International Journal of Sports Physiology and Performance, 2013, 8, 84-91

INTERNATIONAL JOURNAL OF
SPORTS PHYSIOLOGY
AND PERFORMANCE
www.IJSPP-Journal.com
ORIGINAL INVESTIGATION

Amateur Boxing: Activity Profile of Winners and Losers

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An activity profile of competitive 3 × 2-min novice-level amateur boxing was created based on video footage and postbout blood [La] in 32 male boxers (mean ± SD) age 19.3 ± 1.4 y, body mass 62.6 ± 4.1 kg. Winners landed 18 ± 11 more punches than losers by applying more lead-hand punches in round 1 (34.2 ± 10.9 vs 26.5 ± 9.4), total punches to the head (121.3 ± 10.2 vs 96.0 ± 9.8), and block and counterpunch combinations (2.8 ± 1.1 *vs.* 0.1 ± 0.2) over all 3 rounds and punching combinations (44.3 ± 6.4 vs 28.8 ± 6.7) in rounds 1 and 3 (all $P < .05$). In 16 boxers, peak postbout blood [La] was 11.8 ± 1.6 mmol/L irrespective of winning or losing. The results suggest that landing punches requires the ability to maintain a high frequency of attacking movements, in particular the lead-hand straight punch to the head together with punching combinations. Defensive movements must initiate a counterattack. Postbout blood [La] suggests that boxers must be able to tolerate a lactate production rate of 1.8 mmol · L^{-1} · min^{-1} and maintain skillful techniques at a sufficient activity rate.

Keywords*:* combat sport, blood lactate, performance

Amateur boxing is a full-contact combat sport with the aim of punching one's opponent without being punched in return.[1] Points are awarded to a boxer by a group of judges for landing a clean punch with the knuckle area of the glove within the target area of the opponent, defined as any part of the front or sides of the head or body above the belt. Defensive movements are also made by boxers with the feet, torso, and hands to evade punches from their opponent.

Currently, novices box 3 × 2-minute rounds, intermediate boxers 4 × 2-minute rounds, and open-class boxers 3 × 3- or 4 × 2-minute rounds by agreement of the coaches and boxers. Most existing literature is based on the 3 × 3-minute bout format,[2–4] and concise data detailing the physical activities in an amateur 3 × 2-minute boxing bout are rare.[5] A study examining video footage of competitive bouts indicated changes in punching tactics and strategy corresponding with the change in bout format.[2] Compared with the 3 × 3-minute format,[2] the 4 × 2-minute format had a lower number of punches thrown in any single combination based on a punching sequence incorporating 76 straight punches per round, from lead and rear hand in 1-, 2-, and 3-punch combinations.[3] However, additional data on further relevant activities such as other types of punches, blocks, clinching, or trunk movements were not detailed. Research into amateur boxing is limited and, thus far, based on data of selected technical elements rather than all fighting actions[2,3] or physiological acute responses without the corresponding information on fighting activities.[4] Constant reform of the sport's rules and round and bout length is a possible reason for the limited research. In addition, there is speculation based on selected anecdotal evidence that amateur boxing bouts may be misjudged, resulting in the wrong boxer being announced as the winner. However, no studies have reported on judging decisions in the literature.

With respect to the acute physiological response, open-class-level selection trials and competitive bouts of 5 × 2-, 3 × 3-, and 4 × 2-minute duration have shown a range of peak postbout blood [La] values: 8.6, 9.5, and 13.5 mmol/L, respectively.[3] Furthermore, other studies from selection trials have reported postbout blood [La] of 8.2 and 8.1 mmol/L for 3 × 3- and 3 × 2-minute bouts, respectively.[4,5] Inclusion of blood [La] data provides some indication of intensity and allows comparison with previous work. Indeed, previous research suggests that changes in postbout blood [La] between different bout formats may be due to subsequent changes in intensity, tactics, and strategy.[3] There are limited competitive-bout heart-rate data in the literature, possibly due to strict competition rules restricting what a boxer is allowed to wear,[6] although heart-rate data could be examined in simulated bouts.

Therefore, the aim of the current study was to analyze video footage and postbout blood [La] of competitive 3 × 2-minute bouts. Analysis of this footage would produce an activity profile of novice amateur boxing including changes over the progression of a bout and differences between winners and losers. The results may highlight the requirements to be a successful boxer at novice level so that advancement to intermediate level can be as focused as possible for both coach and boxer. Furthermore, the

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results may allow some insight into the problem of bouts being misjudged.

Methods

Participants

Thirty-two male boxers (mean ± SD) age 19.3 ± 1.4 years, body mass 62.6 ± 4.1 kg, currently competing as amateurs at the novice level, were selected from boxing clubs in Great Britain. The boxers had participated in at least 6 senior bouts during 5.1 ± 2.3 years of amateur boxing experience, spending 5.0 ± 1.5 h/wk on technique training, with additional running training as advised by their coaches. All participants gave their written informed consent to take part in the study and were made aware that they could leave the study at any time. The study was approved by the University of Essex Ethics Committee.

Procedures

Video footage of each participant's amateur boxing bout was recorded based on 16 bouts using a single video camera (Sony Hi-8, Berks, UK) in an elevated position to limit any obstruction of view. One bout per participant was analyzed, and data were recorded for both boxers in 16 bouts. The bouts were judged by 3 judges using the scorecard method. Recordings were then analyzed, often in slow-motion replay, by a qualified amateur boxing coach. All bouts were analyzed by the same coach, with 5 random bouts analyzed twice to check for internal consistency. This analysis was used to create an activity profile of amateur boxing including the following performance indicators: A hit was a punch that landed in the target area and should have scored a point according to Amateur Boxing Association rules.[6] A miss was a punch that failed to land in the target area, and an air punch was a punch that failed to make any contact with the opponent. Defensive actions recorded included defensive movements made with the hand, trunk, and foot. Combined actions specified in terms of multiple punches (double and triple punch and 4 or more), combined target areas (body and head combination), repetitive lead-hand punch (lead-hand combination), and direct transition from defensive block to attacking punch (block and counter; Figure 1). Miscellaneous measures included the total time (s) and the frequency of clinching and referee stoppage. Time before first stop (s) was defined as the time taken before the first clinch or referee stoppage. The activity-to-break ratio was calculated as time spent active over time spent

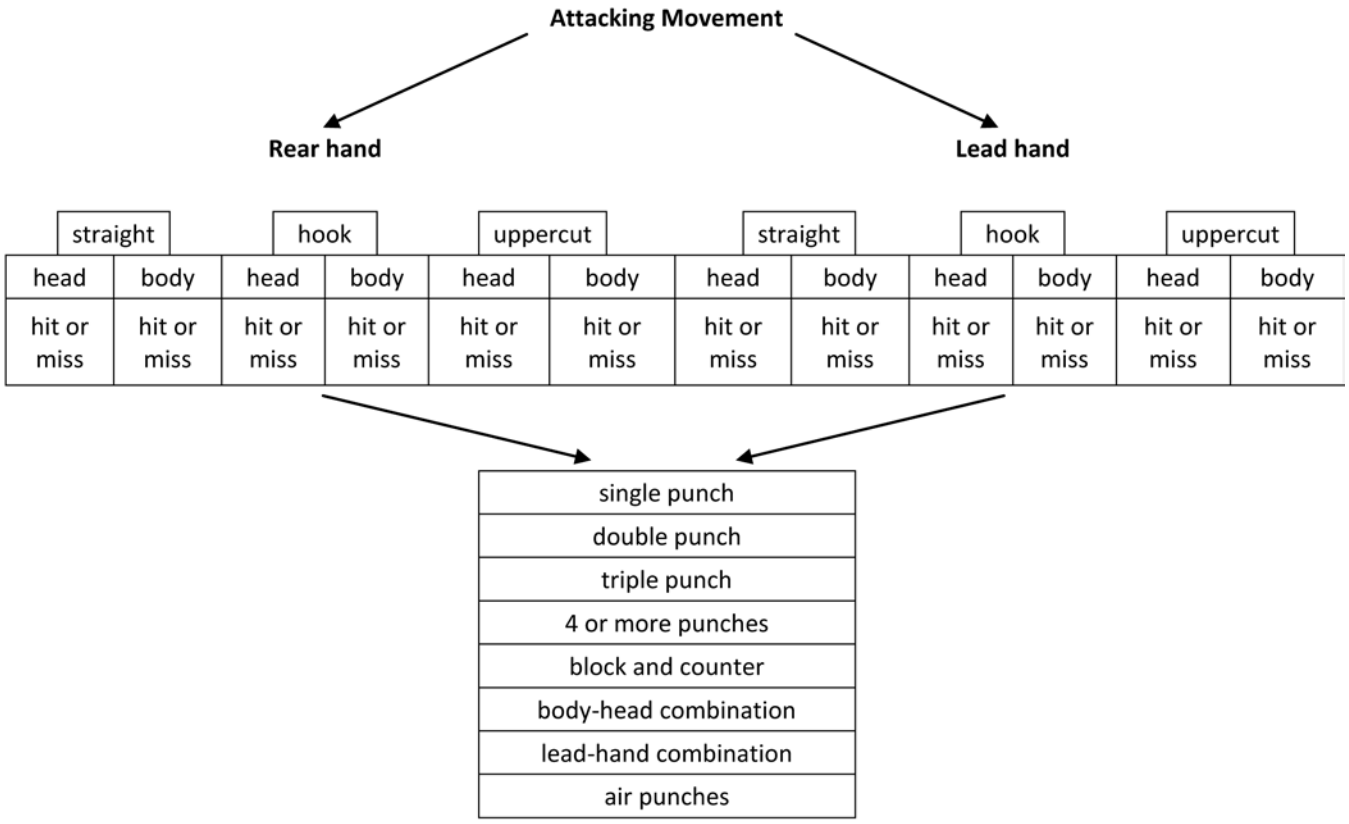

Figure 1 — All attacking movements were recorded, detailing whether the movement was made with the lead or rear hand; with a straight, hook, or uppercut technique; aimed at the head or body of the opponent; and if the movement hit or missed the target area. Whether the movement was a single punch, part of a combination, or missed the opponent completely (air punch) was then recorded.

in a break, irrespective of the cause of the break. Vertical hip movements were defined as any visually identifiable vertical activity of the pelvis during stand and steps. Activity rate per round (actions/s) included all attacking and defensive actions (each movement in a combination was counted separately) and vertical hip movements divided by net activity time (Net activity time = round time – total stop time). Punches per minute were calculated from the total number of punches over the entire bout divided by the collective rounds' duration. The ratio of punches thrown to punches landed was calculated by dividing the number of total punches by punches landed. Punch accuracy was calculated from the number of punches that hit the target as a percentage of the total number of that type of punch thrown.

Winners and losers were identified based on punches landed as counted during the video analysis, and not based on the judges' decision at the time of the bout.

Capillary blood samples (20 µL) were collected from the hyperemic ear lobe in 16 boxers prebout and 3, 5, and 7 minutes postbout and analyzed for blood [La] (EBIO Plus, Eppendorf, Hamburg, Germany).

Statistical Analysis

Results are reported as mean ± SD. Normal distribution was tested based on mean and 5% trimmed mean, normal Q-Q and detrended normal Q-Q plots, and box plots. Values are reported for winners and losers combined and only reported separately where a significant difference was found ($P < .05$). A 3 (round: first, second, and third) × 2 (outcome: winner and loser) analysis of variance for repeated measures was applied for differences in techniques, considering round and outcome as within and between factors respectively. Bonferroni adjustments were applied as appropriate. Interrelationships between variables were analyzed using simple linear and multiple-regression models. Stepwise regression was used to analyze all the attacking movements. The results were analyzed for both winners and losers as classified by punches landed and by the judges' decision. For all statistics, the significance level was set at $P < .05$.

Results

All bouts lasted the full duration. The total number of punches landed was higher in winners than losers in rounds 1 ($P = .006$) and 2 ($P = .009$). The ratio of punches thrown to punches landed was lower for winners than losers in round 1 ($P = .002$; Table 1). Lead-hand hooks landed were higher in winners than losers in rounds 2 ($P = .035$) and 3 ($P = .045$; Table 1). The total number of punches decreased ($P = .025$) between rounds 1 and 2 for winners and losers combined and was higher in winners than losers in rounds 2 ($P = .047$) and 3 ($P = .02$; Table 2). The number of punches with the lead hand ($P = .002$), total straights ($P = .003$), total to the head ($P = .005$), lead-hand straights ($P = .001$), and punches per minute ($P = .008$) were higher in round 1 than rounds 2 or 3 for winners and losers combined (Table 2). The number of punches with the lead hand was higher ($P = .046$) for winners than losers in round 1.

Total punches were higher for winners than losers in rounds 2 ($P = .047$) and 3 ($P = .02$). Lead-hand hooks were higher for winners than losers in rounds 2 ($P = .043$) and 3 ($P = .032$). Total punches to the head were higher for winners than losers over all 3 rounds ($P = .029$, .037, and .026, respectively; Table 2). Air punches were higher ($P = .044$) for losers than winners in round 2 (Table 2).

In 3 of 16 fights (19%), the judges' decisions did not reflect punches landed correctly. This was despite an average point gap between the winners and losers as judged by punches landed of 18 ± 11 over the duration of the bout.

Table 1 Punches Landed in Relation to Round and Outcome, Mean ± SD

	Round 1	Round 2	Round 3
Total punches	17.2 ± 8.3	15.7 ± 5.9	17.6 ± 7.1
winners	2.7 ± 8.1 (.006)	18.6 ± 6.1 (.009)	2.3 ± 7.5
losers	12.6 ± 6.4	13.0 ± 4.7	15.2 ± 6.5
Straight lead hand	6.4 ± 3.7	5.0 ± 3.0 (.031)	6.3 ± 3.5
winners	7.8 ± 3.9	5.6 ± 3.0	6.4 ± 3.5
losers	5.3 ± 3.3	4.6 ± 3.1	6.1 ± 3.9
Hook lead hand	3.1 ± 3.2	3.7 ± 2.3	3.8 ± 2.7
winners	3.6 ± 2.3	4.4 ± 2.2 (.035)	4.9 ± 2.7 (.045)
losers	2.0 ± 3.0	2.7 ± 2.0	2.8 ± 2.5
Ratio of punches to punches landed	2.9:1	2.8:1	2.7:1
winners	2.6:1 (.002)	2.5:1	2.7:1
losers	3.4:1	3.1:1	2.7:1

Note: Number in parentheses in title row round 1 = P value between rounds 1 and 2, in title row round 2 = P value between rounds 2 and 3, in title row round 3 = P value between rounds 1 and 3, and in winners row = P value between winners and losers.

Table 2 Attacking Movements in Relation to Round and Outcome, Mean ± SD

	Round 1	Round 2	Round 3
Single punch	12.6 ± 5.4	13.4 ± 5.5	13.9 ± 5.9
winners	11.6 ± 3.7	12.2 ± 3.7	11.7 ± 5.0
losers	13.3 ± 6.8	14.5 ± 6.5	16.0 ± 6.7
Punches lead hand	3.7 ± 1.5 (.002)	25.5 ± 7.8	25.7 ± 8.2 (.001)
winners	34.2 ± 1.9 (.046)	28.1 ± 8.3	28.5 ± 7.3
losers	26.5 ± 9.4	22.9 ± 7.1	22.7 ± 8.9
Punches rear hand	15.9 ± 8.2	15.1 ± 6.4	16.6 ± 7.1
Hook lead hand	9.0 ± 6.7	8.3 ± 4.5	8.5 ± 4.7
winners	9.8 ± 4.3	9.6 ± 3.2 (.043)	1.3 ± 4.3 (.032)
losers	6.6 ± 6.6	6.4 ± 5.0	6.6 ± 4.6
Straight lead hand	19.5 ± 8.3 (.001)	15.7 ± 7.8	15.9± 7.9 (.017)
Air punches	11.3 ± 4.7	9.8 ± 4.3	9.8 ± 3.9
winners	1.1 ± 2.5	8.5 ± 3.0 (.044)	9.5 ± 3.8
losers	13.0 ± 6.0	11.8 ± 4.7	1.6 ± 4.0
Total to head	39.4 ± 11.9 (.005)	33.9 ± 9.6	35.2 ± 9.9 (.047)
winners	44.0 ± 1.2 (.029)	37.8 ± 1.9 (.037)	39.5 ± 9.4 (.026)
losers	34.4 ± 12.5	3.3 ± 7.3	31.3 ± 9.7
Punches/min	23.3 ± 7.7 (.008)	2.2 ± 5.6 (.35)	21.1 ± 5.9 (.035)
winners	25.6 ± 7.1	22.4 ± 6.2 (.047)	23.7 ± 5.0 (.026)
losers	2.2 ± 7.6	18.2 ± 4.6	18.6 ± 6.1
Total straights	26.9 ± 11.0 (.003)	22.3 ± 9.9	22.3 ± 1.4 (.025)
Total hooks	16.6 ± 1.3	15.6 ± 8.4	17.6 ± 8.6
Total uppercuts	3.1 ± 3.9	2.6 ± 3.5	2.3 ± 3.4
Total to body	7.2 ± 6.3	6.5 ± 5.1	7.0 ± 5.8
Total punches	46.7 ± 15.5 (.025)	4.6 ± 11.2	42.3 ± 11.9
winners	51.2 ± 14.4	44.9 ± 12.5 (.047)	47.5 ± 1.1 (.020)
losers	40.4 ± 15.3	36.5 ± 9.2	37.3 ± 12.4

Note: Number in parentheses in title row round 1 = *P* value between rounds 1 and 2, in title row round 2 = *P* value between rounds 2 and 3, in title row round 3 = *P* value between rounds 1 and 3, and in winners row = *P* value between winners and losers.

The overall bout activity-to-break ratio not including breaks between rounds was approximately 9:1. The activity-to-break ratio in round 1 (16:1) was higher ($P < .05$) than in round 2 (8:1) and round 3 (6:1). The decrease resulted from a higher stop frequency and stop time due to the referee's intervention and clinching in rounds 2 and 3 (Table 3). Clinch time constituted the main fraction of stop time, being 62%, 82%, and 57% in rounds 1, 2, and 3, respectively. There were also fewer vertical hip movements as round number increased ($P = .010$, .030, and .000, respectively; Table 3). In round 2 the activity rate was higher ($P = .026$) in winners than in losers (Table 3).

With respect to punch combinations for winners and losers combined, total combinations ($P = .007$), lead-hand combinations ($P = .042$), and block and counter combinations ($P = .04$; not normally distributed) were higher in round 1 than in round 3 (Table 4). Winners used more lead-hand combinations in round 1 ($P = .02$), more body-head ($P = .001$ and .006), 2-punch ($P = .007$ and .047), and 4-or-more-punch ($P = .004$ and .026; not normal distributed) combinations in rounds 1 and 3. Winners also used more triple-punch combinations in rounds 1 ($P = .000$) and 2 ($P = .029$) and more total combinations and block and counter punch combinations over all 3 rounds than losers ($P = .000$, .019, and .030, respectively; Table 4). The most commonly employed combination was the double punch.

For winners and losers combined, total defensive movements were lower in the third round than in the first 2 rounds ($P = .009$ and .000), where hand defense decreased between rounds 1 and 3 ($P = .021$), foot defense decreased between rounds 1 and 3 ($P = .000$), and trunk defense

Table 3 Time and Activity Data in Relation to Round and Outcome, Mean ± SD

	Round 1	Round 2	Round 3
Total stop time (s)	7.0 ± 1.4 (.000)	12.6 ± 11.7	18.5 ± 19.7 (.002)
Total stop frequency	1.3 ± 1.7 (.000)	2.4 ± 2.0	2.7 ± 2.5 (.001)
Referee stop frequency	0.2 ± 0.4 (.036)	0.6 ± 0.9	0.6 ± 0.6
Referee stop time (s)	1.6 ± 3.5	3.1 ± 5.0	7.1 ± 13.0
Time before first stop (s)	89.0 ± 41.3 (.000)	51.7 ± 31.3	52.3 ± 39.9 (.000)
Clinch frequency	1.0 ± 1.7 (.007)	1.8 ± 1.5	2.0 ± 2.2 (.024)
Total clinch time (s)	5.3 ± 9.4 (.008)	9.4 ± 8.3	11.3 ± 13.3 (.047)
Vertical hip movements	79.7 ± 21.6 (.010)	74.3 ± 2.0 (.030)	69.9 ± 21.7 (.000)
winners	81.4 ± 5.9	77.0 ± 5.4	72.8 ± 6.5
losers	77.5 ± 5.6	70 .5 ± 5.2	66.6 ± 5.5
Activity rate (per s)	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.4
winners	1.2 ±0 .3	1.2 ± 0.2 (.026)	1.3 ± 0.4
losers	1.1 ± 0.2	1.0 ± 0.1	1.1 ± 0.4

Note: Number in parentheses in title row round 1 = *P* value between rounds 1 and 2, in title row round 2 = *P* value between rounds 2 and 3, in title row round 3 = *P* value between rounds 1 and 3, and in winners row = *P* value between winners and losers.

Table 4 Punch-Combination Data in Relation to Round and Outcome, Mean ± SD

	Round 1	Round 2	Round 3
Body-head combinations	1.6 ± 2.2	1.4 ± 1.8	1.1 ± 1.5
winners	1.9 ± 1.9 (.001)	2.0 ± 2.3	1.8 ± 1.7 (.006)
losers	0.7 ± 1.4	0.8 ± 0.8	0.3 ± 0.4
Lead-hand combinations	3.1 ± 2.5 (.050)	2.2 ± 1.9	2.0 ± 2.2 (.042)
winners	4.3 ± 2.9 (.020)	2.4 ± 1.8	2.6 ± 2.6
losers	2.3 ± 1.8	2.0 ± 2.2	1.3 ± 1.8
2-punch combinations	9.8 ± 4.9	9.1 ± 4.2	8.9 ± 3.0
winners	11.0 ± 3.3 (.007)	1.4 ± 4.2	1.2 ± 2.7 (.047)
losers	8.3 ± 5.9	8.0 ± 4.3	7.7 ± 3.1
3-punch combinations	3.0 ± 2.2	2.1 ± 1.9	2.2 ± 2.0
winners	3.7 ± 2.0 (.000)	2.9 ± 1.8 (.029)	3.0 ± 2.1
losers	1.9 ± 2.0	1.3 ± 1.6	1.6 ± 1.9
4-or-more combinations[a]	0.8 ± 1.2	0.8 ± 1.1	0.7 ± 1.1
winners	1.1 ± 1.4 (.004)	1.2 ± 1.2	1.3 ± 1.3 (.026)
losers	0.5 ± 0.9	0.5 ± 1.1	0.3 ± 0.6
Block and counter[a]	0.7 ± 1.2	0.4 ± 0.8	0.2 ± 0.7 (.040)
winners	1.4 ± 1.4 (.000)	0.8 ± 1.0 (.019)	0.6 ± 0.9 (.030)
losers	0.1 ± 0.5	0.0 ± 0.2	0.0 ± 0.0
Total combinations	2.8 ± 8.3	17.2 ± 6.6	15.8 ± 6.1 (.007)
winners	24.7 ± 7.0 (.000)	2.3 ± 5.9 (.009)	19.6 ± 5.7 (.001)
losers	16.3 ± 8.3	14.5 ± 6.8	12.5 ± 5.1

Note: Number in parentheses in title row round 1 = *P* value between rounds 1 and 2, in title row round 2 = *P* value between rounds 2 and 3, in title row round 3 = *P* value between rounds 1 and 3, and in winners row = *P* value between winners and losers,

[a] Not normally distributed.

decreased between rounds 2 and 3 (P = .034; Table 5). There were no significant differences between winners and losers for any of the defensive variables (Table 5).

The lead-hand hook to the head was the only punch where accuracy changed between rounds. Lead-hand hook accuracy increased between rounds 1 and 2 and rounds 1 and 3 (P < .05; Table 6). When considering the accuracy of a punch, punches to the body were more accurate than punches to the head for the lead-hand straight (P = .015 and .003) and rear-hand hook (P = .001 and .028) in rounds 1 and 2, lead-hand hook in round 1 (P = .008), and the rear-hand straight in round 3 (P = .021; Table 6).

Stepwise-regression analysis for winners as classified by punches landed revealed that lead-hand straight punches explained 17% (P < .001) of the variance in landed punches, which could be increased to 31% (P < .001) by including rear-hand hook punches, 40% (P < .001) by further including lead-hand combinations, and 62% (P < .001) by furthermore including rear-hand straight punches. The combination of the latter 3 techniques led to the exclusion of lead-hand straight punches in explaining the variance in landed punches.

However, examination of results for winners as classified by judges' decision revealed that triple-punch combinations explained 18% (P < .001) of the variance in landed punches, which could be increased to 32% (P < .001) by including lead-hand straight punches, 40% (P < .001) by further including rear-hand hook punches, and 49% (P < .001) by furthermore including rear-hand straight punches.

Examination of results for losers as classified by punches landed revealed that rear-hand hook punches explained 44% (P < .001) of the variance in landed punches, which could be increased to 59% (P < .001) by including rear-hand straight punches, 65% (P < .001) by further including lead-hand straight punches, 70% (P < .001) by further including lead-hand combinations, and 74% (P < .001) by furthermore including lead-hand hook punches.

However, examination of results for losers as classified by judges' decision revealed that rear-hand hook punches explained 38% (P < .001) of the variance in landed punches, which could be increased to 55% (P < .001) by including rear-hand straight punches, 69% (P < .001) by further including body-head combinations, 70% (P < .001) by further including lead-hand combinations, and 74% (P < .001) by furthermore including lead -hand straight punches.

Mean prebout and 3-, 5-, and 7-minute postbout blood [La] were 1.3 ± 0.5, 11.8 ± 1.6, 10.8 ± 2.2, and 9.9 ± 2.5 mmol/L, respectively.

Table 5 Defensive Data in Relation to Round, Mean ± SD

	Round 1	Round 2	Round 3
Hand defense	1.3 ± 2.1	1.0 ± 2.1	0.5 ± 1.2 (.021)
Trunk defense	3.1 ± 2.9	3.4 ± 3.0 (.034)	2.4 ± 2.2
Foot defense	4.6 ± 2.4	3.6 ± 3.0	2.8 ± 2.1 (.000)
Total defense	9.1 ± 4.9	8.0 ± 6.3 (.009)	5.8 ± 4.1 (.000)

Note: Number in parentheses in title row round 1 = P value between rounds 1 and 2, in title row round 2 = P value between rounds 2 and 3, and in title row round 3 = P value between rounds 1 and 3.

Table 6 Punch Accuracy in Relation to Round, Mean ± SD

Hand	Punch type	Target	Hit % Round 1	Hit % Round 2	Hit % Round 3
Lead hand	straight	head	31 ± 12 (.015)	33 ± 19 (.003)	40 ± 16
		body	53 ± 38	66 ± 42	44 ± 40
	hook	head	24 ± 18 (.008)	45 ± 24	45 ± 27
		body	65 ± 38	53 ± 44	60 ± 31
	uppercut	head	35 ± 37	42 ± 36	24 ± 38
		body	83 ± 30	51 ± 44	72 ± 40
Rear hand	straight	head	28 ± 22	35 ± 30	33 ± 25 (.021)
		body	52 ± 34	50 ± 50	70 ± 40
	hook	head	36 ± 21 (.001)	38 ± 22 (.028)	31 ± 26
		body	67 ± 36	62 ± 36	46 ± 38
	uppercut	head	0	25 ± 41	32 ± 38
		body	0	61 ± 36	58 ± 43

Note: Accuracy as the number of punches that hit the target is presented as a percentage of the total amount of that type of punch thrown. Number in parentheses in the head row = P value between head and body accuracy.

Discussion

The current study is the first to provide an activity profile of amateur boxing over the 3 × 2-minute bout format. The results appear to support the theory that the single most successful boxing strategy to land punches is a high frequency of straight lead-hand punches.[7–9] However, other successful combinations included rear-hand hook punches, lead-hand combinations, and rear-hand straight punches. Triple-punch combinations were higher in winners than losers, although they did not contribute to the variance in landed punches as classified by punches landed. However, triple-punch combinations did explain the highest percentage of the variance in landed punches as classified by the judges' decision, suggesting that triple-punch combinations have the highest probability of being counted by judges as landed punches regardless of whether they do actually land. It was surprising that this resulted in approximately 1 in 5 bouts being judged incorrectly compared with actual punches landed. There was no evidence of a bias in scoring for the boxer competing at home (home advantage), as often both boxers were away from home.

The number of punches to the head was more than 5 times higher than punches to the body (Table 2). It is acknowledged among amateur boxing coaches that although the front of the abdomen is within the target area, it is often not counted as a landed punch by judges. The reason for this is not clear. It would be reasonable to suggest that the judges' lack of scoring landed body punches places a bias toward head punches in training and competition strategy. This is more surprising when considering that body punches were more accurate than their head equivalent for 6 of the punch types (Table 6).

Winners had more lead-hand combinations in round 1; more body-head, double-punch, and four-or-more-punch combinations in rounds 1 and 3; more triple-punch combinations in rounds 1 and 2; and more total combinations and block and counterpunch combinations over all 3 rounds than losers, which highlighted the importance of throwing punches in combinations (Table 4).

Punches per minute in the current study (~22) were approximately 40% less than the previously reported 38 and 37 in Commonwealth-level boxers.[2,3] This is in addition to winners throwing more punches than losers in the current study from round 2 on, indicating the need to impose dominance via a high work rate to be successful. Furthermore, the lower punches-thrown to punches-landed ratio in winners in round 1 shows that this high punch rate was not to the detriment of precision and highlights the importance of punch accuracy (Table 1). This higher work rate does not appear to reflect a difference in attacking actions, per se, but seems to result from the difference in punching combinations between winners and losers (Table 4). Lead-hand combinations with a rear-hand straight or hook punch explained 62% of the variance of punches landed in winners, emphasizing further the importance of punching combinations.

The total number of defensive movements (Table 5) showed no difference between winners and losers. However, the block and counterattack data (Table 4) suggest that to win, a boxer must use defensive movement to initiate a counterattack. With respect to defensive movements, it needs to be noted that they were hard to categorize accurately; it is hard to tell if a movement made by a defending boxer is a deliberate defensive action to a punch thrown or whether it is coincidental. Second, defensive movements can be subtle and therefore hard to see, especially during in-close boxing.

Data on activity-to-break ratios in combat sports are limited. Data collected in karate kumite—which also combines frequent forward, backward, sidesteps, and vertical hip movements, with attacking and defensive actions, but without breaks between rounds—had an activity-to-break ratio of 2:1.[10] Furthermore, a study in match analysis of taekwondo, which is a combat sport with movements of attack made only with the feet, reported an activity-to-break ratio of 1:1.[11] The current study has an activity-to-break ratio of 9:1 not including breaks between rounds. This ratio still remains approximately 50% higher than that of karate if the breaks between boxing rounds are included and highlights how much higher the activity rate in boxing is than in other combat sports. Furthermore, this may support the assumption that this high activity-to-break ratio results in fatigue, as exhibited by an increase in total stop time and frequency and a decrease in time before first stop and vertical hip movement with round number (Table 3). This effect seems to be more prominent in losers, as their activity rate was lower in round 2 (Table 3) and they had fewer total punches in rounds 2 and 3 than winners (Table 2). However, specific components of the boxers' physical fitness could not be assessed in the current study. Therefore, it remains unclear to what extent the lower work rate in losers during rounds 2 and 3 reflects technical or tactical differences, a lower level of fitness, or higher fatigue as a result of being punched and throwing more air punches (Table 2).

With regard to previous studies that have touched on the physiological response, results suggest that blood [La] increases as bout duration falls, with values of 8.6, 9.5, and 13.5 mmol/L for bout durations of 10, 9, and 8 minutes, respectively.[3] Peak postbout blood [La] of 11.8 mmol/L in the current 6-minute bout does not appear to follow this trend. However, Smith[3] reported a nearly 40% higher punch rate, making comparisons difficult. Examination of the blood [La] with respect to time, assuming a resting blood lactate of ~1 mmol/L, reveals a higher production of lactate of ~1.8 mmol $\cdot$ L^{-1} $\cdot$ min^{-1} in this study compared with 0.8, 0.9, and 1.6 mmol $\cdot$ L^{-1} $\cdot$ min^{-1} for the 10, 9, and 8-minute bouts. This seemingly higher rate of lactate production is despite a lower punch rate and may reflect a lower aerobic-fitness level in novice as compared with Commonwealth-level boxers. Therefore, the physiological response, unsurprisingly, may depend on bout duration and fitness level.

Conclusion and Practical Consequences

The current study is the first to provide an activity profile of amateur boxing, linked with parameters of physiological stress over the 3 × 2-minute format. The results indicate that for boxers to land punches they must be able to maintain a high frequency of attacking movements, specifically the lead-hand straight punch to the head, together with punching combinations. Defensive movements should be used not only to stop the opponent from landing a punch but also to initiate a counterattack. However, regardless of punches landed, triple-punch combinations appear to have the highest probability of being scored by judges, suggesting that landing punches may not be the only way to win. Post-bout blood [La] suggest that boxers must able to tolerate a lactate production rate of ~1.8 mmol · L^{-1} · min^{-1} and to maintain skillful techniques at a sufficient activity rate.

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