Using Video-based Technology in Powerlifting Sport to Support Referees' Decision Making

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ABSTRACT

Referees' decisions in sport games, which must be made in less than a second, have an impact on the games' outcome. The use of hardware and/or software solutions could contribute towards increased accuracy of referees' decisions. Application of such solutions can be expensive, especially in the case of less popular sports. In this respect, we propose and evaluate a video-based system for helping referees in powerlifting to make better decisions. Results reveal promising accuracy rates of the proposed system. This attempt is the first step towards supporting referees in the powerlifting domain and further elaboration of the proposed system is required to achieve higher decision-making accuracy.

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CCS CONCEPTS

• **Information systems → Decision support systems**; • **Human-centered computing → Human computer interaction (HCI)**; • **Software and its engineering**;

KEYWORDS

Technology in sport; video-based decision-making; powerlifting

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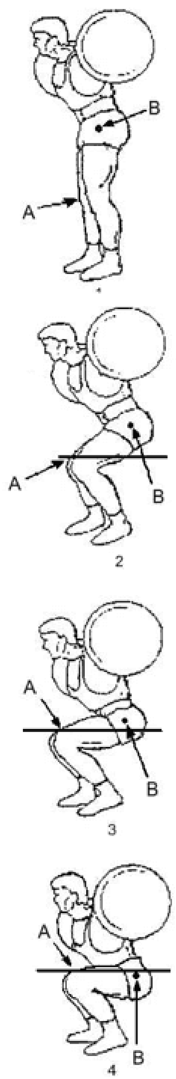

Figure 1: The squat movement.

INTRODUCTION

The referee's decisions can have a major impact on the outcome of a sport game and, in some situations, the direction of the game can be completely changed by a single decision. As such, it is not uncommon for the referee to be targeted as the cause of the failing of an athlete or a team, and to be blamed for influencing the result of a game by either not enforcing the rules or by being biased. In many sports, referees must make split-second decisions. They are required to evaluate an event or a situation and present the appropriate decision in about one second [4].

Considering the dynamic nature of many sport games, the intrinsic nuances, ambiguities and uncertainties they introduce, and the physiological and cognitive characteristics of human beings, the decisions made by the referees could be influenced by several factors [9]. The recent technological advances led to the increasing use of technology to support referees' decision making, in several sport domains [6], aiming to reduce the incidence of controversial decisions and lead to fairer competition. Such assistive systems are often based on expensive hardware (e.g., sensors), which cannot be afforded within less popular sports, such as Powerlifting.

Motivated by the difficulties that less popular sports face to adopt expensive apparatus and considering that camera-based systems are often used as credible alternatives of sensor-based systems in referees' decision making [5], we introduce a novel camera-based software system, which supports referee's decision making in Powerlifting in real-time, along with a preliminary evaluation study.

Powerlifting

Powerlifting is a strength sport that becomes popular day by day, with more than 10,000 athletes from more than 100 countries worldwide. Powerlifting consists of three attempts at maximal weight on three lifts: barbell squat, bench press, and deadlift. The lifter's best valid attempt on each lift counts

Figure 2: From top to bottom: Eye-hawk technology in tennis, goal-line technology, Deep Squatter screenshots.

toward the competition total and the lifter with the highest total for each weight class wins. Three referees are responsible for deciding on the validity of a lift. A lift is considered valid if at least two out of three give it a white light as opposed to red. During World and Continental Championships, a Jury may, by a majority vote, overrule any refereeing result, to correct a referees' mistaken decision.

Out of all three lifts, the squat has been posing the most controversy and ambiguity among athletes, referees, and federations. Proof of this can be found in the 93kg weight class of the EPF 2017 European Classic Powerlifting Championships, where the referees' opinions were split between either 2 red - 1 white lights or vice versa in 14 out of the total 57 attempts. Focusing on the squat movement, the lift (Figure 1) begins with the athlete being in an upright position, with knees, hips and ankles fully extended. The barbell is placed on the upper back, across the trapezius or rear deltoid muscles. Upon receiving the squat command by the front referee, flexion to the knee, hip and ankle joints is performed for the lifter to descend, until the hip crease passes below the top of the knee (i.e. B is lower than A in Figure 1). The athlete then ascends reversing the direction.

RELATED WORK

The implementation of human-computer interaction (HCI) in sports is both athlete and referee-oriented. Movement sonification systems, wireless sensors, and tactor suits have been used to provide real-time feedback aiming to track body poses [10] and improve athletes' technique in various sports, such as snowboarding [11] and speed-skating [12]. Focusing on the technologies used in sports to support referees' decision-making, they lie under two broad categories: the sensor-based and the camera-based. Sensors are typically used in sports which embrace physical contact among the competitors (e.g., taekwondo, fencing). In sports that are not based on physical contact (e.g., football, basketball, tennis), camera-based or hybrid systems are typically used to support referees' decisions.

A popular camera-based technology is the reconstructed track devices (RTDs), with *Hawk-Eye* system (Figure 2:top) being one of the most well-known examples of RTD. RTDs use cameras to capture and track the path of the ball, generating simulations of the on-field events. Another popular technology is the goal-line technology (GLT) used in association football (Figure 2:middle). GLT has both hardware (e.g., implanted chip in the ball) and software (e.g., Hawk-Eye) requirements. These systems have been proven credible, despite the fact that they are not completely infallible, but they typically require expensive equipment. Other popular camera-based referee assistive technologies are the instant-replay and photo-finish, which, however, might require special equipment (e.g., high-speed camera) and do not provide real-time assistance. Focusing on powerlifting, there is no special software that assists referees to make a more objective decision. A few mobile applications, such as *Squat Depth Meter*, *Deep Squat* (Figure 2:bottom), and *SquatRight*, have been developed, but their results are controversial and not accurate on critical situations. Moreover, given that they are based on a mobile phone to be worn by athletes, their integration within a powerlifting meet is impractical.

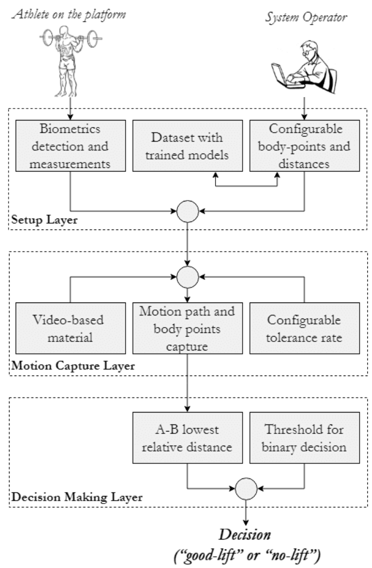

Figure 3: Decision-making prototype architecture for Powerlifting sport.

Table 1: Evaluation results.

Bodyweight category	Accuracy of "good lift" decisions	Accuracy of "no lift" decisions
-59 Kgs	14/15	9/9
-66 Kgs	49/52	11/11
-74 Kgs	91/104	35/37
-83 Kgs	151/167	32/34
-93 Kgs	122/138	43/46
-105 Kgs	128/156	41/43
-120 Kgs	37/59	12/13
120+ Kgs	21/33	5/5
Overall	613/724	188/198

TOOL DESIGN

Design

The prototype of the camera-based software system we suggest consists of three layers: *setup*, *motion-capture*, and *decision-making*. The setup layer is responsible for acquiring the biometrics of the competing athlete. The accurate recognition of skeleton joints (hip center, left/right hip, left/right knee, left/right ankle, left/right foot) and the measure of the hip-to-knee, knee-to-ankle, ankle-to-foot distances is of major importance since the decision-making process is primarily based on these measures. The process is automatic through detection techniques (e.g., neural networks), but it is also configurable by a human operator, in case of spotted mistakes in the detection process. Human subjects can be used to train the detection process and improve its accuracy.

In the motion-capture layer, the movement of the athletes while they squat is captured. The relative position of A and B points (Figure 1) is also tracked during the whole movement (both the ascending and the descending). A tolerance-rate configuration is also available to the operator. The output of this layer is the captured motion path of the athlete which feeds in the decision-making layer. The decision-making layer is based on simple binary logic and measures whether the distance A-B has a negative value. It measures again the body relative distances and calculates the angles between the body joints. This allows for understanding the relevant A-B position in terms of distance from the floor and thus the system provides the appropriate decision. If the distance A-B is greater than or equal to 0, then the lift is considered a "good lift"; otherwise it is considered a "no lift". The main architecture of the prototype is depicted in Figure 3.

Evaluation Study

To evaluate our proposed system towards the accuracy and the credibility of the decisions, we assessed the Squat Lifts of the USA Powerlifting Raw Nationals (USAPL) 2017. More than 1,000 athletes participated in the championships. We limited our study to male participants. The accuracy of our system decision was compared against the Meet Jury's decision, which is the final and official decision regarding a lift. Jury typically consists of multiple (e.g., five in Olympic Weightlifting) members who monitor the referees to ensure that the rules are correctly adhered to. The Jury has access to video material and can correct refereeing mistakes about a lift in later stages of the meet.

To assess the performance of the system we ran multiple binomial tests, which met the required assumptions (Table 1). Regarding the overall system, the correct decisions were more than the false ones ($p < .001$) with .869 accuracy rate (.847 for "good-lift" decisions and .949 for "no-lift" decisions). Focusing on each bodyweight category, the analysis showed that the decisions made by our system were in correspondence to Jury's decisions according to binomial tests (-59 Kgs, -66 Kgs, -74 Kgs,

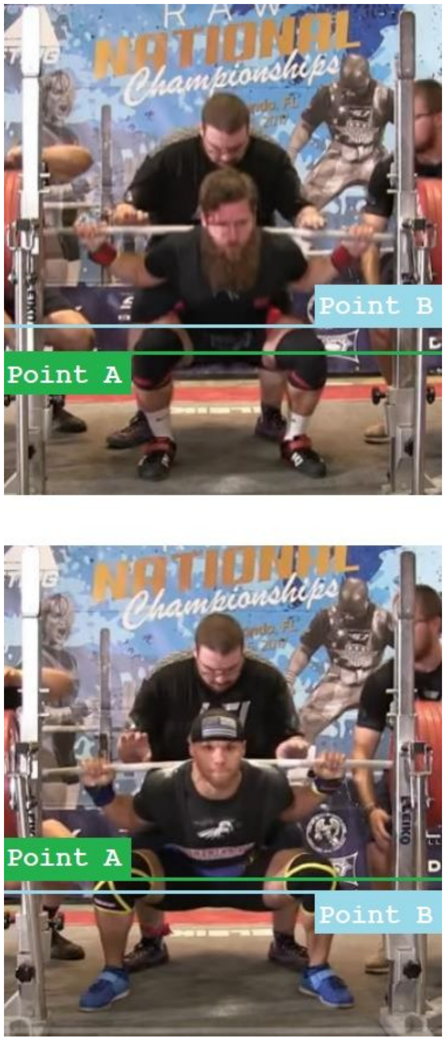

Figure 4: An invalid "no-lift" decision of our system (top), and a valid "good-lift" decision (bottom.

-83 Kgs, -93 Kgs, -105 Kgs: $p < .001$; -120 Kgs: $p = .003$; 120+ Kgs: $p = .035$). However, for the heavy body-weight categories, the accuracy of the system was not as expected regarding the "good-lift" decisions (-120Kgs: accuracy = .681, $p = .067$; 120+ Kgs: accuracy = .684, $p = .163$).

DISCUSSION AND FUTURE STEPS

Our system performed well, as its decisions were in accordance with the Official Jury's decisions. However, there is still room of improvement, especially for the "good lift" decisions and the heavy body-weight categories. That could be accredited to error in prediction/ calculation of the hip and knee joint position due to the increased fat mass of athletes in the heavyweight division, compared to the rest. This should come as no surprise for markerless motion capture systems, because we implement physics and anatomy to limit parameterization of human movement [2]. Thus, variability, inaccuracy, and lack of reproducibility are affected by technical and human factors [3, 7].

We envision that our system could be an efficient and low-cost technological solution that supports referees in the decision-making process. However, considering that the human factor is of major importance as the referee is the one that makes the final decisions, further research is required to investigate situations of contradicting decisions (e.g., "good-lift" by the system and "no-lift" by the referee) and the influence of both the human and the technological factor, especially in scenarios of high pressure (e.g., decision on the winner).

Ways of Improvement

Higher accuracy of the system can be achieved in various ways. A transition can be made towards an optical active-marker system, as proposed by Maletsky et al. [8]. Another option is to introduce two cameras which film each athlete from the frontal and sagittal planes, greatly reducing the margin of error [1]. Our immediate future work consists of a) investigating the influence of human factor in contradicting decisions in real-time meet scenarios, b) performing more studies in powerlifting meets, aiming to have more robust understanding of the weaknesses and strengths of our prototype (especially for the end-points of the bodyweight categories, as we had a limited sample size in this work), c) implanting other factors to improve accuracy (e.g., investigate optimal tolerance rates for each bodyweight category and/or body measures, consider varying view-angles, and add more cameras), d) building decision-making assistive mechanisms for the rest competition lifts (i.e., bench press and deadlift), and e) evaluate the prototype within real-time national and international powerlifting meets and fully develop it. The outcome will be a system capable of providing assistance to referees' and/or Jury's decision making, in all three powerlifts. In law, decision-making algorithms have been praised, when certain explanation styles were provided. Given the nature of judging criteria in powerlifting, we believe our system will be widely accepted by athletes and spectators around the world.

CONCLUSION

In this paper, we described and evaluated a prototype of a software system for supporting the referees in the decision-making process. Preliminary results confirm the feasibility of the system in terms of accuracy. As the next step of this research, we will consider using more cameras from different angles and we are confident that we will be able to provide a cheap still highly accurate system for supporting referees' decision-making in the tight time limitations imposed by the nature of the sport.

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