.64**
							PRE1–POST2	0.001	***r* = 0.61**
							POST1–PRE2	> 0.05	
							POST1-POST2	> 0.05	
							PRE2-POST2	> 0.05	
B	All	0.34 ± 0.65	0.49 ± 0.71	0.55 ± 0.78	1.49 ± 0.87	0.000	PRE1–POST1	> 0.05	
							PRE1–PRE2	> 0.05	
							PRE1–POST2	0.000	***r* = 0.74**
							POST1–PRE2	> 0.05	
							POST1–POST2	0.000	***r* = 0.63**
							PRE2–POST2	0.000	***r* = 0.58**
B	GZj	0.43 ± 0.66	0.73 ± 0.71	0.84 ± 0.78	1.84 ± 0.55	0.000	PRE1–POST1	0.003	*r* = 0.38
							PRE1–PRE2	0.002	*r* = 0.4
							PRE1–POST2	0.000	***r* = 0.87**
							POST1–PRE2	> 0.05	
							POST1–POST2	0.000	***r* = 0.77**
							PRE2–POST2	0.000	***r* = 0.74**
B	GZc	0.14 ± 0.48	0.1 ± 0.3	0.05 ± 0.22	0.62.0.92	0.028	PRE1–POST1	> 0.05	
							PRE1–PRE2	> 0.05	
							PRE1–POST2	0.029	*r* = 0.46
							POST1–PRE2	> 0.05	
							POST1–POST2	0.018	***r* = 0.56**
							PRE2–POST2	0.015	***r* = 0.51**
B	KZ	0.16 ± 0.5	0.25 ± 0.58	0.29 ± 0.68	1.33 ± 0.95	0.000	PRE1–POST1	> 0.05	
							PRE1–PRE2	> 0.05	
							PRE1–POST2	0.000	***r* = 0.78**
							POST1–PRE2	> 0.05	
							POST1–POST2	0.018	***r* = 0.56**
							PRE2–POST2	0.000	***r* = 0.75**
B	MG	1 ± 0.89	1.09 ± 0.83	1.4 ± 0.85	2 ± 0	0.000	PRE1–POST1	> 0.05	
							PRE1–PRE2	> 0.05	
							PRE1–POST2	0.000	***r* = 0.75**
							POST1–PRE2	> 0.05	
							POST1–POST2	0.000	***r* = 0.73**
							PRE2–POST2	0.000	***r* = 0.73**

Mean and SD, *p* values and post-hoc analysis are shown for group A and group B at the four times PRE1, POST1, PRE2 and POST2. Large effect sizes are printed in bold. The scoring for response quality ranged from 0 to 2 points. 0: the athlete was not able to prevent the upcoming attack. 1: the athlete was able to prevent the upcoming attack by a block or an evasive movement. 2: the athlete performed a direct and successful attack

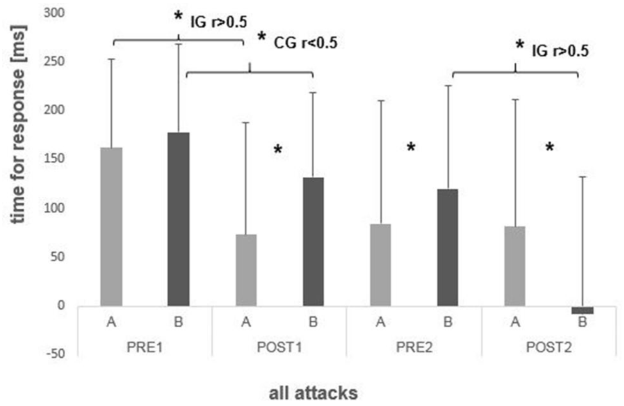

Fig. 5 Time for response for all attacks in group A and group B. Asterisk: significant differences between group A and group B at POST1, PRE2, and POST 2, but not at PRE1. Asterisk: IG $r > 0.5$ significant difference with large effect size for the intervention group A from PRE1 to POST1 and for the intervention group B from PRE2 to POST2. Asterisk: CG $r < 0.5$ with moderate effect size for control group B from PRE1 to POST1

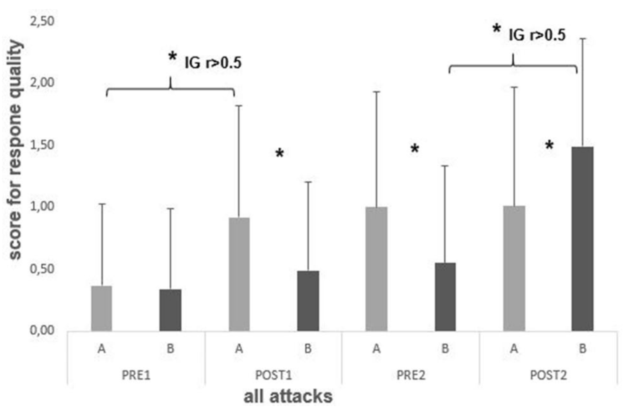

Fig. 6 Score for response quality for all attacks in group A and group B. Asterisk: significant differences between group A and group B at POST1, PRE2, and POST 2, but not at PRE1. Asterisk: IG $r > 0.5$ significant difference with large effect size for the intervention group A from PRE1 to POST1 and for the intervention group B from PRE2 to POST2

Table 6 Proportion of direct attacks in percent as kind of response out of all responses

Group	PRE1 (%)	POST1 (%)	PRE2 (%)	POST2 (%)
A	33.5	64	63	76
B	38.5	46	47	98

seem to be sufficient to induce improvements in time for response, response quality, and kind of response.

In regard to cybersickness, no symptoms were found during our sessions lasting for 15 min, being in line with the previous work of [11]. To our knowledge, this is the first intervention study in karate kumite using immersive VR. This intervention has the advantage that virtual attackers do not fatigue and are thus able to perform natural but repeatable attacks against our athletes. This would not be possible in reality due to natural variability in motion execution of real attackers.

4.1 Limitations of the study

Today, many technological support systems exist, but it is important to handle such technologies in a responsible way. VR can be a tool to adjust reality, but it will never be a replacement [12]. Studies exist showing that experiences in VR and in reality are quite similar (e.g., [1]), but more studies are needed to verify the similarity of movement pattern and gaze behavior between VR and reality to ensure a successful transfer of performance gained from training in VR to reality. The current study shows that VR is a suitable tool to improve response behavior against a virtual character, but transfer into reality was not examined as is suggested by Gray [10]. A way to examine such a transfer would be an additional analysis of a karate fight in reality, or to also investigate response behavior towards real attacks at PRE and POST. Unfortunately, we were not able to analyze the transfer into reality. Brenton, Müller and Dempsey [4] and Müller et al. [18] found that participants were able to improve their skills by training with videos. Therefore, it is likely that a positive transfer from interventions in VR into reality would also occur.

Another shortcoming of this study was our limited number of participants. We tried to solve this problem by creating a cross-over study, but our wash-out period of 4 months was too short, and therefore, at PRE2, all athletes were at a higher level than at PRE1. Thus, we could only run within-group comparisons (group A vs. group B) and no comparisons between all intervention groups and control groups.

In future studies, it would be more appropriate (if available) to use motion capturing data to analyze response behavior, as it was used by Kwan et al. [14] and in Petri et al. [20], instead of a video analysis.

5 Conclusion

VR is an adequate tool for training response behavior in athletes. Our method is suitable to improve response behavior in young karate kumite athletes. At present, we are of the opinion that it is better to integrate VR training sessions in the course of a conventional training or to perform VR training in addition to the conventional training, but VR training should not replace training in reality.

Training using immersive VR has the advantage that coaches can deploy different training methods with different virtual characters as opponents that do not fatigue. Finally, the real athletes can try out different kinds of reactions while being in a safe environment.

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