Introduction and Evaluation of an Alternative Training Approach as Indicator of Performance Improvement in Martial Arts with the Help of Kinematic Motion Analysis Using Motion Capture

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***Abstract*— There are numerous areas in which we can optimize ourselves and our lives in a wide variety of ways. One area is sports, where coaches, athletes and sports scientists are working on their training methods and still researching innovative methods that will bring lasting success. This study focuses on kinematic motion analysis using motion capture (MoCap), a technology for implementing human motion in a virtual environment. The goal is to introduce a training approach in the combat sport of Muay Thai that will promote performance improvement in athletes. The study deals with three different training approaches and two different assessment methods. For this, 15 participants took part in the study and trained three Muay Thai techniques: straight punch, front kick and roundhouse kick. The study shows that a training approach should be individualized to enhance athlete performance. In any case, technologies help generate high-quality data sets that provide detailed insight into nuances in the incorrectness of a movement. In addition to fairness and objectivity, visual feedback promotes internalization and contributes to self-based observational learning. Especially for highly complex movements, motion capture supports athletes' performance growth.**

Keywords – Technique improvements; performance enhancement; training approach; kinematic motion analysis.

I. INTRODUCTION

The original need for motion capture arose in the animation and film industry, where human walking was to be realistically imitated. Today, motion capture systems are used in biomechanics to perform various gait analyses for medical purposes. Not only medicine but also sports are interested in this deeper understanding of diverse movements. Injury prevention, performance enhancement, technique improvement, and objective assessments are driving numerous coaches, judges, and athletes to embrace this new way of motion capture. Future scenarios range from new training approaches to risk reduction during and after rehabilitation, to virtual reality implementations for remote analysis. Reliable analytics, provided by different vendors in various forms, are indispensable. Too few feedback methods yet use cutting-edge technologies, though these can lead to greater effectiveness and efficiency. It is a matter of adopting and establishing new practices in the training environment. To help learners improve and alert them to errors, constant feedback is crucial. Current methods used by coaches to evaluate athletes' performance are neither efficient nor adapted to technological advances in certain sports. For the most part, videos of each team member or student must be analyzed individually to provide feedback [1]. Especially in martial arts, precision, speed, and coordination are crucial. As Muay-Thai is a part of martial art, there are many difficulties by analyzing the movement of the students compared to other sports, as described in the following: With the naked eye of a coach, the fast, dynamic movement sequences can hardly be reliably and accurately detected, tracked, and measured. In addition, most of the time a grandmaster has to control several students at the same time. It is a great challenge to give each student the same attention and thus to improve their performance rapidly and sustainably. The aim of this study is to find out how the intervention of an alternative training approach using motion capture affects the performance improvement of young beginners in martial arts in order to draw conclusions about the most predestined methodology with the highest learning effect.

The paper is divided into five sections, beginning with a short introduction to the topic. Thereupon, the research question is pursued, which results from the problem definition of the initial situation. While first the hardware used and then the associated motion capture software are explained in more detail, the thesis then focuses on the theoretical construct. In the third section, the methodology of the study is discussed in chronological order according to its development. The results are summarized in the fourth section. Finally, the fifth section demonstrates how the research question is answered and the potential of motion capture technology in the field of sports science in the future.

II. RELATED WORK & THEORETICAL FOUNDATIONS

In the following section, the theoretical foundations of the study are described in more detail. In addition to a theoretical construct, similar reference studies are mentioned.

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A. *Theoretical construct*

The final model relied upon in the study is shown in Figure 1. The arrows illustrate the dependent relationships. The submodels from past research are marked with numbers and can thus be assigned to authors and related studies. Component 5 has been newly added as it serves as a basis for future research. In the following, the theoretical sub-models are explained in more detail and the boundaries of previous studies in future science are concretized.

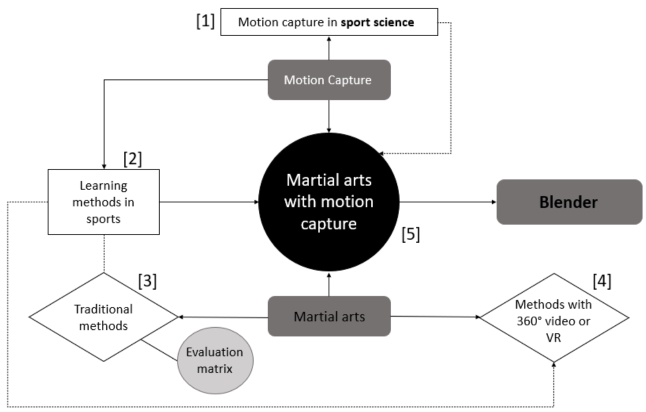

Figure 1. Theoretical construct: [1] = (Grontman et al., 2020), [2] = (Anderson & Campbell, 2015), [3] = (Čoh & Milovan, 2004), (Vít et al., 2016) [4] =(Chan et al., 2011), (Le Naour et al., 2019)

Motion capture in sports counteracts the subjective evaluation in the judging panel and still inaccurate measurement methods. Therefore, an algorithm was developed by a research group to analyze the patterns of correct intersection of the recorded MoCap data by comparing Euclidean distances and the recorded trajectories of the amateurs with the baseline model of the professional athlete Model 1. For this purpose, the techniques of sword fencing, a historically European martial art, were examined. The study analyzed only a few marker positions and neglected execution speeds. Furthermore, closely spaced markers were still omitted [2].

Providing feedback when learning new motor skills is essential in sports. Different methods can be used to address different senses, such as auditory, olfactory, gustatory, visual, and tactile perception. The results of a more recent study suggest that the combination of simultaneous self-observation and real-time expert modeling has a positive effect on accelerating learning. The acceleration of skill acquisition in rowing was investigated. Self-observation was implemented through live video transmission, while expert movement was previously recorded and transmitted in real time. The rowers saw themselves in real time and a slightly delayed image of their execution as soon as it differed from the expert modeling [3] [4].

Studies show that performance is dependent on the learning method. It is assumed that optimized learning conditions can lead to a faster increase in performance, but this does not apply to situations that are different from the learning situation. The methods must be chosen depending on the biological age, the level of knowledge about the techniques and the motor experience of the athletes. It is recommended to focus first on the causes of the wrong movements rather than on the consequences. Faulty conception of technique execution, insufficient motor skills, and close morphological constitution of athletes' bodies are the causes of incorrect movement execution in most cases [5] [6].

Specifically in martial arts training, there are set teaching methods. After the instructor demonstrates the techniques and the student observes, the movements are imitated and repeated. This is followed by verbal extrinsic feedback by the instructor. One study examined the difference between extrinsic feedback in the form of a video and verbal feedback. The researchers concluded that learners are more critical of their own technique execution when they see it on a video [7].

Meanwhile, different technologies can support feedback to improve motor skills. Researchers are investigating training systems based on motion capture and virtual reality. They developed a prototype that implements a student's imitation of a virtual expert's movements. Results showed that the simulation was a successful training methodology because the student's movements, animated in VR, were captured and analyzed in real time while the virtual instructor could point out errors to them [4] [8].

Another study compared the benefits of diverse types of visual feedback to improve movement execution in gymnastics. Additionally, subjective (compared to quantitative) measurement methods were used. The subjective assessment was in the form of a battle court, while the quantitative measurement method consisted of time series analyses. Four different 3D visualizations were contrasted. Learners made the best progress using the 3D feedback, which compared the expert's execution with the learners. Finally, correlational analyses confirmed that subjective judgments by the referee cannot be predicted or justified by objective measurements [9].

III. METHODS

The study references diverse approaches from past research and combines diverse measurement methods with different training approaches to identify the most predestined learning methodology in the martial art of Muay Thai. In the theoretical construct, this is placed in the middle [5] of the reference studies (Figure 1).

A. Setup

The study used the OptiTrack system from NaturalPoint, which is one of the world's largest suppliers in the motion capture field. The experiments took place in a motion capture lab equipped with 28 OptiTrack PrimeX 13s to capture the movements of the trainer and students in real time. At the same time, a virtual figure representing the trainer or the students was animated on a 2.04 m x 3.63 m monitor. The study was conducted in the MoCap laboratory at the Technical University in Würzburg (THWS). The real-time analysis and recording software Motive:Body was used in conjunction with the OptiTrack motion system. Together with the Blender software, the movements could be recorded, measured and analyzed.

The software as well as the high-speed tracking cameras are used in the fields of film, gaming, sports and biomechanics. An optical motion capture system based on infrared markers uses multiple cameras equipped with infrared diodes (IR LEDs) whose infrared light is reflected by the markers. Using multiple 2D images, the 3D position of the markers can be calculated and determined within the space. The OptiTrack systems have a measurement or position error of less than 0.2 mm. In small measuring ranges even only 0.1 mm or less. During tracking, rotation errors of less than 0.5° also occur. The accuracy is maintained by regular self-calibrations throughout the entire service life.

Primex 13 cameras are also particularly suitable for motion capture applications characterized by higher speeds, accelerations or jerky movements, as they have a higher frame rate and therefore higher resolution, lower latencies and a longer focal length.

The resolution affects the minimum distance between markers and the minimum size of markers defined at a certain distance from the cameras. Each actor wears the Motion Capture Suit during motion tracking, which is antimicrobial, stretchy and breathable, so they are comfortable enough to wear even during longer shoots. The suit can be worn over everyday clothing and fits snugly to the body when worn. Components included shoes, a full body suit, gloves and a hat. Attached to the entire suit are X-base markers from OptiTrack. They are embedded in a Velcro base and have a spherical structure with an outer diameter of 14 mm.

B. Participants

- 15 healthy participants took part in the study. The fifteen subjects were divided into 5 females and 10 males with an age range of 20-31. The average height of the subjects was 1.77 m (1.50-1.95 m) with an average weight of 75 kg (50-115 kg). In each group, there was one participant who had previous martial arts experience (<5 y), whereas in group 2 there were two experienced participants, one of whom had even done martial arts for over 5 years. Nearly all subjects reported regular exercise, no known mobility impairments, or other health problems that could affect their mobility. They were familiarized with the study objectives and mode of implementation before the experiment and signed written informed consent to participate in the study. The groups were randomly selected, with the first two groups performing the techniques in the laboratory twice at four-month intervals and the third group performing the techniques five times at four-week intervals.
- They were instructed and evaluated by a multiple world (WKA) and European (MTBD) champion in Muay Thai and kickboxing. As a black belt holder who himself has been training the Far Eastern martial arts daily since the age of 3, he teaches many students in all disciplines in his own fighting schools. Together with the trainer, the three Muay Thai techniques were selected and the most important sub-steps of a single execution were discussed, which were later analyzed in more detail. Prior to the study, he was recorded in the MoCap laboratory, first 2D via video and then 3D via motion capture during the technique execution. Before the 15 students were divided into three groups of five, they received a joint training session with the sensei, during which an initial introduction of the three Muay Thai techniques was given. The professional Muay Thai trainer supervised the subjects during the first sessions of the three groups to be available to answer questions about technique and technique execution. In addition, the sensei evaluated the participants individually via evaluation matrix. For this purpose, a video of the participants at the beginning and at the end of the study was sent to him. The aim of this measurement method is to be able to draw a comparison between the observation of a professional athlete and trainer with the quantitative analysis (angle measurement).
- No subject was motor impaired and all were able to perform the techniques. The focus is on the correct execution of the techniques, performance progress, and knowledge transfer under different training conditions.

C. Measurements

The first group trained with a demonstration video showing the three techniques Straight Punch, Front Kick and Roundhouse Kick, demonstrated by the sensei (shown in Figure 2).

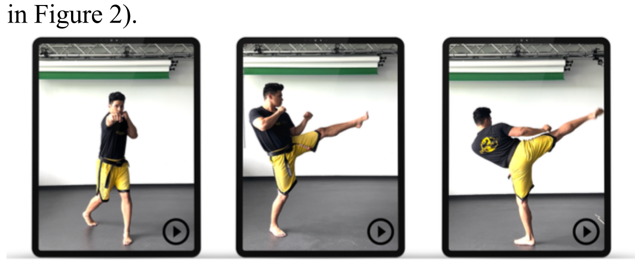

Figure 2. Demonstration video of the sensei

After importing the trainer data from the motion capture recordings into Blender, the second group used this software to track the techniques in 3D. The amateurs were thus provided with a virtual training environment that simulates a real trainer but works even when no real sensei can be present. The third group trained at home with the 2D video and every four weeks in the lab. After each session, the subjects' movements were analyzed in detail. For this purpose, the angles of the joints were evaluated for each partial technique, and then the angles between the bones were measured. After the evaluation, the subject's data was compared with the trainer's data to identify incorrect executions. The Blender software was ideal for showing the students their errors as well as demonstrating the differences between the trainer and the individual performance.
Figure 3 demonstrates the deviation of the angles between the trainer and the amateur in Blender.

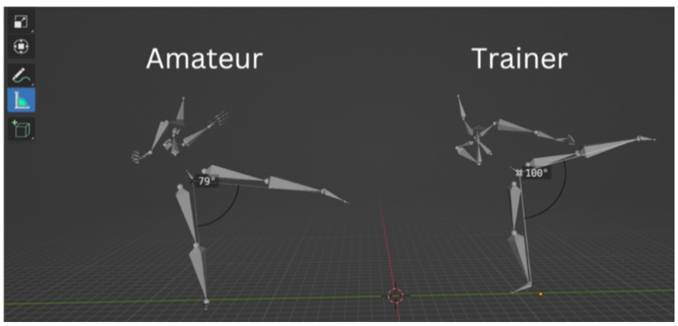

Figure 3. Demonstration of the deviation of the angles between trainer and amateur

It was also possible to show the path of the movement of the sensei to compare to the students as shown in Figure 4.

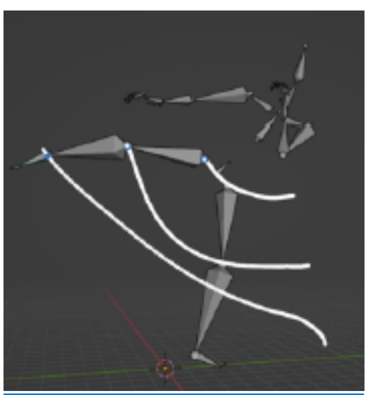
Figure 4. Path of the movement shown in Blender

Overall, two different evaluation methods were used to analyze the angles, but both are based on the consideration of the deviation of the angles between student and trainer. Thus, both evaluation approaches follow the same approach.

In the first evaluation method, the ideal of the coach is determined via rotation angles and compared with the athletes. In the second evaluation method, a simplified model is used for validation. This is based on the 2D angles between individual bones and limbs as shown in Figure 3 (thigh, lower leg, shoulder, etc).

In the following section "Results" we will talk about improvements and deteriorations of the individual groups and athletes. The improvements are always evaluated relative to the ideal in both evaluation methods. The ideal always describes the execution of the coach and its angle between individual body parts or change of angles during a movement. An improvement of 10 %, for example, means that the athlete has come 10 % closer to the ideal execution of the sensei.

IV. RESULTS

The first evaluation methodology shows that one subject from each group improved in straight punch from the first to the last training session. One subject from group 2 has the greatest improvement in performance. Most of the students have deteriorated after the training, some to a lesser extent and some to a slightly greater extent. This can be caused by two reasons. First, it is very challenging to communicate which joint needs to be adjusted and how to achieve the ideal, even though the feedback was supported by visual images in Blender. However, once understanding was present in the student, another hurdle arose. The technical implementation is very complex for martial arts amateurs in this short training period. The Straight Punch represents the most straightforward technique of all three Muay Thai techniques, so the subjects were already extremely confident in their intuitive execution. This is another assumption why performance on this movement could not be significantly increased by any training methodology. One outlier, who already had experience from another martial art, could be enticed to perform the technique in the way he knew.

Just under half of the subjects (approximately 46.67%) improved their execution of the front kick over the training period. In Group 1 and 2, three amateurs each improved, whereas in Group 3 only one did and one student showed almost no change. The training methods used with group 1 and 2 showed successful results and a strong tendency to improve. Especially group 1, who trained with a video of the trainer, showed improvements up to 40% while deteriorations were in the range below 10%. Similarly to group 2, which in addition to the video could view the execution of the trainer in 360°, improvements up to almost 50% and deteriorations below 15% were measured in this group.

Results that differed greatly from the previous techniques were found for the last and most challenging technique. The roundhouse kick, which was an unknown technique for all amateurs, is the most complicated of all three Muay Thai techniques due to its 360° rotation. Nevertheless, almost all students from group 3 improved, whereas the first two groups did not improve significantly. In fact, these two groups showed the greatest drop in performance on the roundhouse kick. This indicates that the novel training method that was used regularly by group 3 produced the greatest success with complex techniques. The regular training at home with video combined with the training in the lab resulted in 80% of Group 3 improving. Using Blender, which visually placed the students next to the trainers and vividly communicated the nature of the rotational deficits, increased performance throughout the training period despite the challenging implementation. Students from Group 3 were intrinsically motivated to excel, especially with this difficult technique.

The results of the second evaluation methodology for the Straight Punch show that 13 out of 15 participants improved while the other two students deteriorated by approximately 2% and 5%. The subjects from Group 3 show the largest increases in performance.

The demonstration, which memorably visualized the deviation between student and trainer, was used regularly with group 3 and resulted in all students from group 3 achieving a deviation below 10% after training. The subjects from group 1 and 2 who improved achieved a low deviation of no more than 10%. Group 3, on the other hand, achieved improvements above 16%, while two other participants increased their performance by approximately 10%.

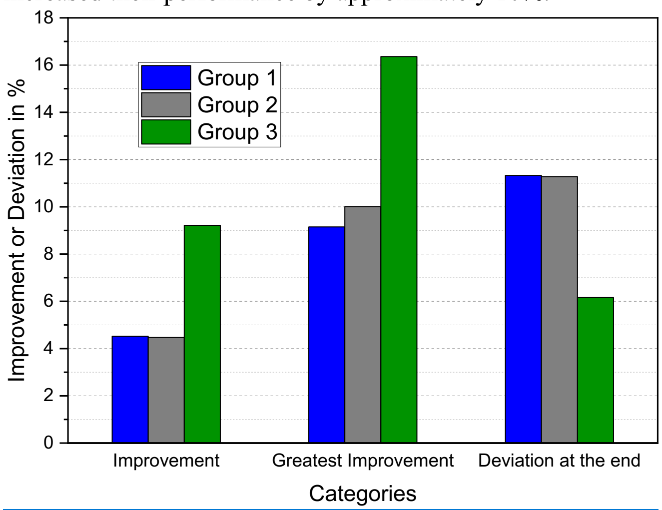

Figure 5. Statistic for the Straight Punch in three different categories

Figure 5 shows exemplarily for the Straight-Punch three different categories, namely the average improvement of the 5 participants, the highest improvement in one group and the average deviation from the ideal at the end of the training sessions. It can be clearly seen that group 3 achieves the best results. The average improvement is more than double that of group 1 and group 2. The absolute best improvement is also highest in group 3. Lastly, it should be noted that the final result (average deviation at the end) for group 3 is also almost half of the other two groups. Thus, group 3 is significantly closer to the ideal at the end than the other two groups - at least in this case shown for the Straight Punch.

Fewer students improved on front kicks than on straight punches. 10 out of 15 athletes were able to improve their performance, of which most from Group 1, three participants from Group 2 and also three students from Group 3 improved. The three subjects from group 3 showed the smallest deviations of max. 6% after the training. Analogous to the straight punches, the front kicks are shown divided into the three categories in Figure 6. It can be seen that group 1 has improved slightly more on average, while in the other two categories group 3 achieves the best results.

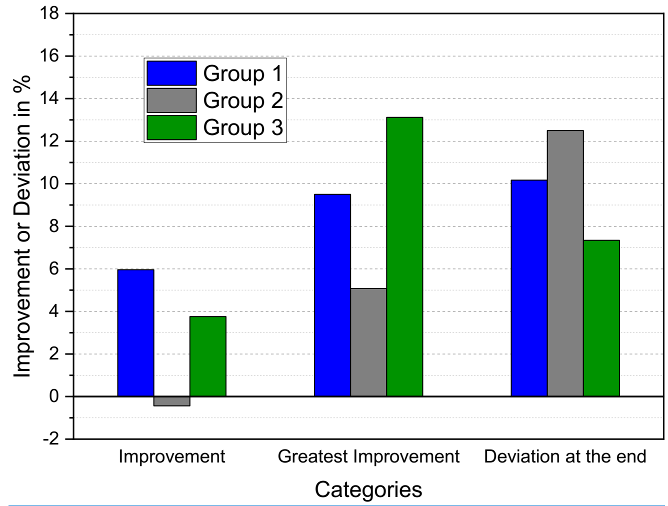

Figure 6. Statistic for the Front Kick in three different categories

When comparing their own execution with the trainer, the simple 2D video may have helped more than the 360° view of the trainer, which is why more students from the first group improved than from the second group. There is less improvement in front kicks than straight punches in group 2.

In the Roundhouse Kick, 10 out of 15 students improved, of which 50% overall came from the first two groups. 50% of the performance increases come from group 3. It can be seen that group 3 was able to improve particularly strongly, which can be seen from the relative deviations before and after training. These are just under 7% for as many as four students. In Group 1, 40% increased their performance, but slightly. The technique contains complex movement sequences and is characterized by its expressive dynamics. The video that Group 1 received for training could not be played in slow motion. The trainer's technique could not be inspected as explicitly as by group 2, which received additional support in the form of the 360° view of the trainer. This may have resulted in more participants from Group 2 improving than from group 1, although both groups showed small improvements on average. For group 1 it was a maximum of 3.9% and for group 2 even only a maximum of 3.27%.

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The results of the Roundhouse-Kick are shown in Figure 7. Group 3 got the best results in every single category. Especially in the average improvement, where Group 1 and Group 2 have almost no deviation while Group 3 reached more than 10 %.

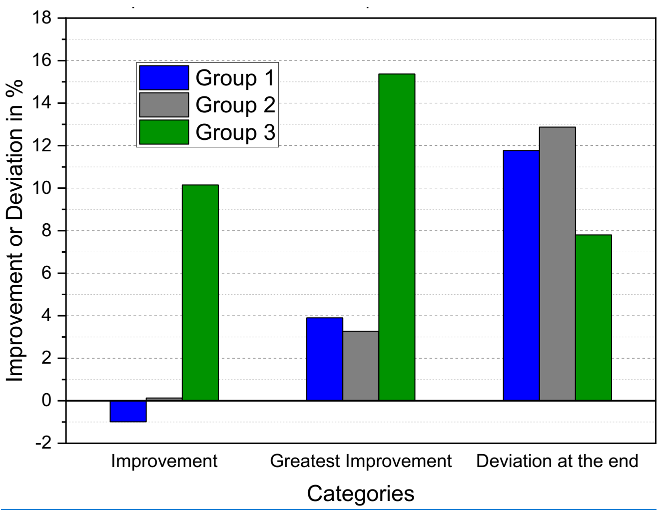

Figure 7. Statistic for the Roundhouse-Kick in three different categories

As with the first evaluation methodology, the second evaluation methodology also confirms that the training method using motion capture and Blender helps to increase the performance of amateurs, especially in complex motion sequences. The results showed that the trainer's assessment was mostly consistent with the assessment that emerged from the two measurement methods.

V. Conclusion, Limitations and Future Research

The aim of the study was to find out how the intervention of an alternative training approach using motion capture affects the performance improvement of young beginners in martial arts in order to draw conclusions about the most predestined methodology with the highest learning effect.

This objective was achieved by analyzing three different training methods and evaluating them in two different ways. These implied the first training method, in which the participants of group 1 trained with a video demonstration of the trainer. The second training method of group 2 used in addition to the video the software Blender, which demonstrated the technique execution of the trainer in a 360° view. The third and final training method used by group 3 used the motion capture system and Blender software. Various measurement tools were used to provide feedback to the students in different ways. Both evaluation methods in combination were relevant to ensure appropriate analysis. The evaluation was first done qualitatively by the instructor, who assessed each technique using relevant criteria. This assessment was compared with the quantitative results. For the simplest technique, the Straight Punch, only 20% were able to improve, which was due to the complicated implementation and challenging teaching of the joint adjustments. The results of the evaluations of the Front Kick, on the other hand, showed that it was the training methods of the first two groups that produced positive changes in performance and that they were particularly well suited for this Muay Thai technique. The more demanding a technique was, the more likely the newly introduced training methodology applied to the third group produced the greatest success. The qualitative assessment by the trainer and the quantitative analyses show three crucial changes in performance:

(1) All three groups significantly worsened in straight punches during the first evaluation methodology but significantly improved in straight punches during the second evaluation methodology.

(2) In front kicks, the training methods applied to group 1 and 2 showed successful results and a strong tendency to improve, shown by evaluation methodology 1.

(3) Both evaluation methods confirmed that group 3 achieved the strongest improvements in the roundhouse kick.

This leads to the conclusion that a training approach supported by motion capture and blender leads to a successful increase in performance, especially in dynamic and complex movement sequences.

The Motion Capture method achieved the highest learning effect with the most demanding martial arts techniques and is considered the most predestined methodology for these.

In order to promote sustainable performance increases, individualized training supported by technology is a prerequisite. This allows reliable, accurate data to be determined and communicated to athletes in a comprehensible manner. In addition, this type of kinematic motion analysis promotes fairness and objectivity of evaluation in a competition. This is not intended to replace professional evaluation by a coach, but to complement it.

In the future, this training setup can be extended with virtual reality to ensure location-independent training. Furthermore, this allows the implementation of diverse training environments and scenarios that can provide different frameworks at low cost and low effort, depending on the use case. This also exceeds the limitations of a traditional training room today. Furthermore, the use of AI can enable even more precise (early) detection of details in (faulty) execution, thus promoting and expanding injury prevention and performance enhancement. These methods can be transferred or directly applied to other sports in future research.

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REFERENCES

[1] P. Cunha, V. Carvalho, F. Soares, “Real-Time Data Movements Acquisition of Taekwondo Athletes: First Insights. Springer International Publishing.”, 2019.

[2] A. Grontman, M. Śmiertka, M. Trybała, Ł. Horyza, K. Koczan, M. Marzec, “Analysis of sword fencing training evaluation possibilities using Motion Capture techniques.”, IEEE 15th International Conference of System of Systems Engineering (SoSE), 325-330, 2020.

[3] R. Anderson and M. J. Campbell, “Accelerating skill acquisition in rowing using self-based observational learning and expert modelling during performance, International Journal of Sports Science & Coaching, 10, 425-37., 2015.

[4] A. Lamošová and O. Kyselovičová, “The Effect of Different Types of Feedback on Learning of Aerobic Gymnastics Elements”, Applied Sciences, 12:8066, 2022.

[5] M. Čoh and B. Milovan, “Motor learning in sport”, Facta Univ Phys Educ Sport, 2, 2004.

[6] T. Bompa, “Periodization, Theory and Methodology of Training”, Champaign IL: Human Kinetics, P.O. Box 5076, 1999.

[7] M. Vít, Z. Reguli, J. Cihounkova, “Extrinsic feedback in martial arts training”, Revista de Artes Marciales Asiáticas, 11(2s), 82, 2016.

[8] J. C. P. Chan, H. Leung, J. K. T. Tang, T.Komura, “A Virtual Reality Dance Training System Using Motion Capture Technology”, IEEE Transactions on Learning Technologies, 4(2), 187–195, 2011.

[9] T. Le Naour, C. Ré, J.-P. Bresciani, “Application to the roundoff movement in gymnastics”, Human Movement Science, 66, 564–577, 2019.