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ORIGINAL ARTICLE

Effect of Anticipatory Shooting Strategy on Performance Consistency in Skilled Elite Archer

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PURPOSE: This study examined the effect of anticipatory control strategies on stable upright posture and consistency in archery performance among skilled elite archers.

METHODS: Nine skilled archery players participated in this study and performed repeated shooting trials under two different shooting conditions: clicker and non-clicker. In the clicker condition, archers shot in response to clicker signals, whereas in the non-clicker condition, they used an anticipatory strategy to determine shooting time in a self-paced manner without using the clicker. A motion capture system with six infrared cameras was used to measure the coordinates of the bow and archers' hands, which were then used to calculate the aiming precision index and draw-related variables. Electromyography of the lower leg muscles and the center of pressure (COP) were also analyzed for a short period immediately before release to determine the differences in anticipatory postural adjustments (APAs) between the two shooting conditions.

RESULTS: The non-clicker condition resulted in a relatively short drawing duration and better precision index. The COP speed rapidly increased immediately before the release (i.e., APAs), and the rate of increase was lower in the non-clicker condition than in the clicker shooting condition. Furthermore, smaller APAs were significantly correlated with better-aiming precision in the non-clicker condition.

CONCLUSION: These findings suggest that using an anticipatory strategy rather than reacting to a clicker can improve archery performance consistency by reducing APA and ensuring a stable shooting posture. This strategy can be used in archery training to predict clicker signals during the aim-release stage.

Key words: Archery, Anticipatory postural adjustment, Clicker, Shooting consistency, Posture stability

INTRODUCTION

Consistency plays a vital role in many sports, especially in archery. In order to achieve successful archery performance, an archer must have consistent shooting abilities [1]. This is demonstrated by repeatedly shooting arrows at the same aiming point, resulting in a tight group of arrows hitting the target. Conversely, a wide distribution of arrows on the target indicates inconsistent shooting behavior, making it challenging to find the correct aiming point. In our previous study, we conducted a simulation of archery shooting under two shooting conditions, self-triggered and external-triggered conditions, and calculated the precision index, reflecting shooting consistency [2]. Specifically, we confirmed that the shooting under the self-trigger condition resulted in better shooting consistency than in the external-triggered condition. The self-triggered condition allowed for the initiation of the shooting action at a self-determined time, facilitating anticipatory control strategies [3]. On the other hand, the external-triggered condition required the shooting action to be initiated reactively to an external signal, reflecting the feedback control

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loop. Since the predictability on the onset of the action ensures plenty of time to prepare and execute specific plans, self-paced performance settings are more favorable for stable target-aiming tasks [4,5]. The different cognitive processes involved in these two types of performance likely led to different shooting performances in our earlier study.

The self-paced and reactive movement were related to using a clicker in archery situations. The clicker serves the purpose of ensuring consistent drawing lengths, and its use is recognized for improving the accuracy and precision of archery performance [6]. Although it is widely believed that archers respond to clicker signals during the release action, the short duration of their reaction time to the clicker compared to the typical closed-loop latency implies that an anticipatory strategy likely aids the aim-release procedures for highly skilled archers [7,8]. Accordingly, our previous findings led us to the conclusion that the utilization of an anticipatory strategy could enhance archery performance consistency, as evidenced by a relatively better target precision observed under the self-paced shooting condition. However, as the participants in that experiment were not professional archers, and the experimental task did not involve actual archery shooting with a recurve bow, there were limitations to applying this conclusion to real archery situations. Thus, further research complementing these limitations was necessary to apply this conclusion to actual archery scenarios.

A decrease in postural sway is often correlated with better performance in sports related to target-based shooting [9,10]. In archery, maintaining a stable posture during aim-release is critical for consistent performance [11]. However, the release of the bowstring can cause sudden and forceful movement, disrupting the archer's stable posture. Archers typically use equipment like wrist straps and release aids to counteract this perturbation. Additionally, they may employ anticipatory postural adjustments (APAs) to minimize the negative effects of the release action. The APAs are a feedforward adjustment made before a known perturbation to help individuals counteract the mechanical effect that the disturbance may cause [12]. Since the APA patterns are known to vary depending on whether the movement is self-initiated or reactive [13, 14], this study aimed to explore the differences in the APA immediately preceding the release. Our earlier study confirmed relatively higher postural stability under the self-paced shooting condition, which caused better target precision [2]. Thus, we expected that the APA behavior would also be linked to performance consistency in a similar manner.

This study aimed to expand on our previous findings observed from laboratory conditions and examine the effect of an anticipatory control strategy on the stable vertical posture and consistency of archery performance in highly skilled elite archers in a real-world archery setting. We instructed participants to perform actual archery shooting using their recurve bows under two distinct shooting conditions, clicker and non-clicker conditions. The clicker condition referred to the conventional approach of responding to clicker signals during shooting arrows, while the non-clicker condition involved an anticipatory strategy in which the archers determined the shooting time by themselves without relying on the clicker signals. We formulated the following hypotheses based on the results of our previous study. 1) Self-paced archery shooting using anticipatory mechanism (i.e., the non-clicker condition) would be beneficial for aiming consistency. 2) The activity patterns of the lower leg muscles, including their co-contraction, would vary depending on whether the clicker is used or not. 3) The APA would appear larger under the clicker-reactive shooting condition, and it would correlate with archery performance consistency.

METHODS

1. Participants

Nine female elite archer (age, 25.9 ± 5.6 years), including national team player participated in this study. The inclusion criteria for the experiment were those who had more than ten years of experience in archery and had won an international competition. This study was conducted in accordance with the recommendations of the institutional review board of Korea Institute of Sport Science (KISS-22018-2206-02).

2. Experimental procedure

The experiment was conducted in the indoor archery range. Before the experiment, light-weight spherical reflective markers (5 mm in diameter) were attached to each participant's bow and drawing hand (Fig. 1). During the experiment, the marker positions were recorded at 100 Hz using a motion capture system with six infrared cameras (Oqus 700, Qualisys^{TM}, Sweden). Two force platforms (Kistler, Winterthur, Switzerland) were used to measure the changes in the center of pressure (COP) at 100 Hz. Further, we measured the electrical activities of bilateral tibialis anterior and soleus muscles using a wireless surface electromyogram (EMG) system (Ultium, Noraxon, AZ, USA) with a sampling frequency of 2,000 Hz. After attaching the EMG electrodes, baseline EMG was measured in the posture where the participants held the bow and pulled the bowstring statically for 3 s. This baseline EMG signal was used to

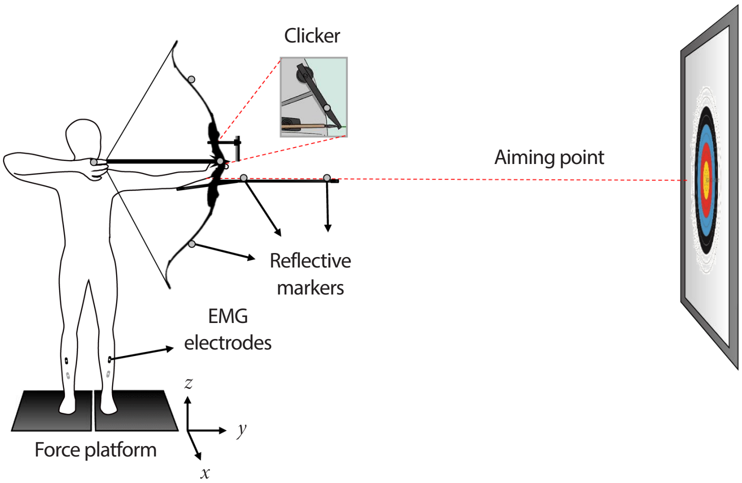

Fig. 1. An illustration of the experimental setup. Spherical reflective markers were attached to participants' drawing hand and the recurve bow, including the bow limbs, clicker, and the proximal and distal end of the stabilizer. The participants repeatedly performed archery shooting on the force platform, and electrical activities of bilateral tibialis anterior and soleus muscles were recorded. The coordinate system was set such that the anterior-posterior, medial-lateral, and vertical directions represented the *x*-, *y*-, and *z*-axis, respectively.

normalize the EMG data acquired in the main task. The foot position on the force platform was marked to ensure consistent stance across all measurements. The coordinates of the motion capture system and force platform were set such that the anterior-posterior (AP), medial-lateral (ML), and vertical (VT) directions corresponded to the x-, y-, and z-axis, respectively (Fig 1).

The main task was for the participants to perform archery shooting at a target from a distance of 8 m using their own recurve bows (Fig 1). We did not give any specific instructions regarding posture during shooting to allow individual strategies of the participants during experiment. They repeatedly shot the arrow aiming at the center of a target under the two release conditions, clicker and non-clicker conditions. The clicker condition was a typical way of archery shooting that shoots in response to the signal of the clicker drop. In the non-clicker condition, the participants were instructed to shoot arrows in a self-paced manner without using the clicker and anticipating the clicker drop. They conducted a total of 40 trials of shooting with two release conditions in random order. Consequently, we could obtain 20 trials of shooting data for each release condition. A mandatory 20 s resting was given between each shooting trial, with additional resting times provided if the participants desired. The entire experimental session, including baseline EMG measurement, lasted for about 50 minutes.

3. Data analysis

All data were analyzed offline using customized code written in MATLAB (Math Works Inc., Natick, MA, USA). The marker positions acquired from the motion capture system and the COP data recorded through the force platform were low-pass filtered with a fourth-order, zero-lag Butterworth filter with a cutoff of 10 Hz. The EMG signals were filtered using a notch filter at 60 Hz, and then band-pass filtered at 20-360 Hz [15,16]. For all the conditions and trials, we first detected the time events of starting drawing and releasing through the position data. Typically, archers raise the bow and then slowly lower it to begin drawing the bowstring. Thus, the time to start drawing was defined as when a marker of bow starts to descend from its maximum height. The release time was detected using the marker attached to the bow limb that started to move rapidly after drawing along the y-axis.

As a set of drawing related variable, we computed the drawing length and duration for all conditions and trials. The drawing length was calculated as the distance of the two markers along the y-axis attached to the proximal end of the stabilizer and the drawing hand at just before release. The drawing duration was the time period from drawing start to release. To determine the precision index (PRI) representing aiming consistency, we first calculated the coordinates of the aiming point for the target at the moment of release. The coordinates of the aiming point in the x- and *z*-axis were calculated as the tangent of an angle between the stabilizer of the bow and the two axes multiplying the distance to the target. The PRI, the average euclidean distance between the aiming point on the target and the mean aiming point across trials, was then computed using Equation 1 [17,18].

$$PRI = \frac{\sum_{i=1}^{n}\sqrt{(x_i - x_{MEAN})^2 + (z_i - z_{MEAN})^2}}{n}, \qquad (1)$$

Where *n* stands for number of trials, *x* and *z* represent the aiming point for the *x*- and *z*-axis, respectively. Subscripts *MEAN* refer to the mean aiming point in the corresponding axis.

The EMG and COP data were analyzed from -200 ms to release time to compare the strategies of postural adjustment with and without the clicker. This analysis period included the APA phase and typical reaction time to the clicker in elite archers. The filtered EMG signals were applied to the root mean square ($\mathrm{RMS}_{\mathrm{EMG}}$) with a 100-ms moving window for detecting EMG envelopes. Then, the $\mathrm{RMS}_{\mathrm{EMG}}$ of individual muscles was normalized to each participant's average RMS value of the baseline EMG. Muscle co-contraction index (CCI), which indicates the simultaneous activation of paired muscles on the opposite side of a joint, was computed using the following Equation 2 [19-21].

$$\mathrm{CCI}\ (t) = \frac{Input_L\ (t)}{Input_H\ (t)}\ (Input_L\ (t) + Input_H(t)), \tag{2}$$

Where *Input* represent RMS of the antagonist muscle pair, $Input_L$ stand for the lower magnitude RMS values at time *t*, and $Input_H$ represent the higher magnitude RMS values. The CCI reflecting the pair of bilateral tibialis anterior and soleus muscles was calculated by summing the RMS values of both sides.

We computed the speed of the COP ($\mathrm{SPEED}_{\mathrm{COP}}$) for the AP and ML direction. The time-series $\mathrm{RMS}_{\mathrm{EMG}}$, CCI, and $\mathrm{SPEED}_{\mathrm{COP}}$ were then averaged over 200 ms of the analysis phase. Notably, we found that the $\mathrm{SPEED}_{\mathrm{COP}}$ were rapidly increased from about 50 ms before the release (Fig. 4C). Thus, we additionally computed the slope of the increasing $\mathrm{SPEED}_{\mathrm{COP}}$ during 50 ms for each trial as a dependent variable reflecting the magnitude of the APA ($\mathrm{SLOPE}_{\mathrm{COP}}$). All dependent variable, including drawing duration, drawing length, $\mathrm{RMS}_{\mathrm{EMG}}$, CCI, $\mathrm{SPEED}_{\mathrm{COP}}$, and $\mathrm{SLOPE}_{\mathrm{COP}}$ were further averaged over across trials for each release condition separately for statistical comparisons.

4. Statistical analysis

All data are presented as means with standard errors. To verify the differences depending on the two release conditions, the paired t-tests were conducted separately on the drawing duration and length, PRI, $\mathrm{RMS}_{\mathrm{EMG}}$, and CCI. Repeated-measures ANOVAs with factors of *Release type* (two levels: clicker and non-clicker) and *Direction* (two levels: AP and ML) were employed to explore their effects on the COP related variables, the $\mathrm{SPEED}_{\mathrm{COP}}$ and $\mathrm{SLOPE}_{\mathrm{COP}}$. Further, Pearson correlation coefficients (*r*) were calculated using the $\mathrm{SLOPE}_{\mathrm{COP}}$ and the PRI data, separately for each release condition. Mauchly's sphericity test was used to confirm the assumptions of sphericity, and their violations were corrected using Greenhous-Geisser estimation. Pairwise comparisons with Bonferroni correction were applied for post-hoc test. The effect size, Co-

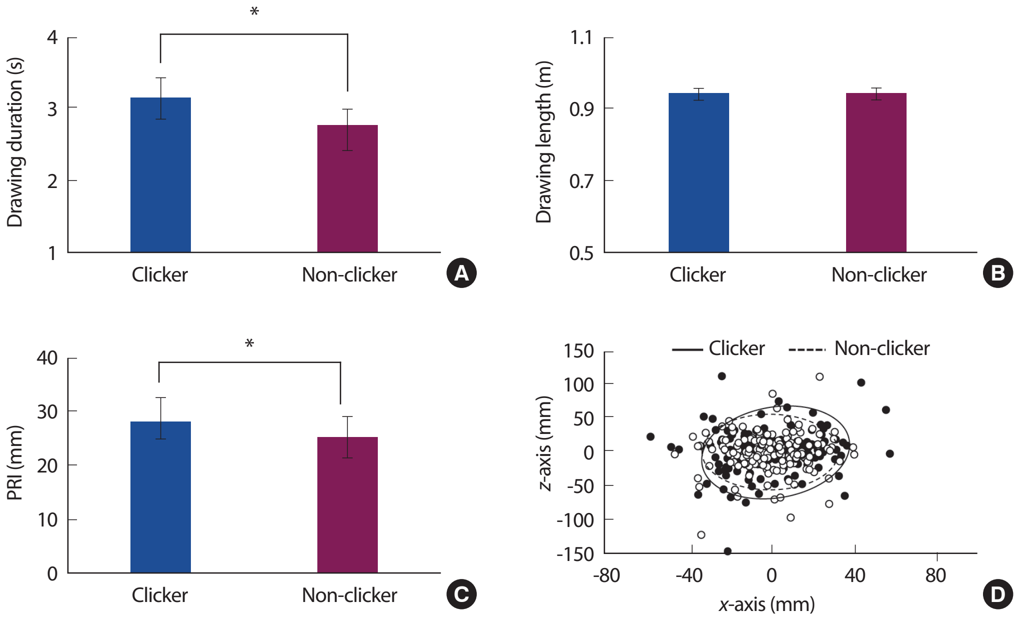

Fig. 2. Average values across subjects of (A) drawing duration, (B) drawing length, and (C) precision index (PRI) were presented. The solid and open bars represent the clicker and non-clicker condition, respectively. The asterisks indicate significant differences between shooting conditions. All data are presented as means±standard errors. The scatter plot (D) shows the aiming points for all trials and subjects, and the 95% confidence ellipse areas for the two shooting conditions are presented. The black dot and solid ellipse correspond to the clicker conditions, and the open dot and dashed ellipse represent the non-clicker condition. The *x*- and *y*-axis correspond to the medial-lateral and vertical direction, respectively, and are expressed in units of mm.

hen's *d* for the *t*-tests and the partial eta-squared (ηp^2) for ANOVAs, was calculated for all the presented results. All statistical analyses were conducted using SPSS version 25.0 (IBM, Armonk, NY, USA), and statistical significance was set at $p<.05$.

RESULTS

1. Indices related to drawing and aiming performance

The drawing duration was significantly shorter in the non-clicker condition than in the clicker condition ($t_{[8]}=3.22$, $p=.012$, Cohen's $d=1.07$) (Fig. 2A), while the drawing length was not different depending on the release conditions (Fig. 2B). The PRI was significantly smaller in the non-clicker condition than in the clicker condition ($t_{[8]}=2.51$, $p=.036$, Cohen's $d=0.84$) (Fig. 2C), implying the aiming consistency was relatively better in the non-clicker condition.

2. Patterns of muscular activity

The RMS_{EMG} for the bilateral tibialis anterior and soleus muscles were not significantly different according to two release conditions (Fig. 3A). The Fig. 3B shows changes in the magnitude of CCI before the release. The difference in the magnitudes of CCI did not reach statistical significance.

3. Indices related to postural adjustment

The magnitude of $\text{SPEED}_{\text{COP}}$ was higher in the ML direction compared to the AP direction, but there were no differences according to the release condition (Fig. 4A). A repeated-measures ANOVA with factors of *Release type* and *Direction* supported these results, which showed significant main effect of the *Direction* ($F_{[1,8]}=10.17$, $p=.013$, $\eta p^2=0.56$) without factor interaction. The $\text{SLOPE}_{\text{COP}}$ in the ML direction was steeper than in the AP direction. For the AP direction, the $\text{SLOPE}_{\text{COP}}$ was significantly higher in the clicker condition than in the non-clicker condition (Fig. 4B). There were significant main effect of the *Direction* ($F_{[1,8]}=9.31$, $p=.016$, $\eta p^2=0.54$) with significant factor interaction ($F_{[1,8]}=6.69$, $p=.032$, $\eta p^2=0.46$). The post-hoc comparisons for *Release type* × *Direction* interaction revealed that the significant difference in the $\text{SLOPE}_{\text{COP}}$ depending on release condition was present only in the AP ($t_{[8]}=3.17$, $p=.013$, Cohen's $d=1.06$), not in the ML direction. The changes of $\text{SPEED}_{\text{COP}}$ for 250 ms before the release according to the two clicker conditions are presented in Fig. 4C. In the ML direction, the increasing slope of $\text{SPEED}_{\text{COP}}$ immediately before release is similar between conditions, but it is steeper under the clicker condition for the AP direction.

Fig. 5 illustrates the results of correlation analysis. The PRI reflecting the aiming consistency was positively correlated with the $\text{SLOPE}_{\text{COP}}$ only in the non-clicker condition for AP direction ($r=0.75$, $p=.019$).

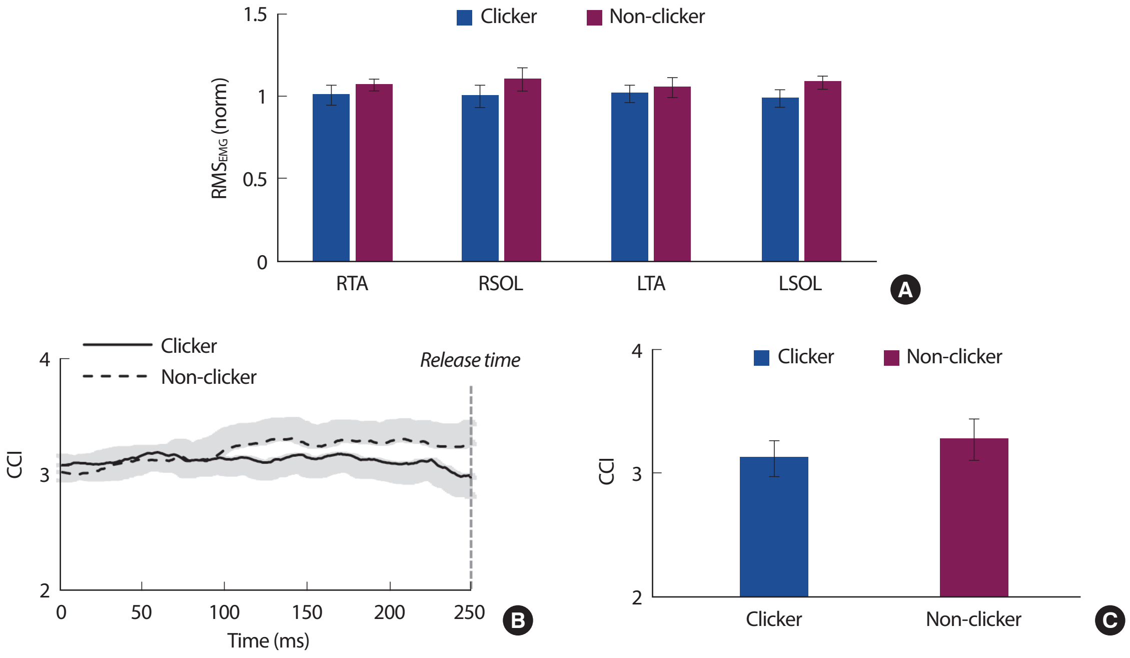

Fig. 3. (A) Root mean squared EMG (RMS_{EMG}) for the lower leg muscles and (B) co-contraction index (CCI) were presented as means and standard errors. The left graph for CCI describes the average profiles before the release under the two shooting conditions. The solid bars and line correspond to the clicker condition, and the open bars and dashed line indicate the non-clicker condition.
RTA, right tibialis anterior; RSOL, right soleus; LTA, left tibialis anterior; LSOL, left soleus.

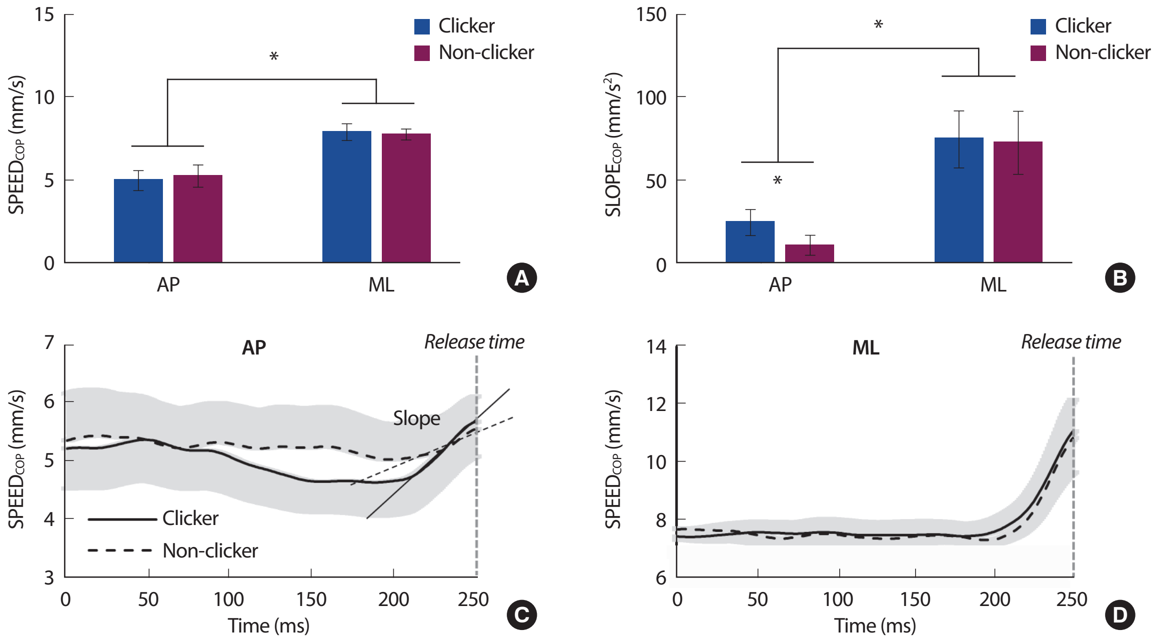

Fig. 4. (A) COP speed (SPEED$_{COP}$) and (B) increasing rate of the COP speed (SLOPE$_{COP}$) for anterior-posterior (AP) and medial-lateral (ML) directions were presented as means and standard errors. The solid and open bars represent the clicker and non-clicker condition, respectively. The asterisks indicate significant differences between shooting conditions. (C) Left and right graphs represent the changes in the COP speed during 250 ms before release for AP and ML direction, respectively. The solid and dashed lines correspond to the clicker and non-clicker condition, respectively. Notably, the COP speed for both directions are increased immediately before release, and the increasing rate (slope) was used to determine the SLOPE$_{COP}$.

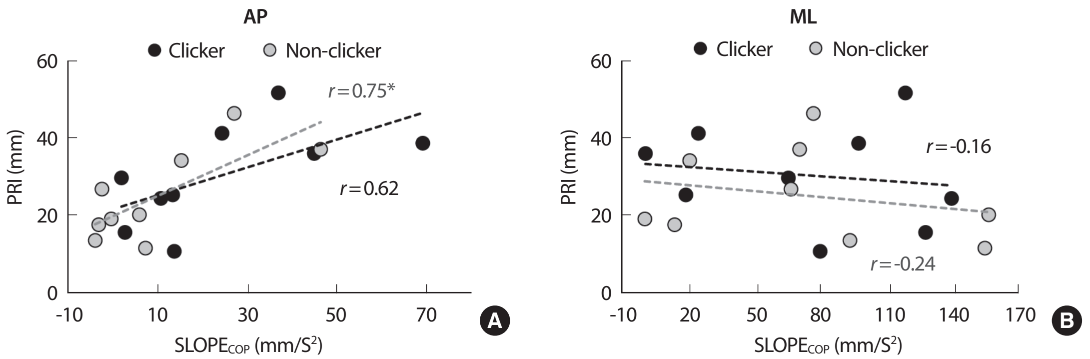

Fig. 5. Relationship of the precision index (PRI) to the increasing rate of COP speed (SLOPE$_{COP}$) for anterior-posterior (AP) and medial-lateral (ML) directions. The black and gray dots indicate the clicker and non-clicker condition, respectively. The best-fit linear regression lines with coefficients of correlation (*r*) are presented separately for each shooting condition. The black regression line and *r*-value correspond to the clicker condition, and the gray line and *r*-value correspond to the non-clicker condition. The asterisk indicates a significant correlation coefficient between two variables.

DISCUSSION

We found a relatively better aiming consistency (i.e., smaller precision index) under the self-paced shooting without the clicker (i.e., non-clicker condition), which corresponded to our first hypothesis. The co-contraction index as well as their excitation levels before release were not statistically different according to the two release conditions. So we failed to reject the second null hypothesis. The average magnitude of COP speed did not differ depending on the release condition, but its increasing rate (i.e., SLOPE$_{COP}$) at immediately before release was steeper under the clicker condition than in the non-clicker condition. Further, it was significantly correlated with the precision index in the non-clicker condition for AP direction, confirming our third hypothesis.

This experiment was executed to extend our previous findings [2] conducted under laboratory conditions to actual archery tasks with elite archery players. The two experiments had distinct differences in the characteristics of the experimental tasks. In the previous study, a customized bow frame attached with sensors for measuring finger forces was used instead of an actual bow, and there was a phase that produced a constant drawing force and maintained it with static vertical posture. Accordingly, we were able to decompose the COP trajectories into rambling and trembling components and utilize recorded drawing force to calculate the precision index. In this study, however, actual shooting was conducted using a recurve bow, and no instructions regarding aim-release strategies were requested. Therefore, we focused on the changes in COP during a short period right before release (i.e., the APA) and determined the aiming precision index with coordinates of the bow at release time. Despite these differences, a similar result — improving consistency of the archery performance in the non-clicker condition (Fig. 2C) — was observed in the current study, providing evidence that it can be effectively applied in actual archery situations.

The non-clicker condition required participants to release the bowstring at the self-chosen time by predicting the time to clicker drop rather than reacting to the clicker. This type of intervention is known to allow anticipatory strategies with feedforward control mechanisms [22-26]. Notably, despite the absence of a clicker that ensures a constant drawing length, there was no difference in the drawing length depending on whether or not a clicker was used (Fig. 2B). It is probably because our participants were highly skilled archery players, so they could almost match the drawing length without the clicker. Further, there were results implying the two conditions required the participants to do distinctly different shooting strategies. The drawing duration was significantly longer in the clicker condition than in the non-clicker condition (Fig. 2A), implying there was obviously some time delay waiting for the clicker signal during the final stage of the aiming. In addition, the rate of increase in the COP speed in the AP direction that appeared about 50 ms before release was significantly smaller in the non-clicker condition (Fig. 4B).

These changes of COP before the release itself begins can be interpreted as APA since the rapid action of releasing the bowstring inevitably perturbs the postural stability [27]. The general role of the APA is to minimize negative effects on upright posture by upcoming perturbations [28]. However, these adjustments are prepared by the central nervous system before the actual perturbations occur, so the mechanical consequences of the APA are frequently suboptimal, leading to adverse effects on the stable vertical posture [29]. Especially for tasks that require precise postural adjustment, such as archery, reducing the magnitude of the APA could be a better strategy for archery performance. This suggestion was indirectly supported by our finding that the relatively low increasing rate of COP speed correlated with improved aiming consistency (Fig. 5). Further, the fact that this APA differed depending on the direction (i.e., AP and ML direction) provides important implications regarding postural strategies in archery situations. The perturbation generated by the releasing action mainly acts on the shooting direction, the ML direction for the archers. It is therefore not noteworthy that the APA was observed to be larger in the ML direction than in the AP direction (Fig. 4B). Notably, there was a difference in the magnitude of the APA according to the release conditions only in the AP direction, and a significant correlation coefficient with the precision index appeared only in the non-clicker condition in this direction. These results were very similar to our previous study [2]. In that study, the difference in postural sway and its relationship with the precision index were only valid in the AP direction. Taken together, utilizing an anticipatory shooting strategy could help improve archery performance consistency by reducing the adverse effects of the APA and ensuring a stable shooting posture for AP direction.

All elite archers generally use the clicker during training and competition. A clicker that provides information on the drawing length is an indispensable item for players because various factors, such as aiming, breathing, stable posture, and wind, must be considered to accurately hit the target in an actual archery situation [6]. In other words, the clickers can be meant to reduce some of the many considerations players have to control. The current results showing improved aiming consistency without clickers do not argue that no clicker is better in archery. A previous study reported that although the timing of the clicker drop cannot be fully controlled by the archer, the skilled archer can partially predict the clicker signals through the vibration on the tip of the arrow [30]. That is, even in the clicker condition intervened to ensure the feedback control mechanism, our participants could anticipate the clicker drop to some extent rather than totally reacting to the clicker. However, unlike the non-clicker condition, since the release time cannot be completely determined by itself, the uncertainty of the clicker timing would have resulted in delayed release time and increased APA behaviors [14]. Thus, we suggest supplementary training to reduce the uncertainty of the clicker timing by anticipating the clicker signals rather than not using the clicker recklessly. Decreased reaction time to clickers in elite archers was associated with improved archery performance [7,31]. Thus, adaptation to this type of training would be useful in effectively reducing the clicker reaction time, maintaining a stable vertical posture, and improving performance consistency.

Lastly, we need to acknowledge the limitation of our study. The participants in the current study shot at a shorter distance (8 m) than what's typically used in archery competitions, and it is an obvious drawback in generalizing the current results to real archery situations. Since environmental influences such as wind can affect the trajectory of the arrow, the aiming precision based on the orientation of the bow immediately before release was employed as the precision index, not the precision of the arrow on the target. In this process, the motion capture system used to measure the orientation of the bow inevitably led to indoor short-distance shooting experiments. Thus, reproduction with a longer shooting distance is required to robust the current conclusion.

CONCLUSION

This study aimed to examine how the anticipatory control strategy affects the stable upright posture and consistency of archery performance in skilled elite archers. Our findings indicate that participants demonstrated better aiming consistency when shooting without a clicker, allowing them to utilize the anticipatory mechanism. Additionally, we observed that reduced anticipatory postural adjustments just before releasing the bowstring were associated with increased aiming consistency. These results suggest that utilizing an anticipatory strategy rather than reacting to the clicker drop can lead to improved consistency in archery performance. As a result, this strategy could be utilized in the field of archery training as a means of predicting clicker signals during the aim-release stage.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization: K Kim, Y Kim, J Park, J Song; Data curation: K Kim, D Baek, J Song; Formal analysis: K Kim, D Baek J Park, J Song; Funding acquisition: Y Kim, K Kim; Project administration: Y Kim, K Kim, J Song; Visualization: K Kim, D Baek, J Song; Writing – original draft: J Song; Writing – review & editing: K Kim, D Baek, Y Kim, J Park, J Song.

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