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ORIGINAL

The Kinematic Factors of Physical Motions During Air Pistol Shooting

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Objective: The purpose of this study was to analyze the kinematic factors of motion during air pistol shooting.

Method: This study aimed to investigate changes in forces during movement and determine the factors that affect changes in force during the first, middle, and last periods of shooting an air pistol. Two ground reaction force systems (force platform), SCATT (a shooting training system), and EMG (electromyogram) to measure the action potentials in the muscles of the upper body were used in this study. Four university air pistol players (age: 19.75 years, height: 175.50 cm, body mass: 69.55±11.50 kg, career length: 6.25±6 years) who are training to progress to a higher rank were enrolled.

Results: In terms of the actual shooting results, the mean score in the middle section was 42.48±1.74 points, higher than those in the first and the last periods when using SCATT. The gunpoint moved 13.48 mm more vertically than horizontally in the target trajectory. With respect to action potentials of muscles measured using EMG, the highest action potentials during the aiming-shooting segments, in order higher to lower, were seen in the trapezius (intermediate region), trapezius (superior region), deltoid (lateral), and triceps brachii (long head). The action potentials of biceps brachii and brachioradialis turned out to be high during grasping motion, which is a preparatory stage. During the final segment, muscle fatigue appeared in the deltoid (lateral), biceps brachii (long head), brachioradialis, and trapezius (intermediate region). In terms of the ground reaction force, during the first period of shooting, there was a major change in the overall direction (left-right F_x, forward-backward F_y, vertical F_z) of the center of the mass.

Conclusion: The development and application of a training program focusing on muscle groups with higher muscle fatigue is required for players to progress to a higher rank. Furthermore, players can improve their records in the first period if they take part in a game after warming up sufficiently before shooting in order to heighten muscle action potentials, and are expected to maintain a consistent shooting motion continuously by restoring psychological stability.

Keywords: Air pistol, Ground reaction force (GRF), Electromyogram (EMG), SCATT (shooting training systems)

INTRODUCTION

Shooting, one of the most important sporting events, is considered a global sport with as many gold medals as in track and field and swimming events. The national team of South Korea demonstrated their world-class level with 3 gold medals and 2 silver medals at the London Olympics in 2012 and has shown excellent performances in recent international competitions. These accomplishments and athletic performances in this competitive sport are attributable to a combination of robust physique, high technical ability, and stable psychological state. However, since there are only a limited number of players with world-class shooting ability, it is required to expand the base of shooting and train highly competitive players for international competitions.

For 10 m air pistol, players shoot 1 shot per paper target for a total of 60 shots at a distance of 10 m. Each series is composed of continuous motions including the preparatory posture, presence, aiming, breathing, shooting, follow through, and prediction. The major factors for effective air pistol shooting include the preparatory posture and present speed of the shooter, trajectory and sway width of the gunpoint, ability to consistently maintain shooting motions, and breathing rhythm and timing (Uh & Lee, 2000). During shooting, a shooter should perform both dynamic and static movements simultaneously, in which, no body parts should be moved except the triggering index finger (Seo, 2007). Since the ultimate goal of shooting is to hit the target, there should be no sway during aiming and shooting; however, it is impossible to continuously maintain immobility of the gunpoint and the main causes of gunpoint sway are instable posture and breathing (Uh, 1999). In order to shoot accurately, gunpoint sway needs to be

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minimized during shooting, for which the shooter's posture should be able to confer stability to the body and the pistol. A previous study has suggested that since there are various factors affecting air pistol shooting, fundamentally shooters should have an excellent ability of stopping pistol movement, while being well-equipped with basic shooting techniques (Lee, 1998). Shooting is a technology intensive sport that requires more scientific training methods compared with any other sports, for which the improvement of athletic performance requires physical, mental, and technical training, muscles for the maintenance of shooting posture, and technical proficiency connecting motor nerve activity and shooting (Kim, 2000; Kim & Kim, 2008).

In pistol shooting, a shooter begins their motion while holding their breath and resumes breathing after shooting. As time goes on, the desire to breathe gradually increases, while the pistol needs to be supported consistently by only the right hand, leading to increased muscle fatigue. Initially, both concentration and stability of the body gradually increase. they then start to decrease after a point. Muscle fatigue is affected by the accumulation of lactic acids produced by the hydrolysis of glycogen. It has been known that lactic acid that has accumulated within a muscle during movement cause muscle pain (Lee, 2006). One of the most popular methods to test muscle fatigue is electromyography (EMG) using surface electrodes (Ament, Bonga, & Hof, 1993). Since shooting athletes need to bear consistent shooting motions in a standing posture for a long time and psychological tension can also lead to fatigue, these factors should be overcome to enable better shooting performances. Investigation of the degree of agonistic muscle utilization and fatigue during movement should be able to provide reference data for the maximization of motor ability and design of various training methods.

The stability of the shooting player is dependent on their posture supporting their body weight. Therefore, it is highly meaningful to study movements of the center of balance in shooters depending on shooting posture within the allowed range in the game rules in order to improve athletic performance. Although the determining factors for athletic performance differ depending on the individual characteristics of each athlete, since technical skills should be exerted based on the support of physical fitness, air pistol shooting requires physical fitness to maintain a consistent static posture without change until the end of game and the ability to maintain balance of the body. In addition, the center of balance is also an important factor involved in long shooting performance and accurate shooting posture (Kim, 2007; Soog, 2010; Lee, 2012; Mononen, Konttinen, Viitasalo, & Era, 2007; Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Viitasalo, Era, Konttinen, Mononen, Mononen, & Norvapalo, 2001).

National athletes or world-class athletes tend to concentrate on psychological factor, a major factor in improving athletic performance. However, even psychological stability also needs to be based on robust physique and perfect technique accompanied by training, enabling maintenance of consistent shooting. Since shooting motions are composed of static and consistent motions for an extended length of time, it is difficult to determine factors affecting game results. To improve these factors, leaders should plan training programs and put efforts on the improvement of records through scientific data analysis. Mental strength, an internal factor mainly composed of concentration and confidence, is highly significant in shooting. High concentration in a shooting game enables a comfortable, stable shooting posture to be maintained continuously. Therefore, mental strength is one of the most important factors in improving athletic performance. However, since shooting is greatly affected by various variables such as psychological factors, physique, and physical fitness, it is hard to find a training method that fits to a specific individual. Hence, it is required to study continuously on the use and development of major muscles and limit muscle fatigue. During air pistol shooting, motions need to be maintained continuously and consistently for a long time. Thus, the present research aimed to provide fundamental data enabling shooting players who endeavor to progress to higher ranks to identify differentiated and diverse training program methods to improve athletic performance. The present study investigated fatigue of major muscles involved un performing fine and consistent shooting motions and factors affecting changes of center of balance by subdividing shooting into segments (first, middle, and last), while recognizing individual differences in psychological characteristics, physique, and physical fitness.

METHODS

1. Study subjects

The subjects in the present study were four male athletes who were registered as air pistol shooting players at K University, who have continuously attended to training to progress to the upper ranks. Their mean game record was 558.87±8.87 points (the mean score in the past six competitions), and their physical characteristics are presented in (Table 1).

Table 1. Characteristics of subjects

Subject	Age (yrs)	Career (yrs)	Height (cm)	Body mass (kg)
A1	21	7	174	86.3
A2	20	8	168	60.1
A3	19	6	176	65.4
A4	19	4	184	66.4
M ± SD	19.75±0.96	6.25±1.71	175.50±6.61	69.55±11.50

2. Experimental equipment and procedure

Experimental equipment and analytical devices used in the present study are presented in (Table 2).

Shooting training systems (SCATT) can sense movement of the gunpoint from aiming to shooting, analyze the relationship between stopping ability and score, and identify the movement trajectory of the gunpoint at the moment of shooting. During the preparatory procedure, a grasp (preparatory) motion was arbitrarily defined as being from when

Table 2. Experimental equipment

Equipment	Product	Manufacturer
SCATT	SCATT system	Elis
Force Plate	9260A6	Kistler
Wireless EMG system	Trigno 16ch	Delsys Ine
Computer	DB-R190	Samsung

gunpoint of the athlete was detected by the photo sensor at the top of target paper to the time of aiming, and aiming-shooting, that is from the aiming section to the shooting section, was defined as the time from aiming to the time point when bullet hits target after coming out of the gun barrel. On the computer target monitor, green represented the time when aiming began, yellow was for 1 sec before shooting, blue was 0.2 sec before shooting, and red was the trajectory of the gunpoint after shooting. These data were subjected to analysis.

The ground reaction force (GRF) measurement device was connected to an amplifier after horizontal calibration of the force plate, and analogue data generated by amplifier were measured for the GRF in the directions of F_x (left-right GRF), F_y (forward-backward GRF), and F_z (vertical GRF) from grasp (preparatory) to aiming-shooting section using 6 wheatstone bridges (Yoon, Kim & Lee, 1998). Known loads were placed at different spots on the force plate for calibration, followed by sensitivity calibration in the F_x, F_y, and F_z directions. Since the body weights of the subjects were different, results were analyzed by the division of individual body weight with body weights of the subjects (%BW) for normalization.

Electrodes were used to obtain EMG signals. Due to telemetry measurements and in order to minimize noise on the signal, skin to be attached with electrodes was shaved and dirt was removed with alcohol-soaked cotton, which was followed by attachment of electrodes. In order to measure the action potentials of muscles, the transmission system of EMG telemetry was checked, followed by calibration. Major muscles measured in the present study were those determined to play important roles in the shoulder and elbow joints during shooting motions, which include trapezius-superior region, trapezius-intermediate region, deltoid-lateral, biceps brachii-long head, triceps brachii-long head, and brachioradialis. Detailed sites for electrode attachment were referred to the anatomical muscle attachment sites of SENIAM (SENIAM, 2013). The Maximum Voluntary Isometric Contraction data of major muscles used in shooting motion from each individual were measured for 5 sec three times and normalized for comparative analysis with data from the present study. EMG normalization is an essential procedure for inter-comparison with the experimental condition and subjects, and its equation was as below:

$$NorEMG_m\ (\%MVIC) = \frac{EMG_m}{EMG_m^{\max}} \times 100$$

NorEMGm refers to the standardized EMG value and its unit is %MVIC. EMGm refers to the EMG value of each muscle measured at actual shooting, after filtering, and EMG_m^{max} refers to the maximum EMG value of each muscle found in the MVIC measurement.

3. Experimental scene and analysis section

The participating athletes used their own air pistols for preparation, and wireless EMG meter was attached to six muscles after they took their clothing off their upper body. After an exercise on two GRF force plates to minimize resistance, the main experimental shooting was performed. Since all participants usually used the shooting training systems (SCATT) in the shooting range during routine exercise, it was determined to have no effect on experiments. Sixty shots were fired in the same manner as in actual games, and they freely performed shooting until completion alone in order to limit interference due to any psychological burden or the environment. Air pistol shooting was divided into segments of preparatory, aiming, and shooting as in (Figure 1) below. The 60 shots were divided into first (shots 1~5), middle (shots 30~34), and final (shots 56~60) periods and the changes in the action potentials of the major muscles and center of balance during the shooting period were compared.

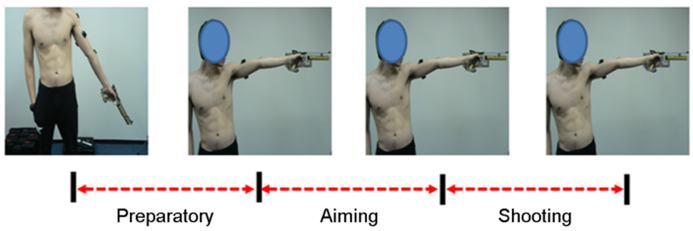

Figure 1. Section of analysis

4. Data analysis

For data analysis, mean values and standard deviations were calculated using elapsed times and scores at the time points of aiming-shooting during each shooting period as measured by SCATT, as well as the vertical and horizontal target trajectories of the gunpoint on the target paper. In order to elucidate influencing factors for EMG and GRF variables during each shooting period (the first, middle and final) during shooting motions, mean values and standard deviations were calculated for comparative analysis.

RESULTS

1. Measurement results from the shooting training system (SCATT) by segment

Results from SCATT by segment are presented in (Table 3).

Elapsed time in the aiming-shooting section was 3.98±0.46 sec in the first period and 3.50±0.82 sec in the last period. The shooting score was 46.48±1.44 points in the middle period. For the target trajectory

Table 3. Results from SCATT

Segment	Shots 1~5 (First)	Shots 30~34 (Middle)	Shots 56~60 (Last)
Aiming-shooting (Elapsed time: sec)	3.98±0.46	3.80±1.00	3.50±0.82
Actual shooting (unit: points)	45.24±1.99	46.48±1.44	46.10±1.04
Target trajectory (unit: mm)	Horizontal distance	Vertical distance	
	157.30±23.84	170.78±44.68	

of the air pistol gunpoint on the target paper, horizontal and vertical distances were 157.30±23.84 mm and 170.78±44.68 mm, respectively. (Figure 2) presents examples of changes in the target trajectory of the gunpoint on the target paper measured using SCATT. The trajectory of a high score, a low score, and the horizontal and vertical displacements are demonstrated.

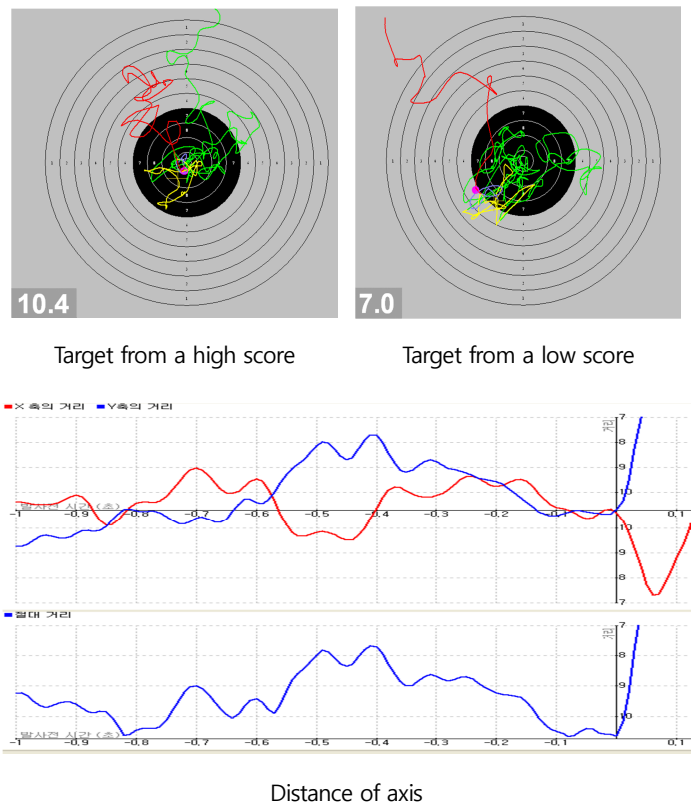

Figure 2. Data from SCATT

2. Action potentials (EMG) by segment

EMG results by period, including the first (shots 1~5), middle (shots 30~34), and last (shots 56~60) periods during air pistol shooting motions were summarized in (Table 4) and (Figure 3).

As shown in (Table 4), changes in action potential of deltoid (lateral) were 37.23±7.20% for the first (1~5 in shot number) shooting period and 36.20±6.78% for the final shooting period, and those of biceps brachii (long head) were 11.38±2.61% for the first (1~5 in shot number) shooting period and 10.06±3.67% for the last (56~60 in shot number) shooting period. In addition, changes in the action potential of brachioradialis were 8.02±1.61% for the first shooting period and 7.80±0.90% for the last shooting period and those of trapezius (intermediate region) were 45.69±8.22% for the first shooting period and 43.32±7.12% for the last (56~60 in shot number) shooting period.

Table 4. Results of action potential (EMG)

(unit: %MVIC)

Muscle	Period	Preparatory	Aiming	Shooting
Trapezius (superior region)	First (shots 1~5)	21.30±1.46	40.24±4.25	42.08±6.02
	Middle (shots 30~34)	19.73±0.68	41.07±3.62	42.91±5.22
	Last (shots 56~60)	18.49±1.10	39.62±4.88	41.93±5.95
Deltoid (lateral)	First (shots 1~5)	19.96±3.07	37.94±5.02	37.23±7.20
	Middle (shots 30~34)	20.79±3.54	38.02±7.75	37.93±7.91
	Last (shots 56~60)	20.07±4.00	36.34±7.38	36.20±6.78
Biceps brachii (long head)	First (shots 1~5)	12.41±4.24	11.31±2.65	11.38±2.61
	Middle (shots 30~34)	13.10±5.80	11.26±3.13	11.17±4.56
	Last (shots 56~60)	13.86±6.19	10.10±2.69	10.06±3.67
Triceps brachii (long head)	First (shots 1~5)	17.86±4.54	18.74±1.63	18.40±1.59
	Middle (shots 30~34)	18.02±4.58	19.05±1.22	18.62±1.93
	Last (shots 56~60)	17.86±4.92	18.80±0.22	18.49±1.01
Brachioradialis	First (shots 1~5)	8.36±1.73	8.27±0.92	8.02±1.61
	Middle (shots 30~34)	8.55±2.57	8.39±0.65	8.05±1.47
	Last (shots 56~60)	8.37±1.58	8.05±1.42	7.80±0.90
Trapezius (intermediate region)	First (shots 1~5)	18.37±2.96	43.97±6.94	45.69±8.22
	Middle (shots 30~34)	17.36±2.87	44.56±6.19	44.73±7.45
	Last (shots 56~60)	17.22±2.45	42.15±5.05	43.32±7.12

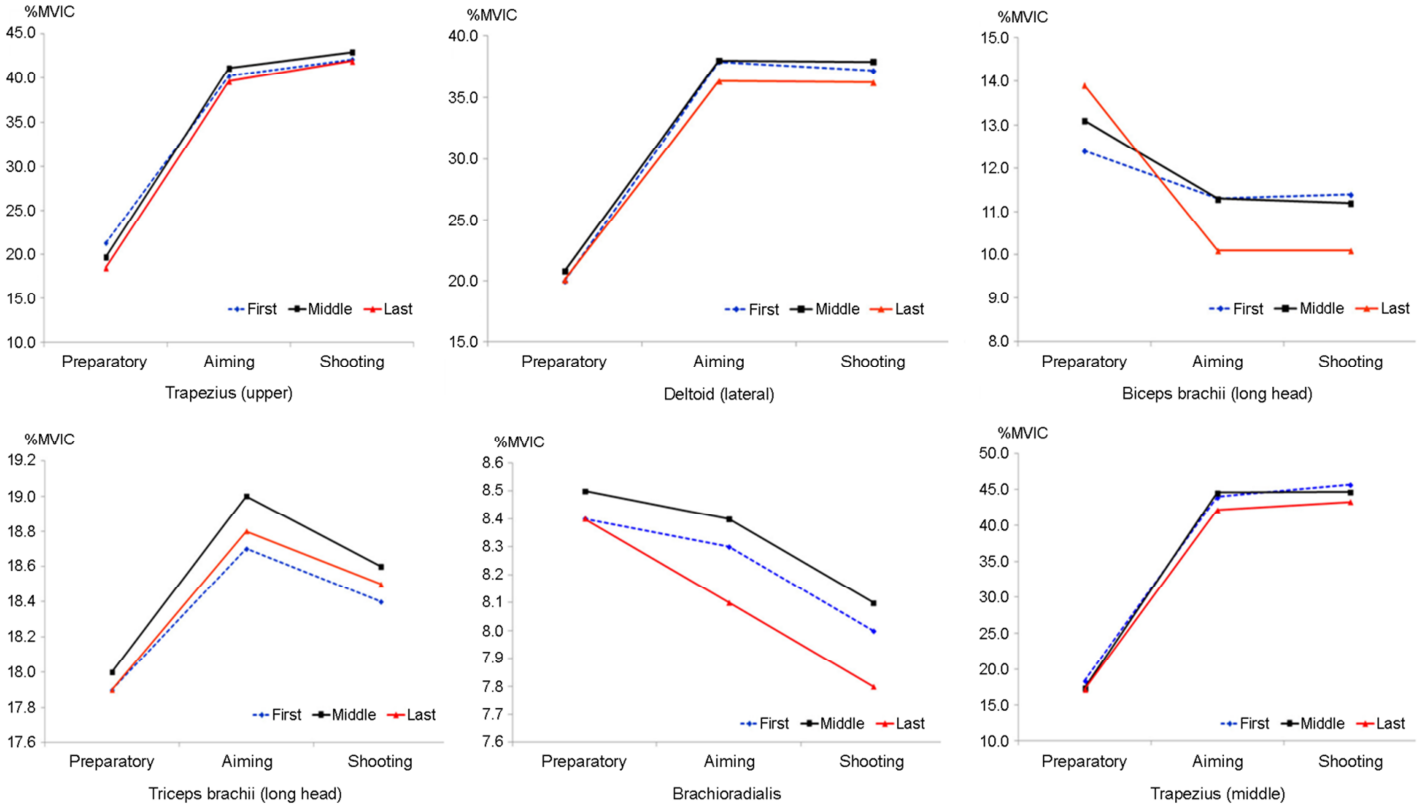

Figure 3. Results of action potentials

3. Results of ground reaction force (GRF) by segment

The GRF results from the first (shots 1~5), middle (shots 30~34), and last (shots 56~60) periods are summarized in (Table 5) and (Figure 4).

As shown in (Table 5), GRF changes in F_x (left - right) were 1.45±0.31%BW for the preparatory section in the first (1~5 in shot numbers) period, 1.26±0.27%BW for the preparatory section in the last (56~60 in shot numbers) period and GRF changes in F_y (forward - backward) direction were 2.66±0.44%BW for the preparatory section in the first (1~5 in shot numbers) period and 1.35±0.05%BW for the shooting section in the last (56~60 in shot numbers) period. In addition, GRF changes in the F_z (vertical) direction were 9.84±0.02%BW for the preparatory section and 9.85±0.02%BW for the shooting section in the first period as well as 9.83±0.01%BW for the preparatory section and the 9.83±0.01%BW for the shooting section in the last period.

Table 5. Results of ground reaction force (GRF)

(unit: % body weight)

Section	Period	Preparatory	Aiming	Shooting
Left-Right GRF F_x	First (shots 1~5)	1.45±0.31	0.67±0.09	0.47±0.07
	Middle (shots 30~34)	1.21±0.16	0.67±0.10	0.50±0.10
	Last (shots 56~60)	1.26±0.27	0.71±0.07	0.48±0.07
Forward-Backward GRF F_y	First (shots 1~5)	2.66±0.44	1.56±0.12	1.45±0.12
	Middle (shots 30~34)	2.16±0.31	1.48±0.04	1.34±0.06
	Last (shots 56~60)	2.43±0.27	1.48±0.15	1.35±0.05
Vertical GRF F_z	First (shots 1~5)	9.84±0.02	9.85±0.02	9.85±0.02
	Middle (shots 30~34)	9.84±0.01	9.84±0.01	9.83±0.01
	Last (shots 56~60)	9.83±0.01	9.83±0.00	9.83±0.01

DISCUSSION

SCATT is a device that enables the analysis of the relationship between the ability to stop the movement of the gunpoint and score and to objectively evaluate the aiming state at the moment of shooting and ability to stop the gunpoint. In terms of the trajectory of the gunpoint on the target paper, horizontal distance was 13.48 mm longer than the vertical distance, which seems to be the effect of vertical (up-down) movement in the arbitrarily defined preparatory section from being detected by the photo sensor at the top of target paper to aiming. Kim (2008) reported that the mean distance of the trajectory and mean score of the skilled male air pistol athletes were 110.8±10.3 cm and 10.3

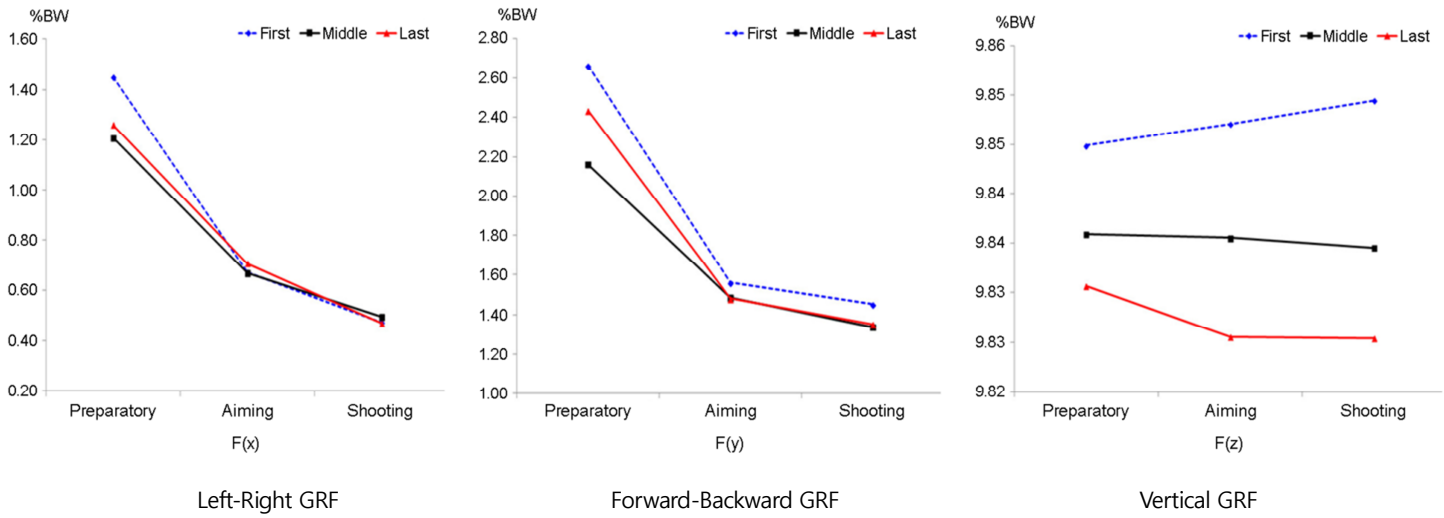

Figure 4. Results of ground reaction force (GRF)

points, respectively, whereas those of non-skilled athletes were 166.5±35.6 cm and 8.7 points, respectively. In comparison to the results of the present study, it seems that the gunpoint stopping ability of the subjects of this study was not as good as that of skilled athletes. The elapsed time for aiming-shooting decreased as the athlete progressed from the first to the middle and the last periods. In a preceding study by Kim and Kim (2009), elapsed times in trajectory for aiming-shooting were 2.8±1.3 sec for skilled athletes and 3.3±1.2 sec for non-skilled athletes. In contrast, the shortest elapsed time of the present study was 3.50±0.82 sec during the last section, so that target stopping ability of gunpoint in the subjects of this study was not as good as that of skilled athletes, which seems to them from obtaining higher scores.

In particular, lower scores in the first period seemed attributable to insufficient adaptation of the muscular metabolic activity to shooting motions, so that they showed shorter shooting time and higher shooting scores from the middle period onwards as they had adapted to shooting motions and the corresponding muscular metabolism was activated. It has been reported that higher body and muscular temperatures could enhance metabolism of skeletal muscles and improve contraction and response time of muscles, leading to reduced joint problems and increased adaptability during performance (Roh & Yuh, 1986). Considering the reduction in shooting time and improved scores in the middle period, it was determined that increased muscular temperature through sufficient warming up before shooting should be helpful for improving athletic performance, because it can increase the coordination level during the moment of shooting, from as soon as aiming to shoot.

In addition, core stability training to improve coordination can maximize cooperation between segments. Continuous segmental training enhances the integrative system of the body from the toes to the trunk (Mirka & Marras, 1993). Kim (2014) has reported that among female shooting players at middle and high school, the group with core muscular training had a higher chance to maintain 10.0 points (SP 10.0) and a shorter aiming time than the control group with muscle training on the upper extremities. If athletes are continuously trained for coordination, they should be able to develop their static balance, improve their ability to achieve higher scores in the first period, and maintain psychological stability.

When changes in the action potentials and anatomical aspects of the major muscle groups during air pistol shooting motions were investigated with division into the first, middle, and last periods, trapezius (superior and intermediate regions), deltoid, and triceps brachii had alary muscle (feather) structures in fiber arrays to exert increased power and numerous muscle fibers, enabling the maintenance of consistent shooting motions for a long time, so that they did not have a significantly high muscle fatigue. However, the deltoid and trapezius (intermediate region) demonstrated muscle fatigue during the last period. Triceps brachii supports the shoulders in shooting motions because the long head of triceps is attached to the scapula. Triceps brachii with the deltoid and trapezius are considered as a significantly important cooperative muscle group. Biceps brachii and brachioradialis have spindle-shaped structures. The attachment site and orientation of the muscles are consistent with the orientation of the bone, while they also have a small number of muscle fibers (Kim, 2003). With these characteristics, biceps brachii and brachioradialis showed muscle fatigue in the last period of shooting. The present study found muscle fatigue in the deltoid (1.7% difference between the middle and the last periods), trapezius-intermediate region (2.4% difference between the first and the last), biceps brachii (1.3% difference between the first and the last) and brachioradialis (0.6% difference between the first and the last), in the last period. This muscle fatigue is attributable to aiming-shooting motions during complete extension of the elbow joint in shooting motions. A long performance of the shooting posture with the least efficient angle of motion in the muscles attached to bone such as the deltoid (lateral), trapezius (intermediate region), biceps brachii, and brachioradialis leads to a higher muscle fatigue, which is considered another factor in the decline of gunpoint stopping ability.

For action potentials of muscles that support and are used in air pistol shooting motions, muscles with the highest action potential in

the aiming-shooting section were, in order, the trapezius (intermediate region), trapezius (superior region), deltoid (lateral), triceps brachii (long head), whereas the biceps brachii and brachioradialis had high action potentials in the preparatory motion. These results were similar to a previous study by Lee (1998), where the trapezius, deltoid, biceps brachii, triceps brachii, and brachioradialis were shown to be major exercising muscles in shooting motions.

In addition, considering analysis of the SCATT data, the vertical trajectory of the gunpoint was on average 13.48 mm higher than the horizontal distance, which seems to be due to the effect of repeated shooting motions in the preparatory section, resulting in muscle fatigue. This meant that consistent shooting and stopping motions was unable to be maintained until the last period. Lee (1998) suggested muscle relaxation training in order to prevent muscle spasms from breathing during shooting motions. Combined with the elapsed time of aiming-shooting in the present study, it appears highly important to enhance muscular activity in the first period. In addition, since SCATT used in the present study can be applied to training programs to analyze the relationship between the ability to stop movement of the gunpoint and score, as well as errors in aiming motions at the moment of shooting, it is apparent that SCATT is an excellent training method that com plements the potential psychological boredom of dry shooting training, investigates the shooting characteristics of each individual, and is helpful for recording improvements. In a study by Soog (2010), an intermediate level group showed a higher improvement in athletic performance after application of 14 weeks of a training program than the higher level group, suggesting that this can be considered as a system that can complement movements during aiming.

With respect to the GRF results, the center of balance in the F_x (left-right), F_y (forward-backward), and F_z (vertical) directions during the first period was greatly changed while performing shooting motions from the grasp to aiming. In general, the middle period showed the least changes in the center of balance. It has been stated that stability changed depending on the method used to support body weight by the posture of the shooter and that shooters could take various postures such as bending the back or standing on the hill to load one's own body weight onto the center of the foot, which enabled the line of gravity to be closer to the center of the basal plane (Park, 1988). In addition, it is required to develop a training program that, while maintaining the ratio of the center of body weight between the right and the left feet as 50:50, the center of mass can be maintained consistently by loading about 1~2% of the center of mass to the left foot in consideration of the effect of the air pistol weight. In a study by Uh and Lee (2000), the skilled group tended to move center of balance from the anterior foot at the beginning to the posterior foot at the time of the first shot, which was explained by complementing displacement during movement from the initial posture to the shooting posture, resulting in a transfer of the center of balance. Jeon (1988) reported that since it took about 1.5 h for women's air pistol shooting, tension should be generated during exchanging targets without changing stance position, so that the stance position needed to be resumed at every shot. Lee (1998) in a previous study suggested that training should focus on maintaining a consistent stance and posture at the shooting range during shooting motions.

In the grasp (preparatory) step, it is difficult to maintain the center of mass consistently while repeating the process of lifting the gunpoint (vertical) and aiming in the F_y (forward-backward) direction. In particular, the higher results in the first period could be due to insufficient adaptation to the shooting motions. In other words, they were not fully warmed up. The trunk muscle (core) that enables the exertion of all power and kinesis of the body and maintains balances should be enhanced to improve balance (Nadler, 2002). As shown by the interfering factors in the first period of shooting, it is important to warm up before shooting and prepare a training program to improve coordination, in order to move the adapted state of the middle period to the first period.

CONCLUSION

In order to analyze kinematic factors during air pistol shooting motions, this study examined four male collegiate air pistol shooters who have been training to progress to the upper ranks and investigated changes in the center of balance, and the practical effects of action potentials in major muscles in the upper body on shooting results during the first, middle, the last periods while using a shooting training systems (SCATT) and EMG system. The following conclusions were drawn:

In measurements using SCATT during actual shooting, the score (42.48±1.74 points) in the middle period was higher than those during the first and the last periods and the shortest elapsed time was found in the last period (3.50±0.82 sec). The vertical distance in the trajectory of the gunpoint on the target paper was 13.48 mm longer than the horizontal one.

Using EMG measurements of muscle fatigue by period, the deltoid (lateral), biceps brachii (long head), brachioradialis, and trapezius (intermediate region) showed muscle fatigue in the last period. The muscles with the highest action potentials in the aiming-shooting section were, in order, the trapezius (intermediate region), trapezius (superior region), deltoid (lateral), and triceps brachii (long head), whereas the biceps brachii and brachioradialis showed higher action potentials in the preparatory section.

The center of balance in F_x (left-right), F_y (forward-backward), and F_z (vertical) directions during shooting performance was stable in the middle period, whereas the grasp-aiming section in the first period showed significantly higher changes in the center of balance in the directions F_x and F_y.

Taken together, for shooting players at intermediate ranks, it is necessary to develop a training program for the muscle groups with high muscle fatigue, followed by continuous training, and applied core training to improve stability of the center of balance. In addition, sufficient warming up before shooting to increase muscular activity for higher body temperatures should be helpful in improving shooting records. The record improvement should lead to psychological stability, after which improvement of athletic performance can be expected while maintaining consistent ability to stop gunpoint movement. However, the present study was unable to be performed to this full extent

due to safety issues in the shooting range and insufficient capability for designing complex experiments, making it difficult to generalize the analyzed kinematic factors. For better ability to generalize, a follow-up study should be performed continuously with a higher number of athletes for an extended period of time.

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