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TARGET SPORTS

Mario Heller and Arnold Baca

UNIVERSITY OF VIENNA, AUSTRIA

Summary

In the first part of this chapter, performance indicators in target sports are defined and justified. A focus is put on Olympic sports (archery, rifle – specifically, biathlon – shooting, and pistol shooting). In particular, aspects of movement kinematics in terms of postural balance and aiming stability are discussed. After that, an overview of psychophysiological research in the area of precision shooting is given and other aspects which influence the shooting performance are reviewed. Methods for acquisition and analysis of respective parameters and/or time courses of parameter values are presented.

Introduction

Target sports in terms of (Olympic) precise shooting disciplines can be classified into four summer categories (rifle, pistol, shotgun, and archery) and biathlon shooting in winter. Despite various types of guns (firearms, airguns, bows), positions (prone, standing, kneeling), distances (10, 25, 50, and 70 m), physical conditions (cardiorespiratory load, strength and endurance of the upper body), and weather (temperature, wind speed, wind direction), all have in common that the environmental goal is to hit the center of the target. In some cases, the shooting score describes how well this goal is achieved. Obviously, the assessment of shooting results is a relatively unambiguous and useful index of successful and less successful task performance (Mononen et al., 2007), but to gain deeper understanding of the underlying mechanisms causing successful performance, some specific factors of influence become apparent: postural and aiming stability, psychophysiological aspects, and other effects affecting shooting outcome. Within the following sections, a survey of important performance indicators in target sports will be given, without, however, claiming to be exhaustive.

Postural and aiming stability

There are a number of studies in the field of postural and aiming stability in precision shooting disciplines that identified (widely) necessary but not sufficient prerequisites for good shots. Mononen et al. (2007) give a good summary of the state of the art regarding postural and aiming stability: highly skilled rifle shooters produced smaller body sway amplitudes both during bipedal standing (Aalto et al., 1990; Niinimaa and McAvoy, 1983) and during shooting (Era
et al., 1996; Konttinen et al., 1999) compared to inexperienced shooters. Among inexperienced rifle shooters, postural balance was significantly worse for the less successful shots (Era et al., 1996), whereas no such differentiation was found among top-level shooters (Ball et al., 2003a; Era et al., 1996). Another prerequisite for successful performance seems to be minimal movement of the gun barrel during the aiming phase (Ball et al., 2003b; Konttinen et al., 1998; Mason et al., 1990; Mononen et al., 2003; Zatsiorsky and Aktov, 1990). With regard to skill level, elite shooters were able to keep their rifle more stable during the aiming period compared to novices (Konttinen et al., 2000; Mononen et al., 2003). The degree of gun barrel stability discriminated among high-scoring and low-scoring shots both among novice and among elite rifle shooters (Konttinen et al., 1998; Mason et al., 1990; Mononen et al., 2003).

Significantly larger slow-drift movements were observed compared to tremor for neck, shoulder, elbow, wrist, and gun among air pistol athletes (Pellegrini and Schena, 2005; Tang et al., 2008). This was particularly the case for lateral movements.

Herpin et al. (2010) performed one of the very few experimental studies to analyze balance control and the related neurosensory organization. They found out that shooters yielded a better balance control during tests with eyes open and eyes closed than fencers and controls, but fencers showed a better balance control in tests with eyes closed with sway-referenced support surface than shooters and controls.

In recurve archery, where the archer has to cope with the breakdown of the static balance of forces between the external tension and his muscular forces at the moment of shooting, body stability (Hinze et al., 2004; Mason and Pelgrim, 1986) and a stable aiming process seem to play an important role. Gruber et al. (2002) analyzed the German junior and national team. The members of the national team showed significantly smaller holding areas and a significantly higher shooting score. Individual analysis revealed no dependence of the result on the stability of targeting in the junior national team but seven archers out of nine showed that dependence in the national team. Moreover, the draw-length should be nearly constant during aiming (Edelmann-Nusser et al., 2006). At the end of the aiming phase, the archer has to pull the arrow back smoothly and steadily (also called ‘regularly’; see Edelmann-Nusser et al., 2006; Leroyer et al., 1993).

Insights on performance may also be gained by analyzing surface electromyographic activation patterns. Soylu et al. (2006) showed that FITA scores in recurve archery were significantly correlated to the variance ratios of musculus flexor digitorum superficialis and extensor digitorum, investigating similarity of the EMG signals. EMG linear envelopes were more repeatable among archers compared to non-archers. A longitudinal analysis of the German national and junior teams revealed two very stable amplitude activation patterns of musculus trapezius pars transversa (Heller et al., 2004). For ten out of twelve archers, a decreasing rectified smoothed EMG and mean power of the musculus trapezius pars transversa could be found immediately before the contact-loss of the arrow with the bowstring; for two archers, the activity increased. However, the median frequency of EMG signals indicated both longitudinal stability and instability among all athletes.

Psychophysiological aspects

Psychophysiology, defined as ‘the scientific study of cognitive, emotional and behavioral phenomena as related to and revealed through physiological principles and events’ (Cacioppo and Tassinary, 1990: ix), can provide an objective and relatively non-invasive method of examining the complex processes involved in sports performance (Collins, 1995: 154). Electroencephalography, electromyography, and measures of heart rate, skin conductance and temperature, gaze
behavior, respiration, and blood pressure are usually used to reflect changes in the central and autonomic nervous system (cf. Collins, 1995: 155).

Based on the fundamental work by Hatfield et al. (1984), there are a number of reports in which the EEG patterns of expert performers have been described when challenged with visuospatial and motor coordination demands during aiming periods in rifle shooting (Deeny et al., 2003; Doppelmayr et al., 2008; Hatfield et al., 1987; Haufler et al., 2000; Holmes et al., 2006; Janelle et al., 2000; Konttinen et al., 2000), pistol shooting (Loze et al., 2001), and archery (Landers et al., 1994; Salazar et al., 1990). A number of these studies revealed that skilled performers exhibit less activation of the left hemisphere (as indexed by an increase in alpha power), relative to that observed in the right, during the preparatory period for self-paced motor tasks. Some authors also report on observed poorer performance when accompanied by the highest observed levels of alpha and low-beta spectral power in the left hemisphere prior to arrow release in archery (Salazar et al., 1990) or in marksmen before shots rejected when compared to shots executed (Hillman et al., 2000).

A slow reduction in heart-rate levels prior to the shot has been shown for elite pistol shooters (Tremayne and Barry, 2001), elite rifle shooters (Hatfield et al., 1987; Konttinen and Lyytinen, 1992), and elite archers (Keast and Elliot, 1990). These findings were not apparent in novice pistol shooters (Tremayne and Barry, 2001). Pre-shot electrodermal levels for the experts were also lower for the best compared to the worst shots, and the duration of the pre-shot cardiac deceleration was longer and more systematic for best than for worst shots (Tremayne and Barry, 2001). With regard to timing of the triggering action of shooting, there are contradictory findings: elite pistol and rifle shooters triggered consistently late in the cardiac cycles, whereas the novice shooters triggered randomly (Helin et al., 1987). Among the novice shooters, better shooting scores were achieved when they triggered during the late phase. However, the timing of the trigger pull in relation to the cardiac cycle is questioned to be a determinant of superior shooting performance in competitive junior elite rifle shooters (Mets et al., 2007) and novice rifle shooters (Konttinen et al., 2003). Konttinen and Lyytinen (1992) describe the typical respiration pattern in rifle shooting consisting of breath holding with slow expiration preceding the trigger pull.

In a more recent study assessing changes in heart-rate variability, Carrillo et al. (2011) found that experienced adolescent archers tend to show higher values for low-frequency activity, square root of the mean of squared differences between successive R-R intervals, and percentage of successive normal-to-normal intervals greater than 50 milliseconds than novice archers during a competition.

Since the 1990s, eye movement analysis has been applied in order to study human movement behavior during different interceptive tasks. Already defined in 1996 (Vickers), a visual phenomenon called ‘quiet eye’ period denotes the final fixation on a specific location or object in the visuomotor workspace within 3 degrees of the visual angle for a minimum of 100 ms. It has been reported that the onset of the quiet eye period occurs earlier and its duration is longer in the elite compared to the sub-elite athletes in small-bore rifle shooters (Janelle et al., 2000), biathlon rifle shooters (Vickers and Williams, 2007), as well as shotgun shooters (skeet, trap, and double trap disciplines; see Causer et al., 2010). Moreover, in all three shotgun disciplines, quiet eye duration was longer and onset earlier during successful compared to unsuccessful trials for elite and sub-elite shooters (Causer et al., 2010).

### Other effects influencing the performance

Besides movement kinematics and psychophysiological aspects, there are also other effects influencing the performance in target shooting. Hoffman et al. (1992) investigated shooting...
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performance among elite American biathletes immediately after exercise of various intensities. They found that exercise intensity had minimal effect on shooting accuracy and precision for prone shooting, but did affect these measures for shooting in the standing position. The latter is in line with the result of Grebot and Groslandert (2003) and Vickers and Williams (2007). In addition, stability of hold was affected more by exercise intensity for shooting in the standing position compared to prone shooting (Hoffman et al., 1992).

Grebot and Burtheret (2007) examined the influence of negative temperatures on the trigger mechanism and on the ballistic responses of the bullet in biathlon shooting. The results showed that from +20°C until −8°C, the triggering force was equal to 5 N, whereas at −20°C, a triggering force of 8 N was required. The authors suppose the increase of the triggering force that was found under −8°C to be caused by the difference between the coefficients of expansion of the different materials constituting the trigger mechanism. Concerning the ballistic measurements, group diameter at room temperature was significantly lower (p<0.05) than −3°C, −10°C, and −20°C. Furthermore, shooting score was significantly better at −20°C (p<0.05) compared to −3°C, −10°C, and −20°C conditions.

Yuan and Lee (1997) examined the effects of rifle weight and handling length on aiming stability in a simulated aiming exercise and the relationship between aiming stability and shooting accuracy in a live-fire test. It was shown that different rifle designs led to an alteration of rifle-holding postures and muscle activation levels in order to maintain the system in balance, thereby affecting aiming stability. Furthermore, in the live-fire study, smaller aiming fluctuations, smaller shot group dispersions, and a higher shot group accuracy could be observed for the rifle with smaller length and lesser weight.

Methods for acquisition and analysis

Methods

To overcome the problem of measuring aiming stability with experimental settings which are entirely unrelated to the real-life shooting situation, Alain and Avon (1976) first developed a measurement technique to take a still photograph of an infrared diode attached to the end of a rifle barrel. The stability score was defined as the total area covered by the diode’s image on the film during aiming. To provide exact information on the spatial orientations of the aiming axis, Hadani and Bergman (1980) improved the technique, taking successive movie photographs of part of the target as reflected by a mirror mounted on the aiming device. Since the beginning of the 1980s, companies like Noptel, SCATT, RIKA, and SAM Trainer have been developing optoelectronic training devices, allowing training, diagnostics, and research in rifle and pistol shooting disciplines. Moreover, a Noptel-ST-2000 system was adapted for archery (Edelmann-Nusser et al., 2002). All systems have in common that a laser device is attached to the rifle – either in combination with a laser-sensitive grid in order to obtain visual information on the deviation from the center of a target in real time or by using image-processing algorithms to reconstruct the movement of a laser point on a secondary target (Chandrapal et al., 2009). Even though these systems are widely used for assessing the aiming process in shooting disciplines, the specificity of shooting training results with an optoelectronic target has been questioned (Zanevskyy et al., 2009).

Nitzsche and Koch (2000) used a different approach; they fixed a small infrared light-reflecting device directly onto the barrel for measuring the movement of the muzzle. A drawback of all these methods for analyzing the aiming process lies in the necessity of attaching devices to the rifle and the expense of calibrating the system.
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Alternatively, optoelectronic motion-capturing systems can be used to track and record the rifle and the athlete’s 3D movements in real time by attaching active (Silva et al., 2009) or passive markers (Heller et al., 2006a) to both rifle and athlete (see Figure 34.1).

However, such systems are expensive and difficult to use outdoors. To overcome these problems, Baca and Kornfeind (2006) developed a video-based system which allows the reconstruction of the horizontal and vertical motion of the muzzle using image-processing algorithms (see Figure 34.2). The usefulness of the system was investigated by Heller et al. (2006b). The results suggested considerable correspondence of the on-target trajectory and the 2D movement of the muzzle, in particular in the vertical direction. However, translation movements of the shoulder during aiming, which are rather difficult to diagnose, may cause differences in the horizontal plane.

A modified version of the video-based system is able to track the sight of the bow from behind the archer (Edelmann-Nusser et al., 2008). This enables the analysis of the aiming process during competition – for example, the German Archery National Championships in 2007
(Ganter et al., 2009) and the World Outdoor Archery Championships in Leipzig, Germany in 2007 (Edelmann-Nusser et al., 2008). Figure 34.3 shows the use of the system and the bow sight which is used for image analysis.

In order to measure additional performance indicators in archery (e.g. the reaction time of an archer to clicker’s fall [see also Figure 34.3], arrow velocity, and external factors that may affect arrow velocity), Ertan et al. (2005) developed an archery chronometer. They concluded that the chronometer could be used for technical evaluation and enhancing one’s shooting technique in archery. A real-time motion analysis system that is able to analyze hand stability of users was developed by Loke et al. (2009). The system uses smart ultrasound sensors and is reasonably satisfactory and acceptable in terms of cost, hardware set-up, functionality, and durability.

A robust compact mobile EEG system has been developed by Alpha-Active Ltd specifically for sports applications. Their HeadCoach™ product provides stable EEG output, especially in the alpha-wave region, even when the athlete is moving. Figure 34.4 shows alpha brainwave trends (6.5 Hz–16 Hz/0.5 Hz–32 Hz) for the left and right side of the front of the head of an experienced archer. Recently developed mobile eye-tracker systems (e.g. ASL Mobile Eye-XG) are acquiring eye movements and point of gaze information during the activity, allowing the analysis of unconstrained eye, head, and hand movements under variable conditions.

Figure 34.3 Left and middle: Use of the video-based system during the World Outdoor Archery Championship in 2007. Right: Camera view from left behind the archer. The bow sight is used for automatic tracking of the movement of the bow.

Figure 34.4 Alpha brainwave trends (6.5 Hz–16 Hz/0.5 Hz–32 Hz) for left and right side of the front of head of an experienced archer (Alpha-Active Ltd, used with permission)
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Analysis

Almost all of these technologies provide time series of positional data and/or instantaneous velocities. Parameters in data analysis are values normally calculated from time series, including sample means and dispersion values of discrete times, displacements, rotations, and their derivatives. However, there are some other approaches published in the field of shooting performance: three of them are shortly figured out.

Goodman et al. (2009) examined regular and random components in aiming point trajectory and discriminated two phases. The first phase was regular approximation to the target accompanied by substantial fluctuations obeying the Weber–Fechner law. In the second phase, beginning at 0.6–0.8 s before the trigger pull, shooters applied a different control strategy: they waited until the following random fluctuation brought the aiming point closer to the target and then initiated triggering. This strategy is tenable when sensitivity of perception is greater than the precision of the motor action, and could be considered a case of stochastic resonance. The strategies that both novices and experts used distinguished only in the parameter values of linear regression models and distances (see Goodman et al., 2009).

Hwang et al. (2008) adopted the linear time invariant auto-regressive moving average exogeneous (ARMAX) process to model the aiming trajectory of skilled archers at a distance of 70 m. Both of the vertical and the horizontal deviations were studied instead of the radius or score only. The proposed order-three auto-regressive part was used to represent the stable exponential decay and the oscillation of the aiming trajectory. The magnitude of associated poles of the auto-regressive part whether slightly greater than one was used to determine the fairness of the proposed model. Subsequently, the moving average part was related to the muscle strength and stability of archers. The exogenous part was initially designed to model the adjustment of the deviation between the aiming point and the center of target (Hwang et al., 2008).

Baca and Kornfeind (2012) analyzed the stability of the aiming process of elite biathlon athletes using a special variant of an artificial network of type SOM (self-organizing map; DyCoN, Perl 2004a, 2004b; Figure 34.5). The horizontal and vertical motion of the muzzle was divided into ten time intervals of equal duration. Eight kinematic parameters were calculated describing the motion in these intervals and the artificial network was trained. Similar neurons were combined into clusters. For each shot, the ten data sets describing the aiming process were then mapped to the corresponding neurons. The sequence of the related clusters in the respective succession was used as a representation of the complex aiming motion. In a second processing step, types of shots were identified, applying a second net. A more stable pattern could be inferred for the members of the national squad compared to the biathletes classified in the next best performance level. Only small differences between the two tested shooting conditions (one target five times or all five targets) could be observed.

Perspectives

Virtually every aspect in athletes’ performance and preparation could be dissected analyzed and improved. However, it seems that the balance has been tilted towards technological developments that are pushed on athletes and support staff and then have been frequently changed, creating confusion and discomfort.

(Baca et al., 2009)
When performance needs to be analyzed at a more specific level, the results of research studies assessing athletes’ performance have to be brought into praxis. This applies for most sports and is particularly true for shooting disciplines.

However, the level of complexity rises if systems are to provide useful information derived from the collected data rather than passing just the sensor data. Such systems perform deeper computational and logical analysis by detecting patterns and complex relationships and by extracting summary-type information that addresses directly users’ needs (Baca et al., 2009). They directly supply a higher level of organized information, leaving only the decision making to the end users.

In performance analysis of target shooting, one first attempt was presented by Silva et al. (2009). Their prototype system for air rifle/pistol shooting provides recommendations to the coach based on some input data from the shooter and fuzzy rules.

There will be continuing progress towards intelligent systems due to the availability of algorithms for fast and/or accurate data processing (Baca et al., 2009). This will also enable automatic feedback provision.

**Concluding remarks**

This chapter has described performance indicators in different target sport disciplines with a focus on Olympic sports. After a short introduction, movement kinematics in terms of posture balance and aiming stability has been reviewed for air rifle, pistol, shotgun, and archery shooting. Besides several psychophysiological aspects of shooting, there are also other external and internal effects influencing the performance. The main methods for acquisition have been presented and some remarkable ideas of analysis have been introduced. A development towards intelligent systems is expected in future.
References


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