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ORIGINAL ARTICLE

Changes in cross-punch speed and torso motion associated with round progression in amateur boxers

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ABSTRACT

The aim of this study was to examine changes in cross-punch speed and trunk motion associated with the progression of rounds in amateur boxing athletes. We included 11 male amateur boxers (height: 167.3 ± 3.8 cm, weight: 65.3 ± 10.1 kg). Cross-punch performance was assessed before and after a 3-minute maximal-effort punching test, based on a previous study by Dunn et al. (2019). Performance was evaluated using an optical three-dimensional motion-capture system, with measurements conducted four times: once under a baseline condition (Pre) and three times under post-test conditions (Post1–Post3). No significant changes in punch speed were observed from Pre to Post1–Post3. The negative values of lower and upper torso axial-rotation angular velocities (rotation opposite to the punching direction) were significantly higher in Post1–Post3 than in Pre. The negative values of torso separation angular velocity and angle (upper torso twisting relative to the lower torso) were significantly higher than Pre in Post1–Post3 for angular velocity and in Post3 for angle. These findings suggest that rapid countermovement of the lower and upper torso and torso separation play an important role in maintaining high punch speed even with increased progression of rounds.
Keywords: Performance analysis, Combat sports, Kinematics, Countermovement motion, Torso separation.

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INTRODUCTION

In amateur boxing, boxers typically compete in three rounds of three minutes each. Victory is determined either by points based on a scoring system that evaluates the number of high-quality strikes to target areas, or by knocking out the opponent. Amateur boxing as an activity is characterized by intermittent high-intensity exercise, and athletes are required to maintain high performance even as rounds progress (Davis et al., 2013; Davis et al., 2015).

Punches in amateur boxing mainly consist of four types: jabs, crosses, hooks, and uppercuts. Davis et al. (2018) analyzed high-level male amateur boxing matches and reported that winning requires the ability to continuously deliver a large number of cross punches and maintain punch accuracy even in the later rounds. A previous three-dimensional motion analysis study of cross punches by Cheraghi et al. (2014) reported that amateur boxers prioritize fast punches over heavy punches. Therefore, maintaining a fast and effective cross punch that is difficult for opponents to evade even in the later stages of a bout is considered crucial for amateur boxing performance.

Dunn et al. (2021) reported that repeated maximal rowing ergometer efforts significantly reduced cross-punch force during combination punching, suggesting that fatigue of the trunk muscles impairs trunk rotation and hinders the execution of powerful punches. In contrast, Hukkanen and Häkkinen (2017) reported that the force of a single cross punch after three rounds of a simulated bout was higher than before the bout, suggesting that fatigue-induced changes in body movement increase punch force; however, the detailed kinematic changes underlying this phenomenon remain to be elucidated. Previous studies have reported that torso rotation is important even in single cross punches (Lenetsky et al., 2013; Satkunskiene et al., 2024; Tong-Iam et al., 2017). The torso has the greatest mass and moment of inertia among body segments (Ae, 1996) and contains a high proportion of muscle mass (Abe et al., 2003), indicating that it plays a major role in generating mechanical energy during movement. Nevertheless, to our knowledge, no study has specifically focused on the torso to examine changes in single cross-punch performance across rounds. El-Ashker (2011) reported that both single punches and combinations must be effectively utilized to win, indicating that investigating performance changes in single cross punches with a focus on torso movement across rounds will offer insights for enhancing amateur boxing performance.

This study employed an amateur boxing–specific punching performance test designed based on the movement patterns and exercise intensity of amateur boxing matches (Dunn et al., 2019). The reason for employing this test was to examine changes in single cross-punch speed and torso movement under conditions that replicate movement patterns and high-intensity progression similar to real matches. By replicating movement patterns and high-intensity progression similar to real matches, this approach can provide practical insights into key torso movements that enable the production of fast punches even in later stages of a bout.

The aim of this study was to investigate changes in cross-punch performance associated with round progression under match-like intensity conditions in amateur boxers.

METHODS

Participants

Eleven healthy male amateur boxers (age: 17.0 ± 1.0 years, height: 167.3 ± 3.8 cm, body mass: 65.3 ± 10.1 kg) participated in this study. Seven participants had an orthodox stance (left foot and left hand forward,

performing cross punches with the right hand), and four participants had a southpaw stance (right foot and right hand forward, performing cross punches with the left hand).

Prior to the experiment, the aim of the study, measurement procedures, and potential risks associated with the measurements were explained to the participants and their parents/guardians. Written informed consent for participation and publication was obtained. This study was conducted with the approval of the Ethics Committee of the National Institute of Fitness and Sports in Kanoya (approval number: 24-1-51).

Experimental protocol

After performing sufficient warm-up exercises, such as dynamic stretching, the participants put on boxing gloves and performed a 3-minute maximal-effort punch test (hereafter abbreviated as "*3MPT*") against a suspended punching bag set at a height of 150 cm. The 3MPT (Dunn et al., 2019) is an amateur boxing–specific punching performance test developed based on the exercise intensity and punch frequency observed in amateur boxing matches. The test consists of a total of 3 minutes, divided into six cycles of 30 seconds each (Figure 1). Within each cycle, participants performed combination punches consisting of jabs, crosses, and hooks with maximal effort in a predetermined sequence in response to external cues given every 5 seconds, resulting in a total of 126 punches over the 3-minute period.

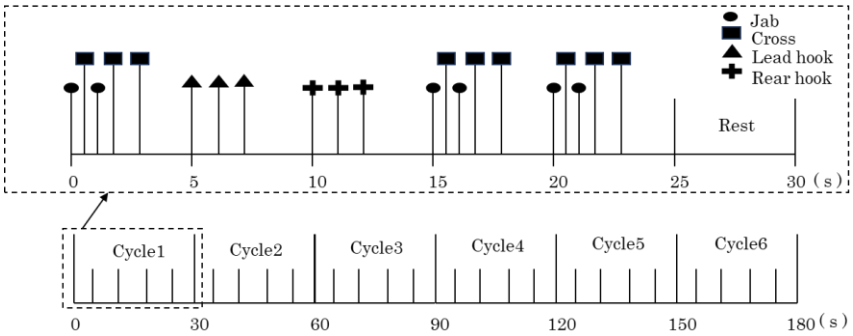

Figure 1. Schematic of the 3MPT (Dunn et al., 2019).

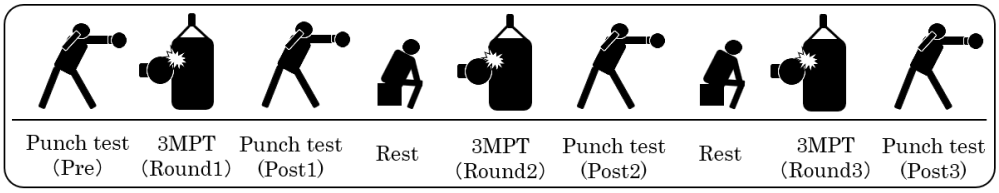

Figure 2. Flow of performance assessment.

We recruited participants who had no prior experience with the 3MPT. They practiced the task sufficiently beforehand and began the actual experiment after taking adequate rest. In the experimental session, participants first performed one trial consisting of a cross punch in a resting state (hereafter "*Pre*"). They then completed the first 3MPT (hereafter "*Round1*"), immediately followed by one trial consisting of a cross punch (hereafter "*Post1*"). Subsequently, after a 1-minute rest period, which aimed to replicate the conditions of an actual amateur boxing match, participants performed the second 3MPT (hereafter "*Round2*"), immediately followed by one trial consisting of a cross punch (hereafter "*Post2*"). After another 1-minute rest, they completed the third 3MPT (hereafter "*Round3*"), immediately followed by a trial consisting of one cross punch (hereafter "*Post3*") (Figure 2). For each cross-punch trial, the participants' standing position during Pre was

standardized to a fixed location that facilitated punching, and they were instructed to perform the cross punches at the same position for Post1 to Post3. In all trials, participants were instructed to perform with maximal effort. The cross-punch condition was limited to only one trial to minimalize the influence of fatigue recovery over time and to maintain consistent experimental conditions.

Data collection

During each 3MPT, heart rate was measured using a chest-worn heart rate monitor (POLAR), and ratings of perceived exertion (RPE) were assessed using the Borg scale (Onodera & Miyashita, 1976). For RPE measurement, the Borg scale was displayed on a television monitor immediately after the completion of each 3MPT, and participants reported their perceived exertion based on the displayed scale. For the measurement of cross-punch performance in each trial, a 16-camera optical three-dimensional motion analysis system (Mac3D, Motion Analysis Corporation) equipped with Kestrel cameras was used. For motion capture, 47 reflective markers were attached to specific anatomical landmarks, and three-dimensional coordinates of body segments were recorded at a sampling frequency of 250 Hz with a shutter speed of 1/1500 s (Figure 3). The 47 reflective marker locations were as follows: three points on the head (vertex and bilateral tragus); 16 points on the upper limbs (bilateral anterior shoulder, bilateral posterior shoulder, bilateral acromion, bilateral medial epicondyle of the humerus, bilateral lateral epicondyle of the humerus, bilateral medial wrist, bilateral lateral wrist, and bilateral third metacarpal); 10 points on the trunk (anterior and posterior aspects of the suprasternal notch, anterior and posterior aspects of the xiphoid process, bilateral inferior borders of the ribs, bilateral anterior superior iliac spines, and bilateral posterior superior iliac spines); and 18 points on the lower limbs (bilateral higher trochanter, bilateral medial femoral condyle, bilateral lateral femoral condyle, bilateral medial malleolus, bilateral lateral malleolus, bilateral medial metatarsophalangeal joint, bilateral lateral metatarsophalangeal joint, bilateral calcaneal tuberosity, and bilateral toes). The global coordinate system was defined with the punching direction, representing the horizontal anterior–posterior axis, assigned to the X-axis; the mediolateral direction perpendicular to the X-axis assigned to the Y-axis; and the vertical direction assigned to the Z-axis.

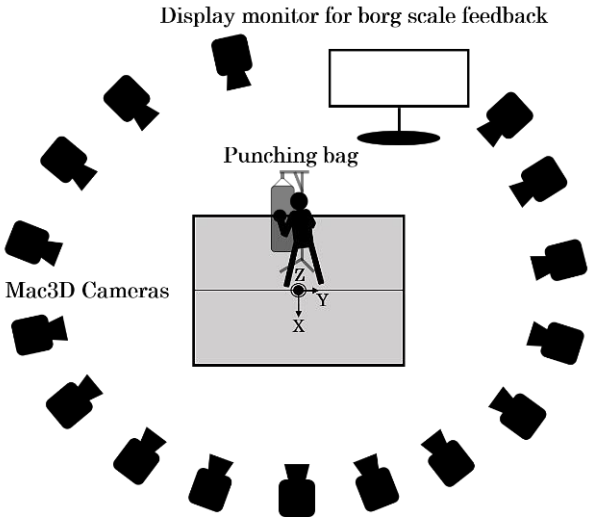

Figure 3. Overview of the performance assessment.

Data processing

The three-dimensional coordinates of the reflective marker attachment points were calculated using the Direct Linear Transformation method in the motion capture system control software (Cortex 6.0.0.1645,

Motion Analysis Corporation). The obtained three-dimensional coordinate data were smoothed using a fourth-order Butterworth low-pass filter. The cut-off frequency was set to 12 Hz, based on previous studies (Piorkowski et al., 2011; Stanley et al., 2018).

Motion analysis phase

The motion analysis phase was defined from the peak of the Z-coordinate of the centre of mass of the lead foot (0%) to one frame before the glove contacted the punching bag (100%), in consideration of potential coordinate distortion caused by impact with the punching bag, and this time point was normalized as the moment of bag contact (Figure 4). The moment at which the glove contacted the punching bag was defined as one frame before the point at which the three-dimensional resultant velocity calculated from the unsmoothed reflective marker on the third metacarpal rapidly decreased due to contact with the punching bag, using the impact detection method used in baseball batting (Ae et al., 2014). The centre of mass of the lead foot was calculated based on the body segment inertia coefficients reported by Ae (1996).

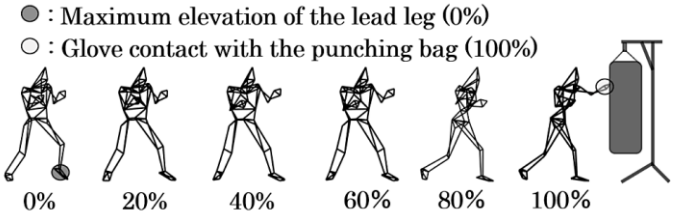

Figure 4. Definition of analysis phase.

Calculated variables

Motion time

The time from the peak of the Z-coordinate of the centre of mass of the lead foot (0%) to one frame before the glove contacted the punching bag (100%) within the motion analysis phase was defined as motion time.

Punch speed

In impact-related movements, it has been reported that appropriate peak velocities may not be obtained when coordinate data are smoothed in the usual manner prior to numerical differentiation (Kawamura et al., 2008). Therefore, punch speed was defined as the maximum value of the three-dimensional resultant velocity obtained by numerically differentiating the unsmoothed displacement of the reflective marker attached to the third metacarpal within the motion analysis phase. For participants using an orthodox stance, velocity was calculated from the reflective marker on the right third metacarpal, whereas for participants using a southpaw stance, velocity was calculated from the marker on the left third metacarpal.

Joint angles and angular velocities

Figure 5 illustrates the definitions of the movements of the lower torso, upper torso, and torso separation. The angles of each movement were calculated based on previous studies (Fuchs et al., 2018; Kageyama et al., 2014).

The rotational angle of the lower torso was defined as the angle between the vector connecting the midpoints of the pelvis (midpoint between the anterior superior iliac spine and posterior superior iliac spine on both sides) projected onto the XY plane and the Y-axis of the global coordinate system (Figure 5(a)). The rotational angle of the upper torso was defined as the angle between the vector connecting the midpoints of the left and right shoulder joints (midpoint of the anterior shoulder, posterior shoulder, and acromion) projected onto

the XY plane and the Y-axis of the global coordinate system (Figure 5(b)). For both the upper torso and lower torso, leftward rotation was defined as a positive angle, and rightward rotation as a negative angle. Furthermore, because the direction of movement is reversed depending on stance, the sign of the angles for the southpaw stance was adjusted to correspond to the rotation direction of the orthodox stance. Torso separation was defined as the difference between the upper torso angle and the lower torso angle (upper torso angle − lower torso angle) (Figure 5(c)). Accordingly, a negative torso separation angle indicates that the upper torso is rotated to the right relative to the lower torso, whereas a positive value indicates rotation to the left.

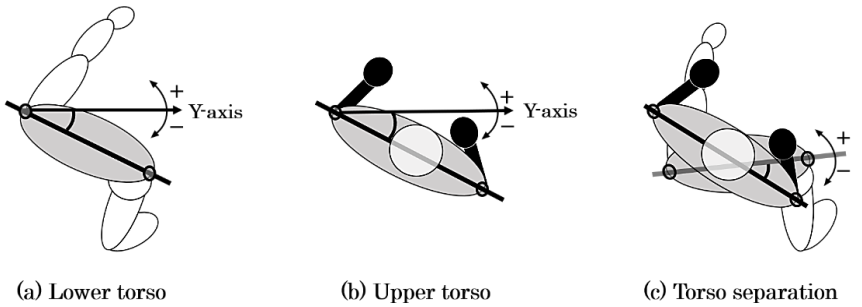

Figure 5. Definition of joint angles.

The angular velocities of the lower torso, upper torso, and torso separation were calculated by differentiating each angle with respect to time. The signs of the angular velocities were defined to correspond to the direction of rotation of each joint angle.

Statistical processing

Performance outcomes of cross-punch measurements in Pre and each Post condition (Post1, Post2, and Post3), as well as physiological indicators during the 3MPT, were compared using a linear mixed model adapted from Dunn et al. (2021) to examine changes in punch performance associated with fatigue. In the linear mixed model, the trial condition was treated as a fixed effect and participant as a random effect, and differences in performance outcomes and physiological indicators among trial conditions were compared. Bonferroni correction was applied as a post hoc adjustment for multiple pairwise comparisons. For normalized data, the same statistical procedure was conducted at each 1% time point. All statistical analyses were performed using IBM SPSS Statistics 29 (IBM Corp., Armonk, NY, USA), and the significance level was set at $p < .05$ for all tests.

RESULTS

Table 1 shows the highest heart rate and RPE during each 3MPT. The values of highest heart rate and RPE were significantly higher in Round2 and Round3 than Round1. Furthermore, Round3 had significantly higher values than Round2.

Table 1. Physiological indicators in each 3MPT round.

	Round1	Round2	Round3
Highest HR (bpm)	178.9 ± 10.0	186.6 ± 9.6 * #	190.1 ± 9.0 * #
RPE (Borg Scale)	14.0 ± 1.7	16.3 ± 1.8 * #	18.1 ± 2.0 * #

*Note. Values are expressed as mean ± SD. * = significantly different to Round1 ($p < .05$). # = significantly different between Round2 and Round3($p < .05$).*

Table 2 shows punch speed and motion time for Pre and each Post trial. No significant differences were observed between Pre and any of the Post conditions for either punch speed or motion time.

Table 2. Punch speed and motion time at Pre and each Post.

	Pre	Post1	Post2	Post3
Punch speed (m/s)	8.53 ± 0.98	8.66 ± 0.75	8.84 ± 0.87	8.93 ± 0.95
Motion time (s)	0.32 ± 0.04	0.32 ± 0.05	0.33 ± 0.08	0.32 ± 0.05

*Note. Values are expressed as mean ± SD. * = significantly different to Round1 (p < .05). # = significantly different between Round2 and Round3(p < .05).*

Figure 6(a) shows the time-series changes in the rotational angle of the lower torso for Pre and each Post. In all trials, the lower torso rotated in the negative direction from 0% to approximately 40%, then changed to the positive direction after approximately 40%, reaching a peak near 100%. In Post1, positive rotation was significantly higher than Pre from 78% to 85%. In Post2, no significant changes were observed compared with Pre. In Post3, positive rotation was significantly higher than Pre from 69% to 92%. No significant changes were observed among the Post conditions.

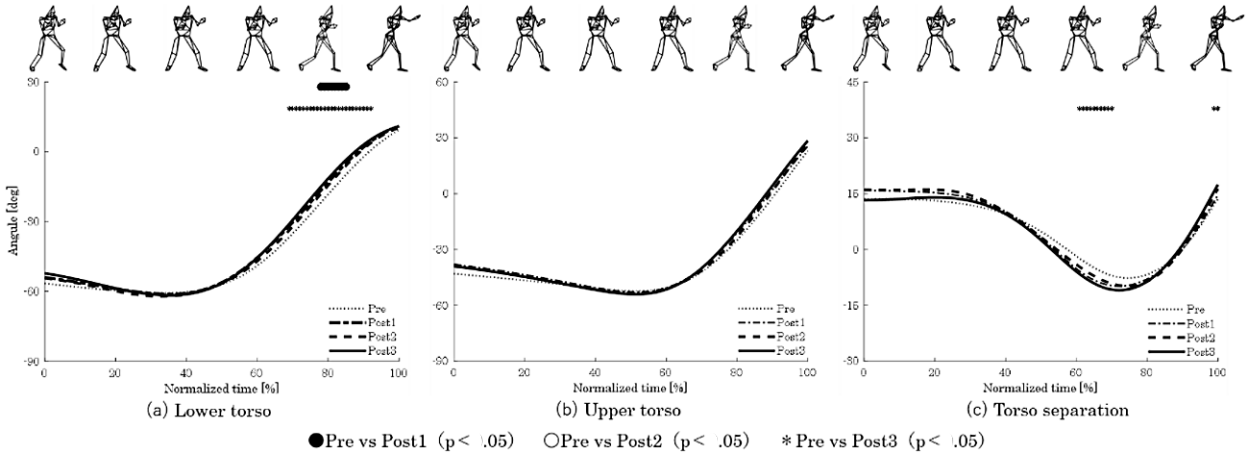

Figure 6. Time series data of axial rotation angle for each torso movement at Pre and each Post.

Figure 6(b) shows the time-series changes in the rotational angle of the upper torso for Pre and each Post. In all trials, the upper torso rotated in the negative direction from 0% to approximately 60%, then changed to the positive direction after approximately 60%, reaching a peak near 100%. No significant differences were observed between Pre and any Post condition at any time point. In addition, no significant changes were observed among the Post conditions.

Figure 6(c) shows the time-series changes in the torso separation angle for Pre and each Post. In all trials, the torso separation rotated in the negative direction from approximately 40% to 70%, then changed to the positive direction after approximately 70%, reaching a peak near 100%. In Post1 and Post2, no significant changes were observed compared with Pre. In Post3, the negative values were significantly higher than Pre from 61% to 70%. and the positive values were significantly higher than Pre from 99% to 100%. No significant changes were observed among the Post conditions.

Figure 7(a) shows the time-series changes in the rotational angular velocity of the lower torso for Pre and each Post. In all trials, the lower torso angular velocity showed negative values from 0% to approximately 40%, then reached a peak around 70%, followed by a decrease. In Post1, the positive values were

significantly higher than Pre from 50% to 58%, and in addition, the positive values were significantly lower than Pre from 90% to 100%. In Post2, the negative values were significantly higher than Pre from 13% to 22%, and the positive values were significantly lower than Pre from 90% to 100%. In Post3, the negative values were significantly higher than Pre from 7% to 26%, and the positive values were significantly higher than Pre from 51% to 71%. Furthermore, the positive values were significantly lower than Pre from 86% to 100%. No significant changes were observed among the Post conditions.

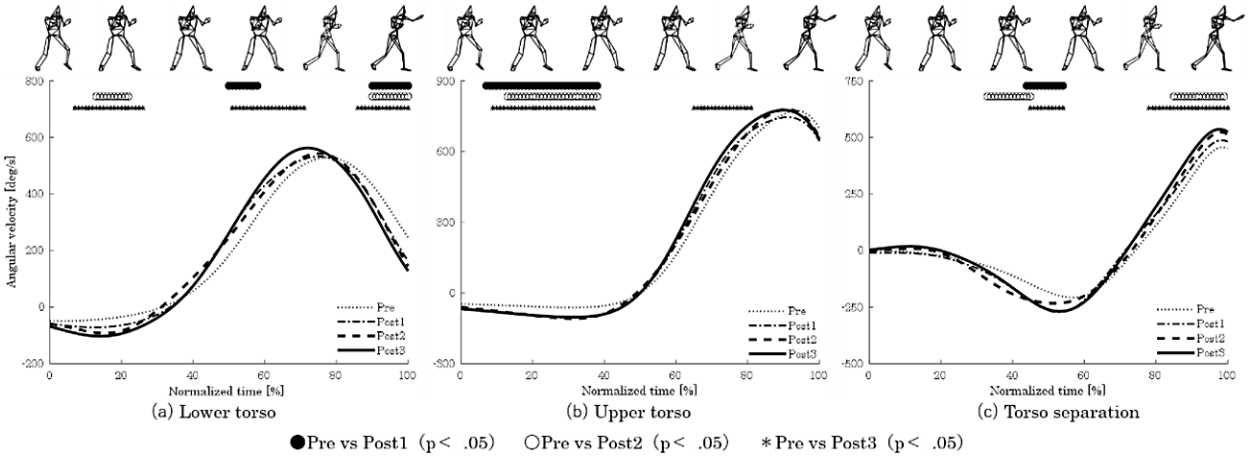

Figure 7. Time series data of axial rotation angular velocity for each torso movement at Pre and each Post.

Figure 7(b) shows the time-series changes in the rotational angular velocity of the upper torso for Pre and each Post. In all trials, the upper torso angular velocity showed negative values from 0% to approximately 50%, then reached a peak around 90%, followed by a decrease. In Post1, the negative values were significantly higher than Pre from 7% to 38%. In Post2, the negative values were significantly higher than Pre from 13% to 38%. In Post3, the negative values were significantly higher than Pre from 9% to 37%, and in addition, the positive values were significantly higher than Pre from 65% to 81%. No significant changes were observed among the Post conditions.

Figure 7(c) shows the time-series changes in the angular velocity of torso separation for Pre and each Post. In all trials, the angular velocity of torso separation showed negative values from approximately 20% to approximately 70%, then reached a peak near 100%. In Post1, the negative values were significantly higher than Pre from 44% to 54%. In Post2, the negative values were significantly higher than Pre from 33% to 45%, and the positive values were significantly higher than Pre from 85% to 99%. In Post3, the negative values were significantly higher than Pre from 44% to 54%, and the positive values were significantly higher than Pre from 78% to 100%. No significant changes were observed among the Post conditions.

DISCUSSION

This study aimed to investigate changes in cross-punch speed and torso movement associated with round progression in amateur boxers. We found that cross-punch speed was maintained despite the progression of rounds, whereas there were changes in torso movement.

Changes in physiological indicators with round progression

As shown in Table 1, the mean values of all physiological indicators in Round2 and Round3 were significantly higher than those in Round1. In addition, Round3 values were significantly higher than Round2. In this study,

Round1 to Round3 are positioned as trials corresponding to three rounds in an actual boxing match. A previous study that simulated boxing matches (El-Ashker et al., 2018) reported lower mean highest heart rate values for each corresponding round than the present study (Round1: 176 ± 4.1 bpm; Round2: 179 ± 1 bpm; Round3: 182 ± 5 bpm). Furthermore, in Round3 of the present study, the highest heart rate reached was 190.1 ± 9.0 bpm, which is higher than that reported by El-Ashker et al. (2018), indicating that an extremely high physiological load was imposed. On the other hand, the values were similar to those reported by Hukkanen and Häkkinen (2017) for Round1 (183 ± 6 bpm) and Round3 (191 ± 7 bpm). Regarding RPE, the mean values in Round2 and Round3 were significantly higher than in Round1, and a significant difference was also observed between Round2 and Round3. In particular, the RPE in Round3 reached 18.1 ± 2.0, which indicates a very hard level of exertion. The mean RPE values for each round were higher in all corresponding rounds compared with a group that rested in a standing posture during simulated matches in a previous study (Nikolaidis et al., 2017).

Taken together, these findings suggest that each round in the present study elicited physiological responses that were higher than or comparable to those observed in previous simulated match studies in terms of both heart rate and RPE, and thus likely imposed a high-intensity load equivalent to that of actual amateur boxing matches.

Changes in punch speed and motion time with round progression

In the previous study by Dunn et al. (2021), a decline in punch performance was reported after high-intensity exercise targeting the lower limbs and trunk. However, Dunn et al. analysed cross punches during combination punching, whereas the present study focused on single punches immediately after the 3MPT. In Dunn et al. (2021), the researchers performed nine sets of 1-minute maximal rowing ergometer exercise with 1-minute rest intervals between sets, totalling 18 minutes. Therefore, compared with the present study using the 3MPT, the movement pattern differed and the physical load was higher.

Combination punching performance may decrease following high-intensity exercise. The present study used the 3MPT based on Dunn et al. (2019), which was designed based on the exercise intensity and punch frequency of amateur boxing matches. We found no changes in punch speed or motion with round progression (Table 2). These findings suggest that even under conditions similar to actual amateur boxing matches, it is possible to maintain single punch performance by modifying body movements. Hukkanen and Häkkinen (2017) reported that the force of a single cross punch after three rounds of a simulated bout was higher than before the bout, suggesting that changes in body movement with round progression are likely to influence punch performance. Furthermore, Piorkowski et al. (2011) reported that single punches exhibited significantly higher punch speed than combination punches. They attributed this to single punches allowing more time for countermovement compared with combination punches, and that the associated stretch–shortening cycle (SSC) contributes to increased punch speed. Faster punches are more likely to inflict higher damage when contacting the opponent's head or torso, potentially leading to knockouts and control of the bout. Therefore, because single punches are as important as combination punches for achieving victory, the present finding that single-punch speed did not change as the rounds progressed represents a novel contribution.

Changes in torso movement with round progression

A maximal-effort cross punch is initiated by lifting the lead leg and subsequently stepping forward, during which the pelvis and shoulders rotate in the opposite direction of the target, stretching the trunk musculature and inducing an SSC, which enhances cross-punch performance (Turner et al., 2011). The countermovement actions of the lower torso and upper torso are considered an important factor for generating high cross-punch

speed. As shown in Figure 7(a, b), significantly higher negative angular velocities than Pre were observed for the lower torso and upper torso in Post1 (upper torso: 7%–38%), Post2 (lower torso: 13%–22%; upper torso: 13%–38%), and Post3 (lower torso: 7%–26%; upper torso: 9%–37%). In addition, although no significant difference was observed in lower torso angular velocity in Post1, higher negative angular velocity than Pre was observed in the approximately 5%–30% interval, in which significant differences were observed for the lower and upper torso. In contrast, as shown in Figure 6(a, b), the negative rotational angles of the lower torso and upper torso in each Post did not differ significantly from Pre. These findings suggest that the amateur boxers unconsciously completed the movement within a limited time and as the rounds progressed, attempted to execute punches by increasing the speed of the countermovement of the lower torso and upper torso rather than the range of motion. This is also supported by the finding that motion time did not change significantly (Table 2). Previous studies examining the effect of countermovement speed on countermovement jump performance (Hernández-Davó et al., 2024; Pérez-Castilla et al., 2021) reported that performing the countermovement phase rapidly (from the initial posture to the negative peak of vertical velocity of the body centre of mass) improved performance in the propulsion phase (from the negative peak of vertical velocity to take-off), suggesting that this effect is due to higher force production early in the propulsion phase. Takahashi et al. (2018) reported that in bar-twist trunk rotation exercises, conditions involving countermovement resulted in significantly higher angular velocities of the upper torso and lower torso during the phase in which the barbell rotated in the positive direction, indicating that utilization of countermovement contributes to higher angular velocity production in the trunk. Considering these findings, the increase in countermovement speed of the lower torso and upper torso with round progression is likely related to the significantly higher positive angular velocities in Post1 (lower torso: 50%–58%) and Post3 (lower torso: 51%–71%; upper torso: 65%–81%) compared with Pre (Figure 7(a, b)), thereby contributing to the maintenance of punch speed across rounds. Even in trials where no significant differences were detected, the increased countermovement speed of the lower and upper torso may have contributed to maintaining positive angular velocity between approximately 50% and 80% of the movement. Furthermore, the increased positive angular velocity of the lower torso likely led to the significant increases in positive rotational angles of the lower torso for Post1 (78%–85%) and Post3 (69%–92%) (Figure 6(a)). In addition, significantly higher negative angular velocities of torso separation than Pre were observed in Post1 (44%–54%), Post2 (33%–45%), and Post3 (44%–54%) (Figure 7(c)). The increase in negative angular velocity indicates that in each Post, the upper torso rotated more rapidly to the right relative to the lower torso compared with Pre. This suggests that in each Post, in addition to the faster countermovement of the lower torso and upper torso, rapid torso separation may have further emphasized the SSC of the trunk. Effective force production via the SSC is reported to occur through the reuse of elastic energy stored in the muscle–tendon complex during the stretch phase as mechanical energy in the shortening phase (Asmussen & Bonde-Petersen, 1974; Cavagna, 1977), as well as through reflexive muscle contraction induced by rapid muscle stretch via muscle spindle activation (Komi, 2000; Van Hooren & Zolotarjova, 2017). Previous studies have reported that the SSC of the trunk influences performance in throwing and striking movements involving trunk rotation (Kageyama et al., 2014; Tauchi et al., 2005). A similar mechanism may apply to the participants in the present study. In particular, it has been shown that the enhancement of muscle output via the SSC is influenced by the velocity of muscle stretching during the stretch phase (Cavagna et al., 1968; Aura & Komi, 1986). Therefore, in each Post, where the countermovement speed of the lower torso and upper torso was higher than Pre and the upper torso rotated rapidly to the right relative to the lower torso, the enhanced SSC of the trunk likely contributed to maintaining punch speed. Furthermore, the effects of the SSC are known to be most pronounced immediately after the transition from the stretch phase to the shortening phase (Takamatsu et al., 1991; Walshe et al., 1998). This aligns with the present study, as we found that the positive angular velocities of torso separation were significantly higher than Pre in Post2 (85%–99%) and Post3 (78%–100%), suggesting that the SSC of the trunk becomes increasingly important for maintaining punch speed in later

rounds (Figure 7(c)). Myers et al. (2008), in their analysis of golf swings, reported that higher torso separation angles contribute to increased upper body rotational velocity and torso separation angular velocity during the downswing, ultimately enhancing ball speed. In the present study, the significantly higher negative torso separation angles in Post3 (61%–70%) compared with Pre may similarly have contributed to maintaining punch speed in the later rounds (Figure 6(c)). Moreover, the positive angular velocity of the lower torso was significantly smaller in Post1 (90%–100%), Post2 (90%–100%), and Post3 (86%–100%) compared with Pre (Figure 7(a)). Putnam (1993) reported that, in a kinetic chain, deceleration of proximal segments facilitates the transfer of kinetic energy to distal segments, promoting distal acceleration. Therefore, the significant reduction in lower torso angular velocity in each Post compared with Pre may have increased inertia and facilitated the transfer of energy to subsequent distal segments, thereby contributing to the maintenance of punch speed with round progression.

Limitations and future directions

This study had several limitations. First, changes in torso movement, such as countermovement actions of the lower torso and upper torso and torso separation, were observed with round progression in this study. However, such preparatory movements may increase the risk of opponents anticipating the intended action in actual competitive situations. Therefore, it remains unclear to what extent the present findings are applicable to real amateur boxing matches. Further research involving actual opponents is warranted in the future. Second, the 3MPT used in this study is a whole-body exercise involving not only the trunk but also the limbs. Future studies should employ force plates and electromyography to investigate changes in whole-body movement patterns associated with round progression. This approach may help elucidate the mechanical factors underlying why punch speed did not exceed Pre values in each Post despite changes in torso movement. Third, most participants in this study were junior amateur boxers. Although previous studies involving national-level athletes have also reported no decline in punch performance with round progression (Hukkanen & Häkkinen, 2017), further research involving elite boxers is necessary to determine whether the present findings can be generalized to higher-level competitors.

CONCLUSION

This study evaluated changes in cross-punch speed and torso movement with round progression in amateur boxers using the 3MPT. The results showed that punch speed did not change with round progression. However, the cross-punch movement changed such that faster countermovement actions of the lower torso and upper torso, and more pronounced torso separation were emphasized as rounds progressed. These changes may have contributed to maintaining punch speed across rounds.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Shinya Kimoto was responsible for the conceptualization of the study, experimental design, data collection, data analysis and interpretation, and writing of the original draft. Kanzi Ohyama provided methodological guidance, assisted in data interpretation, and critically reviewed and edited the manuscript. Akira Maeda contributed through supervision and project administration, provided methodological guidance, assisted in data interpretation, critically reviewed and edited the manuscript, and handled correspondence with the journal. All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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