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Improvement of movement execution in karate due to observational learning with a virtual reality application for smartphones – a pilot study

Abstract

Observations of motor executions in videos are useful to improve own movement execution but no study has used virtual reality (VR) for this so far. In an intervention over two weeks with eight sessions of ten minutes each, eighteen karate athletes were randomly assigned in a control group (CG), a video group (ViG), and a VR group (VRG). ViG watched movement executions with a video and VRG with a VR app for smartphones in a Head Mounted Display. CG had no additional observational learning. In pre- and posttests, eight parameters in the movement executions of all athletes, which were chosen after consultation with an expert coach, were examined using video analysis. Mixed ANOVAs and paired t-tests showed significant improvements in the movement execution for VRG in four parameters (p<0.05), for ViG in two parameters (p<0.05), but not for CG (p>0.05). Questionnaires showed that VRG felt comfortable in VR and had no technical problems with the VR app. Furthermore, the VR app was preferred due to interactivity and depth information. Thus we conclude that the VR app is suitable for observational learning additionally to physical training in order to deepen the knowledge and to improve own motor execution.

Keywords

interactive virtual reality, VR app, VR training, observation of movement execution, observational learning using VR

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1 Introduction

Learning in sports can be done via practice, observation and imitation (Blandin, Lhuisset & Proteau, 1999). Observational learning by demonstration of movements is one of the most often used methods for teaching (Hodges, Williams, Hayes & Breslin, 2007) and is applied in many domains, such as surgery (e.g. Harris et al., 2018a), or sports (e.g. Lago-Rodriguez, Cheeran & Koch, 2014). It can be used to either accompany the practical training, or as compensation in case of illness or if any danger is given during learning in practical training. It is well known for increasing the (motor) performance, perceptual ability, and the comprehension of action consequences (Hodges, Williams, Hayes & Breslin, 2007, Lago-Rodriquez, Cheeran & Koch, 2014). In many cases, observers watch perfect motor executions according to a technique model (Blandin, Lhuisset & Proteau, 1999), but it can also make sense to let participants observe executions with some errors for sensitizing them to a differentiation between correct and incorrect movements (Harris et al., 2018a).

According to the common-coding theory (Prinz, 1997), perception and action are coupled. Vision and motor response are linked, and thus, eye movements and hand movements go hand in hand (direct matching hypothesis, Flanagan & Johansson, 2003). During observation of movements as well as in actual movement execution, the same brain areas are activated (Lago-Rodriguez, Cheeran & Koch, 2014), as long as the observed movements exist in the own movement repertoire (Hodges, Williams, Hayes & Breslin, 2014). The mirror neuron system, which generates action potentials during observation and motor execution, is thought to be the neurophysiological basis for the common-coding-theory (Lago-Rodriguez, Cheeran & Koch, 2014). Therefore, observational learning can be used in motor learning to improve own movement executions.

To apply observational learning, video material is often used in which the observers see executions. Already Starkes and Lindley (1994) showed that observational learning using video training can be used to enhance performance in sports by better learning, reviewing and organizing (Muir, Chandler & Loughead, 2018), but the results are still quite inconsistent (Starkes & Lindley, 1994, Larkin, Mesagno, Spittle & Berry, 2015). Up to now, observational learning was often examined for quite simple hand movements (e.g. grasping tasks), and not for more complex and sports specific tasks with high-skilled athletes. In addition, such observational learning interventions have not been carried out in immersive and interactive virtual reality (VR) so far, although we assume that observation learning using VR can be beneficial due to three-dimensionality, interactions and different perspectives.

Here, we define VR as a computer generated reality, which provides stereoscopic information, interactivity (the VR adapts according to the user’s perspective and the user’s actions), and the possibility for athletes to act sports specifically. That definition is inspired by Neumann et al. (2018). Such VR is an often-used instrument in sports science (Petri, Bandow & Witte, 2018) and sports training (Petri et al., 2018). In recent reviews, Miles et al. (2012), Petri et al. (2018), and
Petri, Bandow and Witte (2018) found that, although VR is widely used in the context of practical training, most studies are conducted in ball sports and endurance sports (e.g. rowing). There is still a lack in sports specific studies analyzing experienced athletes.

Craig (2013) showed how VR can be used to analyze perception-action coupling. In that context, Bandow (2016) has let karate athletes respond to attacks of a virtual character and used the standardized immersive VR condition to analyze anticipatory signals in karate kumite. Furthermore, Vignais et al. (2015) discovered that for perception tasks, VR is more appropriate than normal videos, because VR provides depth information, interactivity due to the real-time update of the virtual scene following the user's head movements, and a high degree of realism because the user can completely dive into VR and becomes an active part instead of just being a passive observer.

There are several studies, which used VR for practical training. Petri et al. (2019) conducted an intervention study to improve the response behavior of young karate athletes. In ten sessions over six weeks, the athletes responded to several attacks of virtual characters. It could be shown that the response behavior improved due to the intervention in VR, but no transfer test was performed to analyze if the athletes also benefitted in real training and competition. Gray (2017) performed a training study in baseball comparing normal training with VR training and also analyzing transfer effects. He found that athletes benefitted more from training in VR than from normal training alone and showed positive transfer into reality. These studies show that training using VR can be useful to improve athletes’ performance but transfer effects have not been confirmed enough, yet, although it is the most important component regarding the evaluation of VR systems (Gray, 2019, 2017). To use the advantage of great immersion in VR, Panchuk, Klusemann and Hadlow (2019) utilized 360° videos of different basketball scenarios which were observed by female and male athletes in a Head Mounted Display (HMD) to improve their decision-making. They found improvements in men but not in women, but the sample was too small to draw general conclusions. Sielużycki et al. (2019) used the Microsoft Kinect system to improve motor learning in young judo athletes. On a screen, they saw judo techniques performed by a virtual character and they had to mimic these techniques and got a feedback of their own motor execution because the athletes’ movements were also recorded and visualized next to the character’s movements. It was found that such a VR system was able to improve correct movement execution.

To our best knowledge, there are no VR apps, providing 3D information and interactivity, which have been used in sports science research. Furthermore, there are no studies, and especially, no intervention studies in practical sports training, available that examined if observations of movements by the use of the VR app lead to benefits in the movement execution skills in reality compared to observation learning using video, and to a further control group.
Due to previous research where it was shown that observational learning using video training can be used to improve movement execution and to deepen the knowledge about the sports, we also expect that our observational learning intervention using immersive VR will improve the motor execution skills. Because of the advantages of VR compared to video, and the previously demonstrated positive effects in other VR training interventions, we expect a greater benefit of movement executions in the VR intervention group compared to the video intervention group and to a further control group due to observational learning. Moreover, Mann, Williams, Ward and Janelle (2007) and Panchuk, Klusemann and Handlow (2019) state that the transfer from the intervention into reality is greater when interactions with the medium are possible, which is the case in interactive VR.

The current study aims to analyze if the observation of movements using a VR app compared to watching a normal video leads to improvements of the own movement execution. We chose the karate attack Gyaku-Zuki (GZ) as demonstration task, which is the reverse punch performed with the rear arm, because based on previous competition analysis (Petri et al., 2017), this attack is the most often and most successfully conducted attack in international karate kumite competitions. However, even experienced athletes still have slight problems to execute that attack properly because GZ is very complex. Therefore, it makes sense to practice and optimize the attack GZ frequently in the karate training.

We decided to examine young karate athletes because in the current literature also young athletes were analyzed due to the fact that in the youth, most of relevant performance skills are still well trainable. We included subjective measurements (feedback questionnaires with open and closed questions) which are used frequently in cognitive research (Rhodes, May, Andrade & Kavanagh, 2018), but also more objective movement analyses with several raters.

Methods

The study was part of a large research project (DFG, WI 1456/17-1) and also a part of a project submission (BMBF, Germany). Ethical approval was obtained from the first author’s university’s ethic committee, and the study was conducted in accordance with the declaration of Helsinki.

Participants

Youth karate athletes (n=18, 7 female and 11 male athletes, age: 13-19 years) with at least five years of karate experience and one year of national competition experience took part on voluntary basis. All athletes came from the German JKA Karate Association (DJKB) and practiced the shotokan style. They, and their parents, were informed about the study prior to the beginning and gave their written consent. Sixteen athletes often watch videos posted from other karate athletes in social media, such as facebook and instagram. However, none of our athletes has executed an observational learning intervention using video or interactive VR.
before. All athletes reported normal or corrected-to-normal-vision and no problems in 3D vision.

Procedure
The athletes were randomly assigned into three groups. We divided the athletes in three groups according to age, expertise based on graduation from 4th Kyu to 1st Dan, and gender, and thus, made triplets from the present sample. Each group contained six athletes: control group (CG), video intervention group (ViG) and VR intervention group (VRG) (Fig.1).

All groups were analyzed in pretest (PRE) and posttest (POST1). In between those tests, ViG and VRG completed an observational learning intervention in addition to the normal karate training, which is usually two to four times per week for 90 minutes each. ViG and VRG performed the observational learning in eight sessions (each ten minutes) over two weeks self-reliantly in a seated position at home in that intervention phase 1. CG only conducted the regular physical karate training and did not receive any further treatments.

ViG watched a film about the karate attack Gyaku-Zuki (GZ), in which several athletes performed the attack in different velocities and from different perspectives. Additional advices about the movement execution were also given. They were free to watch the video on their smartphones, tablet computers or laptops. After each session, the athletes answered one multiple choice question concerning the execution of GZ, thus, in total eight multiple choice questions (feedback questionnaire 1, Tab. 1).


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VRG used a VR app which they started on their own smartphones and latched into a Head Mounted Display (HMD, Renkforce-RF-VR1, Hirschau, Germany). We decided to choose the app and the HMD because the use of HMDs in sports has been increasing recently (Miles et al., 2012, Petri, Bandow & Witte, 2018). Additionally, the app can be started on the smartphone, and thus can be used everywhere, and without cable connections. This reduces the risks of falling, which is the case when the HMD is cable-connected to a computer. In the app, the athletes watched virtual characters performing GZ, but they could also change the speed and the perspective individually according to their wishes. Furthermore, the same advices concerning the movement execution were shown as was given in the videos. The app was developed on the basis of binoo (binoo, Edu2VRPte Ltd, Ohl & Dumke, 2018). The virtual environment was created by a 360° image taken in a martial arts sports hall. The virtual characters were created on the basis of two male international successful karate athletes (black belt, 2nd Dan, shotokan style) whose movements were recorded by motion capturing (Vicon, Oxford, UK and A.R.T., Weilheim, Germany). The motion capturing data were mapped on a skeleton and a hautmesh, and integrated in the app (see also Figure 2). The VR adapted according to the user’s head movements.

After each session, the athletes of VRG answered one multiple choice question concerning the execution of GZ, thus in total eight multiple choice questions. These questions were the same for both ViG and VRG. Furthermore, VRG answered several questions concerning their physical well-being and the technical handling of the app and the HMD (feedback questionnaires 1 and 3, Tab. 1). Afterwards, ViG and VRG changed their functions. ViG from intervention phase 1 became VRG during intervention phase 2 and VRG from intervention phase 1 became ViG during intervention phase 2. In that intervention phase 2, the groups performed the described self-reliant intervention with the other technology in addition to their regular physical karate training. Please see also Figure 1.
Pre- and posttest measurements

In PRE and POST1 the athletes were instructed to perform six GZ with the left arm and six GZ with the right arm as they would do in a competition. However, all attacks were performed in the absence of an opponent. All movements were recorded from three cameras (frontal view, lateral view 45° and lateral view 90°, all 25 Hz, Canon, Krefeld, Germany) to the punching arm side.

In each video, the following parameters were analyzed: “stepping for attack preparation”, “lowering of center of mass (CoM) and active get off the ground before the actual attack”, “upright upper body during the punch”, “rotated hip before and after the punch”, “posture of the arms before the punch”, “extension of the punching arm and fast pulling back” as well as “adequate speed of the punch”. The described parameters were chosen in agreement with an international successful karate coach (black belt, 4th Dan). Furthermore, CG answered also all multiple choice questions concerning GZ which the other two groups answered during the intervention (feedback questionnaire 2, Tab. 1).

The two intervention groups, ViG and VRG, answered a questionnaire about their subjective feeling of motivation, deepening of knowledge about the GZ, improvement of actual movement execution and of movement imagination regarding the technology they used for the intervention (feedback questionnaire 4, Tab. 1). For each statement, the participants should mark their answer on a scale from 1 (does not apply to me at all) to 10 (fully applies to me).

In POST2, the two intervention groups answered the same questionnaire about their subjective feelings as they were given in POST1 (feedback questionnaire 4, Tab. 1), as well as two additional questions: 1) What makes more fun: video or VR? 2: What do you prefer: video or VR? For further information about the study design see also Figure 1.

Tab. 1: Overview about the feedback questionnaires

<table>
<thead>
<tr>
<th>no.</th>
<th>description</th>
<th>time</th>
<th>group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8 multiple choice questions concerning the execution of the karate attack Gyaku-Zuki (GZ)</td>
<td>during intervention phase 1</td>
<td>ViG and VRG</td>
</tr>
<tr>
<td>2</td>
<td>8 multiple choice questions concerning the execution of the karate attack Gyaku-Zuki (GZ) (equal to feedback questionnaire 3)</td>
<td>POST1</td>
<td>CG</td>
</tr>
<tr>
<td>3</td>
<td>feedback concerning physical well-being and usage of the VR app</td>
<td>during intervention phase 1 and 2</td>
<td>VRG</td>
</tr>
<tr>
<td>4</td>
<td>feedback questionnaire concerning their motivation, deepening of knowledge about Gyaku-Zuki (GZ), and improvement of movement imagination and movement execution and two additional questions: 1: What makes more fun: video or VR? 2: What do you prefer: video or VR?</td>
<td>POST1 and POST2</td>
<td>ViG and VRG</td>
</tr>
</tbody>
</table>

Analysis of Data

All videos were analyzed by the first and the second author using the software kinovea (version 0.8.15). The parameters “stepping”, “lowering of CoM and active get off the ground”, “upright upper body”, “rotated hip after the punch” and “adequate attacking speed (fast attack execution)” were analyzed by a scoring system (1-6 points), which bases on the grading system in Germany. 1 point would be a perfect execution while 6 would be a very bad execution.

So, a very good “stepping” for attack preparation would be unpredictable with gain of space, while a very bad execution would be simple and easy to predict stepping up and down in place. A good execution in “lowering of CoM and active get off the ground” for attack initiation would be a generation of preload in the rear leg and a get off forward towards the opponent with both legs synchronously. A bad execution would be a simple step forward with the front leg and a tailing of the rear leg.

A perfect execution of the “upright upper body” would be a straight back during the whole attack while a bad execution would be a “falling into the punch”, or a lateral bending. With an upright upper body it is easier to perform an own attack from a stable position. Furthermore, it is harder for the opponent to attack because of the larger distance between both athletes.

A perfect active “rotated hip after the punch” would be seen when shoulder axis and hip axis would be parallel during the extension of the punching arm. A bad execution would be if the hip rotated only because of lowering of the CoM and a bending of the rear knee without any further preload on the rear leg.

For an “adequate attack speed”, our expert karate coach gave an example which we used as reference to compare it with the attacking speeds in our videos.

For each of the above described parameters, mean values for GZ left side and GZ right side were calculated for each participant and a mixed analysis of variance (ANOVA) was carried out with “time” (PRE to POST1) as within-subject factor and “attack” (GZ with left or right arm) and “group” (CG vs. ViG vs. VRG) as between-subject factors. The effect sizes were calculated by partial eta-square ($\eta^2$) which is classified in $\eta^2 < 0.06$ small effect, $0.06 - 0.14$ moderate effect and $\eta^2 > 0.14$ large effect. For the factor “group”, Bonferroni post-hoc-tests were performed to analyze group differences (CG vs. ViG vs. VRG). Furthermore, paired t-tests were carried out to analyze differences from PRE to POST1 for each group. Normal data distribution was given.

Interrater reliability was assessed with two different raters who analyzed the parameters “lowering CoM and active get off the ground” and “rotated hip after the punch” in 25% of all videos using Cohen’s kappa which is classified in $k<0.1$ no reliability, $k=0.1-0.40$ fair, $k=0.41-0.6$ substantial, $k=0.61-0.8$ good and $0.81-1$ very good reliability. Interrater reliability was substantial ($k=0.446$) for “lowering CoM and active get off the ground”, and good ($k=0.646$) for “rotated hip after the punch”. These two parameters for interrater reliability were chosen.
because, according to our karate expert, they are the key features for adequate and strong GZ execution. 25% of all data were also crosschecked by our expert coach. On a random basis, several videos were also checked by the last author to ensure objective data analysis.

The parameters “rotated hip before the punch”, “posture of the arms before the punch” and “extension of the punching arm and fast moving back after the punch” were analyzed descriptively by a simple Yes / No analysis. Furthermore, the number of the correct movement executions (number of “yes”) were used to run paired t-tests to investigate differences from PRE to POST1 for each group. Normal data distribution was given.

For the parameter “rotated hip before the punch”, it was important that the hip was rotated outwards before the attack to support a stronger hip rotation inwards during the attack and hence, to ensure a stronger punch.

The parameter “posture of the arms before the punch” was given a „Yes“, when the shoulders and arms were relaxed and the fists rotated in a way that the thumbs turned inwards / upwards.

For the parameter “extension of the punching arm and fast moving back after the punch”, the punching arm should be (almost) completely extended (around 170° in the elbow joint), but not overextended (180° and more). After the extension, the punching arm should be pulled back immediately.

The feedback questionnaires (1 - 4, Tab. 1) were analyzed descriptively. The movement execution of GZ which were recorded at PRE and POST 1 can be seen in Figure 3.

Fig. 3: Gyaku-Zuki (GZ). A: Stepping unpredictably forward and backward for attack preparation. B: Approaching the opponent by stepping forward with both legs simultaneously (fast distance reduction) and following moving forward of the front leg. Initiation of a rotation around the longitudinal axis and begin of rotation of the hip to support the movement of the punching arm (hip rotation is not seen in Fig. 3). C: End of hip rotation and extension of the punching arm. D: Fast pulling back of the punching arm and increase of interpersonal distance.
Results

Movement analysis

The Box-Tests were not significant with p>0.05 in all parameters. Hence, variance homogeneity was given.

The mixed ANOVA for “stepping” showed a significant time effect (PRE to POST1) with F (1/15)=28.24, p<0.001, ηp²=0.15 (large effect) as well as an interaction effect (time x group) with F (2/15)=5.46, p=0.01, ηp²=0.27 (large effect). The post-hoc-tests showed no significant group differences between CG, ViG and VRG with all p>0.05: between CG and ViG p=0.99, between CG and VRG p=0.99, and between ViG and VRG p=0.27. The other interactions failed the level of significance: time x attack: F (2/15)=0.66, p=0.42, and time x attack x group: F (2/15)=0.08, p=0.92.

For the parameter “lowering of CoM and active get off the ground”, the mixed ANOVA found a significant time effect with F (1/15)=4.46, p=0.04, ηp²=0.13 (large effect). The other interactions failed the level of significance: time x attack: F (2/15)=1.95, p=0.17, time x group: F (2/15)=2.5, p=0.1, and time x attack x group: F(2/15)=0.43, p=0.66.

For the parameter „rotated hip after the punch“, the mixed ANOVA showed a significant time effect with F (1/15)=7.61, p=0.01, ηp²=0.20 (large effect) and an interaction effect (time x group), F (1/15)=5.05, p=0.01, ηp²=0.25 (large effect). The other interactions failed the level of significance: time x attack: F(2/15)=0.82, p=0.37, time x attack x group: F(2/15)=0.515, p=0.60. However, post-hoc-tests showed no significant differences between the groups CG, ViG and VRG (all p=0.99).

The mixed ANOVA revealed no significant time effect in “adequate attacking speed” (F(1/15)=0.52, p=0.48), but only an interaction effect (time x attack) with F (2/15)=4.67, p=0.04, ηp²=0.13 (moderate effect). No further significant interaction effects were found for time x group: F(2/15)=0.4, p=0.68, and for time x attack x group: F(2/15)=0.51, p=0.6. However, paired t-tests showed no significant differences from pretest to posttests in each group both in all attacks (GZ left + GZ right) and in GZ left side and right side alone (all p>0.05), indicating that the sample size is too low.

The mixed ANOVA also showed only a significant time effect for the parameter “upright upper body” with F (1/15)=6.45, p=0.02, ηp²=0.177 (large effect). However, no other interaction effects were found for time x attack (F (2/15)=0.04, p=0.85), for time x group (F (2/15)=0.37, p=0.7), and for time x attack x group (F (2/15)=1.8, p=0.18. Surprisingly, post-hoc-tests showed a significant difference between CG and VRG (p=0.009), indicating again that the measured sample might be too small.

In general, no interaction effect was seen for time x attack (all p>0.05) and for time x attack x group (all p>0.05) in all analyzed parameters except of “adequate attacking speed”, indicating that the factor “attack” had no significant influence in our sample size. Therefore, the paired t-tests were carried out with GZ left arm and right arm together instead of distinguishing between left and right arm.

The paired t-tests showed a significant difference between PRE and POST1 for the parameters „stepping“, „lowering of CoM and active get off the ground“, „upright upper body“ and „rotated hip after the punch“ for VRG (all p<0.05). ViG showed only a significant difference from PRE to POST1 for the parameter „stepping“ (p=0.001). CG showed no significant differences at all (all p>0.05). Mean and standard deviation values for the parameters „stepping“, lowering CoM and active get off the ground“, „upright upper body“, rotated hip after the punch“ and „adequate attacking speed“ for each group at PRE and POST1 as well as the results of the paired t-tests (GZ left + GZ right) are given in Table 2.
Tab. 2: Mean and SD of all trials for each group at PRE and POST1. The best value would be 1 and the worst value would be 6. CG: control group. ViG: video group. VRG: VR group. GZ: Gyaku-Zuki. GZ_L: Gyaku-Zuki with the left punching arm. GZ_R: Gyaku-Zuki with the right punching arm. GZ_L+R: Gyaku-Zuki with left and right punching arms. The paired t-tests are given for the combination of Gyaku-Zuki with the left and right punching arm. Significant differences for GZ_L+R from PRE to POST1 are given in bold.

<table>
<thead>
<tr>
<th>parameter</th>
<th>PRE (mean ± SD)</th>
<th>POST1 (mean ± SD)</th>
<th>paired t-test</th>
<th>PRE (mean ± SD)</th>
<th>POST1 (mean ± SD)</th>
<th>paired t-test</th>
<th>PRE (mean ± SD)</th>
<th>POST1 (mean ± SD)</th>
<th>paired t-test</th>
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<td>GZ_L</td>
<td>4.28 ± 1.39</td>
<td>4.08 ± 1.52</td>
<td></td>
<td>5.14 ± 0.90</td>
<td>4.11 ± 1.65</td>
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<td>3.94 ± 1.74</td>
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<td>3.81 ± 1.47</td>
<td></td>
<td>5.14 ± 0.96</td>
<td>3.78 ± 1.81</td>
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<td>4.06 ± 1.36</td>
<td>3.94 ± 1.49</td>
<td>T=1.95, p=0.08</td>
<td>5.14 ± 0.92</td>
<td>3.94 ± 1.73</td>
<td>T=4.31, p&lt;0.01</td>
<td>3.86 ± 1.6</td>
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<td>3.17 ± 1.16</td>
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<td>3.25 ± 0.87</td>
<td>3.47 ± 0.65</td>
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<td>T=4.230, p&lt;0.01</td>
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<tr>
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<td></td>
<td>1.72 ± 0.82</td>
<td>1.47 ± 0.56</td>
<td></td>
</tr>
<tr>
<td>GZ_L+R</td>
<td>2.82 ± 1.04</td>
<td>2.62 ± 0.96</td>
<td>T=0.89, p=0.4</td>
<td>2.31 ± 1.16</td>
<td>3.06 ± 1.12</td>
<td>T=1.07, p=0.31</td>
<td>1.74 ± 0.82</td>
<td>1.47 ± 0.63</td>
<td>T=3.824, p&lt;0.01</td>
</tr>
<tr>
<td>rotated hip (inwards) after the punch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GZ_L</td>
<td>2.69 ± 1.19</td>
<td>2.53 ± 1.18</td>
<td></td>
<td>2.89 ± 1.41</td>
<td>2.78 ± 1.36</td>
<td></td>
<td>3.36 ± 1.29</td>
<td>2.69 ± 0.95</td>
<td></td>
</tr>
<tr>
<td>GZ_R</td>
<td>2.31 ± 0.82</td>
<td>2.64 ± 1.27</td>
<td></td>
<td>2.72 ± 1.54</td>
<td>2.53 ± 1.48</td>
<td></td>
<td>2.86 ± 1.27</td>
<td>2.08 ± 0.65</td>
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<tr>
<td>GZ_L+R</td>
<td>2.50 ± 1.04</td>
<td>2.58 ± 1.22</td>
<td>T=-0.54, p=0.6</td>
<td>2.81 ± 1.47</td>
<td>2.65 ± 1.42</td>
<td>T=1.87, p=0.09</td>
<td>3.11 ± 1.28</td>
<td>2.39 ± 0.87</td>
<td>T=3.31, p&lt;0.01</td>
</tr>
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<td>adequate attacking speed</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>GZ_L</td>
<td>2.44 ± 1.73</td>
<td>2.42 ± 1.25</td>
<td></td>
<td>3.19 ± 1.53</td>
<td>3.72 ± 1.34</td>
<td></td>
<td>2.47 ± 1.73</td>
<td>2.78 ± 1.57</td>
<td></td>
</tr>
<tr>
<td>GZ_R</td>
<td>2.67 ± 1.66</td>
<td>2.67 ± 1.31</td>
<td></td>
<td>3.17 ± 1.53</td>
<td>2.94 ± 1.4</td>
<td></td>
<td>2.67 ± 1.64</td>
<td>2.69 ± 1.62</td>
<td></td>
</tr>
<tr>
<td>GZ_L+R</td>
<td>2.56 ± 1.69</td>
<td>2.54 ± 1.28</td>
<td>T=0.31, p=0.76</td>
<td>3.18 ± 1.52</td>
<td>3.33 ± 1.41</td>
<td>T=-0.61, p=0.56</td>
<td>2.57 ± 1.7</td>
<td>2.74 ± 1.58</td>
<td>T=-1.12, p=0.29</td>
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</table>
The results for the parameters “rotated hip before the punch”, “posture of the arms before the punch” and “extension of the punching arm and fast moving back after the punch” are shown in Table 3. Paired t-tests only found a significant improvement from PRE to POST1 for ViG (p=0.010) in “extension of the punching arm and fast moving back after the punch”. No significant differences from PRE to POST1 were found for CG and VRG in these three parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Attack</th>
<th>CG</th>
<th>CG</th>
<th>PRE [%]</th>
<th>POST1 [%]</th>
<th>paired t-test</th>
<th>PRE [%]</th>
<th>POST1 [%]</th>
<th>paired t-test</th>
<th>PRE [%]</th>
<th>POST1 [%]</th>
<th>paired t-test</th>
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<tbody>
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<td></td>
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<tr>
<td>rotated hip (outwards) before the punch</td>
<td>GZ_L</td>
<td>77.8</td>
<td>86.1</td>
<td>80.6</td>
<td>83.3</td>
<td></td>
<td>69.4</td>
<td>75</td>
<td></td>
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<tr>
<td></td>
<td>GZ_R</td>
<td>83.3</td>
<td>91.7</td>
<td>88.9</td>
<td>83.3</td>
<td></td>
<td>66.7</td>
<td>72.2</td>
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<td></td>
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<tr>
<td></td>
<td>GZ_L+R</td>
<td>80.55</td>
<td>88.9</td>
<td>84.75</td>
<td>83.3</td>
<td>T=-2.17, p=0.06</td>
<td>68.05</td>
<td>73.6</td>
<td>T=-0.80, p=0.44</td>
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</tr>
<tr>
<td>posture of the arms before the punch (relaxed shoulders and fists in which the thumbs are rotated inwards / upwards)</td>
<td>GZ_L</td>
<td>50</td>
<td>83.3</td>
<td>83.3</td>
<td>83.3</td>
<td></td>
<td>83.3</td>
<td>83.3</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>GZ_R</td>
<td>66.7</td>
<td>69.4</td>
<td>75</td>
<td>72.2</td>
<td></td>
<td>100</td>
<td>94.4</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>GZ_L+R</td>
<td>58.35</td>
<td>76.35</td>
<td>79.15</td>
<td>77.75</td>
<td>T=-1.34, p=0.21</td>
<td>91.65</td>
<td>88.85</td>
<td>T=1.00, p=0.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>extension of the punching arm and fast moving back after the punch</td>
<td>GZ_L</td>
<td>72.2</td>
<td>83.3</td>
<td>38.9</td>
<td>77.8</td>
<td></td>
<td>66.7</td>
<td>83.3</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>GZ_R</td>
<td>77.8</td>
<td>83.3</td>
<td>36.1</td>
<td>75</td>
<td></td>
<td>58.3</td>
<td>69.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GZ_L+R</td>
<td>75</td>
<td>83.3</td>
<td>37.5</td>
<td>76.4</td>
<td>T=-1.15, p=0.28</td>
<td>62.5</td>
<td>76.35</td>
<td>T=-1.56, p=0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab. 3: Number of correct execution given in percent at PRE and POST1. CG: control group. ViG: video group. VRG: VR group. GZ: Gyaku-Zuki. GZ_L: Gyaku-Zuki with the left punching arm. GZ_R: Gyaku-Zuki with the right punching arm. GZ_L+R: Gyaku-Zuki with left and right punching arms. Significant differences for GZ_L+R from PRE to POST1 on the basis of the number of correct executions are given in bold.
Feedback questionnaires

Feedback questionnaire 1 and 2: content questions regarding GZ execution
Concerning the multiple choice questions for the correct execution of GZ, CG had 83.3% correct answers, ViG had 95.83% correct answers and VRG had 97.9% correct answers. This might be a clue that observational learning, either with video or VR app, can help to deepen the knowledge about correct movement execution.

Feedback questionnaire 3: usage of the app and physical comfort
Participants from VRG (phase 1 and phase 2, n=12) reported no problems in the handling of the VR app and the HMD. The app for which we wrote a precise instruction was easy to use. Furthermore, for only one third of these participants, small problems with cybersickness occurred. Two participants reported slight headache and two other participants had slight nausea at the first session but for three of the four participants, these problems disappeared from the second session.

Feedback questionnaire 4: feedback of the technologies video and VR and their comparison
The answers of the video groups and VR groups in both phases concerning the subjective feelings are given in Figure 4. As can be seen, especially in phase 2, VRG reported higher values for the motivation, the deepening of the knowledge, and improvements of own motor execution and movement imagination. Furthermore, in POST2, all athletes (n=12) are of the opinion that the intervention with the VR app was more fun compared to the video intervention. Three quarters of them stated that the VR app was better than the video because it provided more immersion and interactivity. And the athletes could change speed and perspectives individually, so the movements could be watched more easily and individually.
Fig. 4: Mean ± SD values concerning the four statements after the first and the second phase on a scale from 1 (does not apply to me at all) to 10 (fully applies to me) in the video groups (ViG, observational training using video) and VR groups (VRG, observational learning using VR app). In the second phase both intervention groups changed their function and completed the intervention with the other technology.

Discussion

Already Farrow and Raab (2008) demanded more low-impact cognitive training to improve cognitive and mental skills as well as decision-making in sports while not physically overexerting athletes. In line with that requirement, we carried out a study to analyze the benefits of observational learning using video and a VR app for smartphones and HMDs.

As we expected, we did not find any significant changes in the movement execution in the control group. Furthermore, also as we expected, the VR intervention group gained more improvements than the video intervention group regarding attack execution.

For the video group, we found significant improvements from pretest to posttest measurement in the parameter “stepping” (Tab. 2) which means that after the video training, the athletes were better in unpredictable stepping gaining more space in all directions. Furthermore, a significant improvement was found in the parameter “extension of the punching arm and fast moving back after the punch” (Tab. 3). Thus, in the posttest, they were able to pull back the punching arm faster and not to “park” their fists ahead. These improvements are in line with previous results (e.g. Marshall & Gibson, 2017) regarding observational learning using videos (Larkin, Mesagno, Spittle & Berry, 2015, Starkes & Lindley, 1994) who also found benefits of athletes’ performance due to video trainings.
Even more benefits were seen in the VR group, which improved significantly in “stepping” for attack preparation, “lowering of center of mass (CoM) and active get off the ground” before the attack, “upright upper body” during attack execution, and “rotated hip after the punch” (all Tab. 2). Hence, movements could be improved which are crucial for adequate GZ execution. Unpredictable stepping is important to test the opponent and to prepare the attack properly. Lowering of CoM and active get off the ground is crucial to approach the opponent very fast to “surprise” with speed and strength. And the upright upper body protects the offending athlete to get hit by a counterattack. These improvements are in line with the VR studies of Panchuk, Klusemann and Hadlow (2019) and Sielużycki et al. (2019) in which improvements in performance due to 360° video watching and motor learning with the Microsoft Kinect system were found.

Blandin, Lhuisset and Proteau (2003) and Lago-Rodriquez, Cheeran and Koch (2014) state that observational learning should always be accompanied with physical training. In our study, observational learning was carried out at home without further physical training. However, the combination of the observational learning intervention at home and the regular physical karate training (at least twice a week) seemed to complement each other well.

The improvements both in ViG and VRG can be explained by the common-coding-theory which says that the observation of familiar movements is linked to movement execution (e.g. Abreau et al., 2012, Agliotti, Cesari, Romani & Urgesi, 2008). The observational learning seems to lead to the activation of brain regions, which are also activated during physical exercise. These areas, in which the mirror neuron system is located, are inferior parietal lobule, inferior frontal gyrus, adjacent ventral premotor cortex, primary motor cortex, cerebellum and parts of the limbic system (Lago-Rodriquez, Cheeran & Koch, 2014). Thus, the observation of movements which already exist in the own movement repertoire, which was the case with the GZ in our advanced karate athletes, led to an improved comprehension of the attack and a better own attack execution.

However, our results are not in line with the results reported by Harris et al. (2018b). In that study, observational learning in robotic surgery was compared between the two conditions 2D and 3D, and it was found that observational learning improved the performance to a similar degree in both conditions. In the present study, we found that observational learning in the 3D condition (VR group) showed greater improvements than in the 2D condition (video group). Assuming that observational learning occurs through the activation of mirror neurons, 3D condition seems to achieve this better. Reasons for the differences observed from our study and the study of Harris et al. (2018b) could be the level of expertise of the tested participants, and the degree of familiarity with the demonstrated movements. While in the study of Harris et al (2018b) the tested participants were beginners and not quite familiar with the shown task, in the current study, advanced athletes were analyzed who already had a large amount of own motor experience of the demonstrated karate movement. Thus, the greater benefit of the 3D
condition can also be based on the task familiarization – as the shown movement was a part in the participants' movement repertoire.

All participants who underwent both interventions (VR and video) preferred the training with the VR app (Fig.4). VR training made more fun because the degree of realism, immersion and interactivity were greater in the app compared to the video. This result confirms the result of Vignais et al. (2015) who found that VR is better than video for perception tasks. It can be seen in Figure 4, that VRG reported better values than ViG in motivation, knowledge concerning the attack technique, movement imagination and movement execution. These findings support the results of the study of Guarnera, Stumiello, Cascio and Di Corrado (2016) in which it was found that first person perspectives are very important in imagination training, especially for expert athletes.

Each of our intervention session lasted only ten minutes and the VR intervention groups had either no problems with cybersickness (physical discomfort due to VR) at all or only slight symptoms (headache and nausea) at the beginning of the intervention. The symptoms then disappeared or became weaker during the next sessions. This is in line with findings from Hartnagel, Taffou and Sandor (2017) in which no problems with cybersickness during a stay in VR for ten minutes were detected either.

Limitations

However, we have to critically mention some limitations of the current study. First, we only had a small sample size with a total of eighteen athletes. Very likely our sample size of only six athletes per group is questionable to draw general conclusions in all analyzed parameters. However, we consider the present study as promising preliminary study which can be used as basis to conduct further studies in the field of observational learning using interactive VR.

Secondly, we analyzed only one attacking technique. The current study was used as a pilot study, but we think that it is possible to get a further increase in performance by implementation of more virtual characters, more karate attacks, and more information about the demonstration tasks. In future interventions it would be desirable to include more athletes as basis for the virtual characters and more karate techniques to be learned. Then, we could also extend the intervention phase and create a more diverse training with movement variation as already demanded by Blandin, Lhuisset and Proteau (1999) and Lago-Rodriguez, Cheeran and Koch (2014). The athletes also noted that the virtual character was only a blue character (see Fig. 2C) which disturbed the degree of realism. So, our next step would be to change the look of the virtual character into a more sports specific appearance (character with a karate-Gi as it was the case in Petri et al. (2019)) and to also include a haut mesh for a male and a female character, maybe even in several ages, to ensure that the athletes, no matter of age and sex, can identify themselves with the character. So, every athlete could then choose his own favorite design and movement executions of the own expertise level and gender.
Thirdly, we only analyzed young athletes who were already quite familiar with technologies, such as videos, exergames and virtual reality. Hence, it is possible that participants of older age would not prefer the VR app towards the video. Therefore, it would be interesting to include more participant groups in future studies.

Fourthly, we did not include retention tests. Hence, we cannot analyze if the positive effects seen in the VR group last, and if they last, for how long. So that inclusion of one or more retention tests would also be desirable in a future larger intervention.

**Future Directions**

Our athletes recommend the VR app for further applications in karate, but would especially recommend the app for young athletes and for competition preparation. The app can be used both in karate kumite (actual karate fight between two opponents) and kata (presentation of adequate karate techniques in a choreography). Furthermore, the app can be used in several other sports to learn and improve movement execution due to movement watching. Therefore, the environment can be adapted to the normal sports environment and the relevant movements can be recorded by motion capturing and integrated in the app. It would also be possible to just use 360° videos from the movements, as it was made by Panchuk, Klusemann and Hadlow (2019), but these videos cannot further be controlled or manipulated by the user as it is the case with the virtual character in our app.

Since that pilot study showed that observational learning can be beneficial to improve movement executions, we want to repeat that study including a larger sample size and more karate attacks recorded from more karate athletes. Then we could create a greater database for observing athletes with different attacks and also variations of movement executions. It would also be desirable when every athlete could choose a virtual character of his own expertise level and also the same gender. In the current study, young athletes only saw movement executions of male athletes with a higher level of international expertise.

In many observational learning studies, often a perfect demonstration can be observed. But it was also shown that both the presentation of correct and incorrect demonstration can be beneficial to recognize errors better (Harris et al., 2018a). Therefore, the integration of correct and incorrect movement execution together with further feedback in 2D and 3D observational learning could be a future field of research to exploit the full potential of 3D observational learning. Moreover, it should be clarified which kind of feedback, which duration, and which number of intervention sessions is appropriate to induce benefits without making the participants dependent to VR or any external feedback (Harris et al., 2018a). In the present study, we could show that for one karate attack, eight sessions of ten minutes each over two weeks were appropriate to induce benefits.
Additionally, a next step could be to develop the app in a new way that performers do not only watch but also interact in some way. Active viewing is quite different from passive watching, and can likely have greater benefits. Thus, it could be possible to analyze the benefits when participants watch the movement executions on the VR app via the HMD, and afterwards imitate the movement and also get a feedback. A visual feedback, in which they see their own movements either in VR or in a real mirror in reality could be useful.

Conclusions
Based on the results of our preliminary study, we conclude that the VR app is useful for an independent observational learning in addition to the physical training to deepen the knowledge about the correct movement execution and also to improve the actual own movement execution. Key movements, such as unpredictable stepping for attack preparation, and an upright upper body during the attack execution to avoid getting too close into the opponent’s attacking distance can be improved. Thus, the observation of experts’ movement in VR is a suitable tool to improve the performance of young karate athletes. The VR app intervention group could gain more improvements in movement execution than the video intervention group. Additionally, the VR training was more fun than training with a normal video because in VR, the athletes had control about the character and hence, the degree of realism, involvement, immersion and interaction was larger. We assume that our VR app would also be applicable in several other sports which have similar demands as those in karate, such as martial arts or racquet sports, to improve movement execution.

Such observational learning program has the advantage that it is very cheap because the app can be downloaded for free on the smartphone, and HMDs only cost around 10-20 dollars. The training can be conducted individually and independent of the time and the place as long as the user has wireless internet.

Acknowledgements
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References


Gray, R. (2019). *Virtual environments and their role in developing perceptual-cognitive skills in sports*. In A.M. Williams & R.C. Jackson (Eds.) *Anticipation and Decision Making in Sport*. DOI: 10.1007/978-3-319-58753-0_2


