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Intra-Rater and Test–Retest Reliability of Barbell Force, Velocity, and Power during the Landmine Punch Throw Test Assessed by the GymAware Linear Transducer System

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Abstract: Background: Velocity-based training (VBT) requires measurement of the velocity at which the barbell is moved in the concentric phase with regard to different resistance exercises, which provides accurate, indirect estimations of 1 RM. However, for assessing punch performance, no study has been carried out to date. The purpose of this study was to analyse the reliability of the GymAware linear transducer for the measurement of barbell velocity during the landmine push throw (LPT) test using four loads. Methods: Twenty-five healthy, physically active male students, aged 24.13 ± 2.82 years, volunteered to take part in this study. The reliability of the LPT test was measured at two separate visits, with a 2-day interval between them. One series of the test protocol included four parts of the LPT test with progressively increasing loads (20, 25, 30, and 35 kg) and 5 min intervals for rests between loads. Results: For all four loads, excellent intra-rater and test–retest reliability was noted for the mean force variable (ICC = 0.97–0.99). Additionally, very strong and significant correlations were established between measurements (r = 0.96–0.99). Poor reliability was observed for barbell height and total work (ICC below 0.5). A trend of decreasing reliability was detected with increasing barbell load. Furthermore, measurements without the barbell throw were more reliable than those with it. Conclusions: These results support the use of the GymAware linear transducer to track barbell velocity during the LPT test. This device may have valuable practical applications for strength and conditioning coaches. Therefore, we suggest that the LPT assessed with the GymAware linear transducer may be a useful method for evaluating upper limb strength and power during boxing punches.

Keywords: reliability; GymAware linear transducer; landmine punch throw test; sport; training; punch strength

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1. Introduction

Training intensity is considered a fundamental variable for the design of resistance training programmes [1–3]. The one-repetition maximum has been the most widely used method for quantifying training intensity [4,5]. However, the main drawback of this approach is that it requires the performance of a maximal lift [3] or a number of repetitions with submaximal loads to failure [6,7]. Recently, many authors, based on the force–velocity relationship [8], have recommended the use of velocity feedback to quantify training loads [1,9,10]. This approach is based on a previously reported high correlation ($R_2 > 0.97$) between the load and the mean velocity at which each load is lifted [10–12]. Velocity-based training (VBT) requires measurement of the velocity at which the barbell is moved in the concentric phase with regard to different resistance exercises, which provide accurate, indirect estimations of the 1 RM without the need to perform a maximal lift [7,13,14]. It has been reported that barbell velocity during the bench press, back squat, and bench pull are highly correlated with training intensity in terms of %1RM [15–18]. It has been further underlined that controlling barbell velocity is a good way to monitor resistance training intensities [19,20].

The ability to punch with high-impact force is important for many athletes. In the case of boxers, maximal and explosive strength of the upper body are strongly related to punch impact force [21]. Due to the close similarity to punching movement patterns, some authors have reported the use of the landmine punch throw (LPT) test to assess the speed–strength component of punching [22]. During this test, an athlete pushes and throws one end of the barbell at an approximately 60° angle from the floor while the other end of the barbell is inserted into a landmine attachment on the floor [22,23].

However, there is no gold standard for assessing punch performance. A variety of assessment devices and protocols have been applied, such as pressure sensors, motion capture systems, accelerometers, force transducers, and force platforms [24–26]. Linear position transducers (LPTs) are often used for measuring velocity in resistance exercises through a vertical displacement of a cable that is attached to the barbell [27,28]. In some studies, it has been reported that LPTs seem to be the most reliable and valid tool [7,21,29,30]. Recently, the GymAware linear transducer (GYM; Kinetic Performance Technologies, Canberra, Australia) has become increasingly popular in the monitoring of resistance training and optimisation of training prescriptions [31–33]. Fernandes et al. [33] reported that it appears to be the most valid; nonetheless, its reliability was evaluated only for deadlifts and squats, but there are no studies in which it would have been assessed for upper body movement [17,18].

We hypothesised that the GymAware linear transducer may be similarly reliable when measuring barbell velocity for upper body movement during the landmine push throw test. Therefore, the purpose of this study was to analyse the reliability of the GymAware linear transducer for the measurement of barbell velocity during the landmine push throw test applying four loads.

2. Materials and Methods

2.1. Participants

Twenty-five healthy, physically active male students, aged 24.13 ± 2.82 years, with a body mass of 75.2 ± 7.4 kg and body height of 175 ± 4 cm, volunteered in this study. They all met the inclusion criteria: age between 18–30 years; not having any pain, injury, and/or disease in the upper limbs 1 year before the study; not having any systematic disease; performing sports at a recreational level for a minimum 1 h, 3 times a week and no competitive history in combat sports. The participants were recruited through advertising on university social media. They were familiarised with all measurement procedures. The familiarisation was performed after the warm-up before the tests. The subject was allowed to practice the test technique with the lower load (20 kg) using the right and left hand. After the practice trial, 15 min rest was required. Then, the test trials were performed.

The study participants were informed in detail about the research protocol. They provided their written informed consent to participate in the study. Approval of the Ethical Committee at the Regional Medical Chamber in Kraków was obtained for this study (13/KBL/OIL/2021). All procedures were performed in accordance with the 1964 Declaration of Helsinki and its later amendments.

2.2. Study Design

The trials were carried out in the morning hours at normal room temperature (22–23 °C). All the measurements were performed in the laboratory by the same rater, who was trained and had good experience with the equipment as well as the test protocol. The participants were asked to avoid vigorous physical activity during the time between both visits. Body mass (kg) and height (cm) were measured prior to testing. Body height was measured via a stadiometer (Metrisis, Thessaloniki, Greece). Body mass was determined with an octopolar analyser (Tanita MC 780 MA, Tokyo, Japan)

The reliability of the LPT test was measured on 2 separate visits with a 2-day interval between them. One series of the test protocol included 4 parts of the LPT test with progressively increasing loads (20, 25, 30, and 35 kg) with a 5 min rest between loads. For each load and for each of the 4 series of the test protocol, the subject performed 2 repetitions. For each repetition, subjects performed the concentric component in an explosive manner, with the aim of trying to produce maximum velocity.

2.2.1. Test Protocol

1. Measurement of right-hand punch with right leg behind without throwing the barbell (no throw—NT): 2 repetitions with each load and 5 min interval for rest between loads.
2. Measurement of right-hand punch with right leg behind with throwing the barbell (throw—T): 2 repetitions with each load and 5 min interval for rest between loads.
3. Measurement of left-hand punch with left leg behind without throwing the barbell(no throw—NT): 2 repetitions with each load and 5 min interval for rest between loads.
4. Measurement of left-hand punch with left leg behind with throwing the barbell (throw—T): 2 repetitions with each load and 5 min interval for rest between loads.

Visit 1: For intra-rater reliability, 2 series of the LPT test protocol were performed with 30 min dedicated to rest between them.

Visit 2: For test–retest reliability, 1 series of LPT test protocol was performed 2 days later. The reliability was calculated between the 1st measurement from Visit 1 and the measurement from Visit 2.

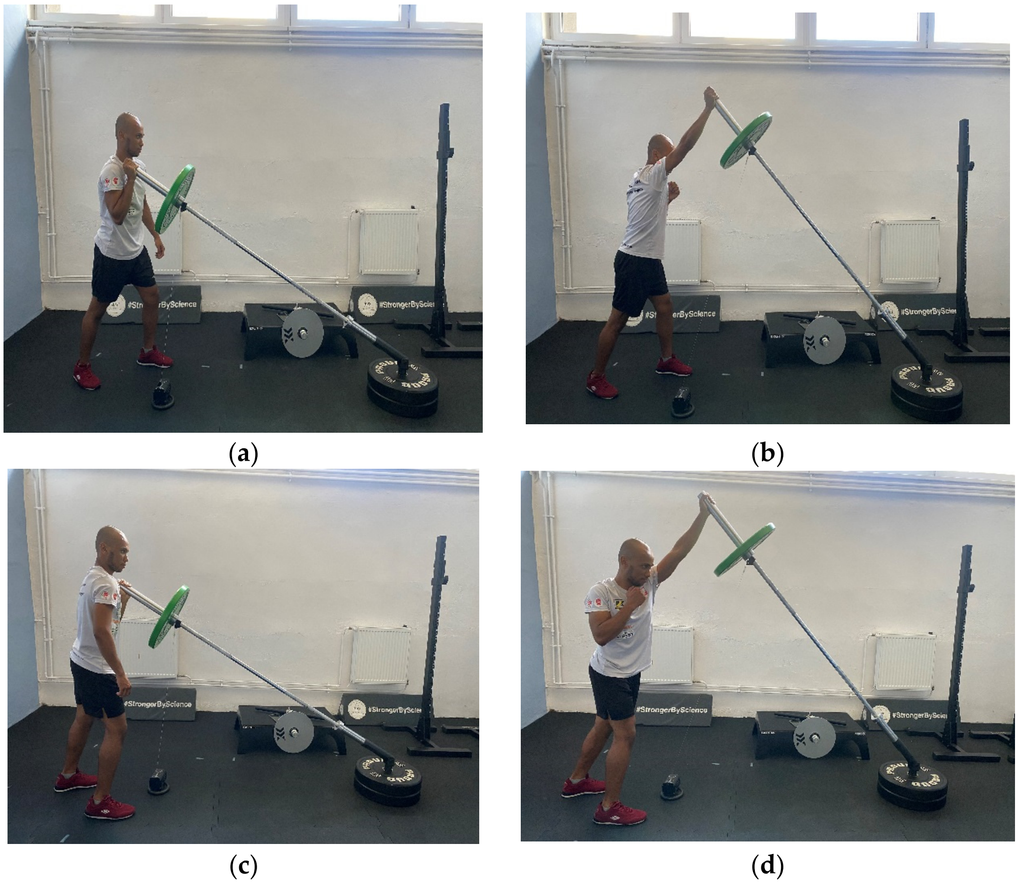
2.2.2. Landmine Punch Throw Test

The LPT test was used to assess the ability to produce high velocity in a movement pattern similar to a rear-hand punch. A barbell was inserted into a landmine attachment, which positioned the bar at angles between 40–60 degrees, depending on the subject's height. Subjects were instructed to produce a maximal effort in order to throw the bar as fast as possible [34] (Figure 1).

Barbell velocity during the LPT test was collected at 50 Hz via the GymAware linear position transducer (Kinetic Performance Technology, Canberra, Australia) attached to the throwing end of the barbell. GymAware was previously reported as a valid and reliable method of position encoding [35,36]. The following outcomes were measured during the concentric phase of the test: height (m), mean force (N), mean power (W), mean power (W/kg), mean velocity (m/s), peak force (N), peak power (W), peak power (W/kg), peak velocity (m/s), and total work (kJ).

2.2.3. Statistical Analysis

Statistical analysis was carried out using STATISTICA 13.0 software. Data distribution, evaluated via the Shapiro–Wilk test, was normal. The intra-rater and test–retest reliability of the variables were determined using the Intraclass Correlation Coefficients ICC (2.1) model according to Shrout and Fleiss [37]. The interpretation of the ICC agreement was performed according to Koo et al. [38]: below 0.50: poor; between 0.50 and 0.75: moderate; between 0.75 and 0.90: good; above 0.90: excellent. Variability within each data set was described using means and standard deviation (SD), coefficients of variation (CV), and standard error of measurement (SEM). Pearson's correlation coefficient (r) was calculated between measurements. The level of statistical significance was set at ($p < 0.05$). The minimal sample calculation was based on Bujang and Baharum's proposal [39]. Power analysis indicated that at least 22 subjects were required to obtain a power of 0.8 at an alpha level = 0.05 with an effect size of d = 0.8 and a minimum ICC of 0.50 [17,18,33].



(**a**) (**b**) (**c**) (**d**)

Figure 1. Study setup and location of the GymAware transducer on the barbell. (**a**) start position for the right hand; (**b**) end position for the right hand; (**c**) start position for the left hand; (**d**) end position for the left hand.

3. Results

3.1. Intra-Rater Reliability

For all four loads on both left and right sides, the highest (excellent) reliability was noted for the mean force variable (ICC = 0.97–0.99). Additionally, very strong and significant correlations were observed between measurements (r = 0.96–0.99). The lowest (poor) reliability was exhibited for barbell height and total work (ICC below 0.5). Furthermore, Pearson's correlation for those variables was weak to moderate and non-significant. The mean and peak force, power and velocity demonstrated good to excellent reliability. Higher reliability (ICC good to excellent, stronger, and significant correlations) was observed for measurements with a load of 20 and 25 kg compared to measurements with a load of 30 and 35 kg. For higher loads, more variables demonstrated moderate ICC and low as well as non-significant correlations. Additionally, better reliability was established for measurements without the barbell throw (NT) than those performed with a throw (T). The CV and SEM were relatively low, indicating good data consistency (Tables 1–4).

3.2. Test–Retest Reliability

The level of test–retest reliability was similar to intra-rater reliability. The trend of decreasing reliability was observed with increasing barbell load. Additionally, measurements without the barbell throw were more reliable than those with its performance. The CV and SEM were relatively low, indicating good data consistency (Tables 5–8).

Table 1. Intra-rater reliability of landmine punch throw test with 20 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
			1st			2nd				
Height (m)	NT	R	0.44 ± 0.06	0.01	13	0.43 ± 0.06	0.01	15.7	0.82	0.83 *
		L	0.43 ± 0.06	0.01	14	0.42 ± 0.06	0.01	14	0.88	0.80 *
Mean Force (N)		R	149 ± 110	19	73	129 ± 117	23	90	0.99	0.99 *
		L	145 ± 107	18	73	134 ± 118	23	87	0.99	0.99 *
Mean Power (W)		R	413 ± 131	23	31	429 ± 120	24	28	0.77	0.75 *
		L	374 ± 109	19	29	404 ± 115	22	28	0.87	0.77 *
Mean Power (W/kg)		R	5.39 ± 1.26	0.22	23	5.37 ± 1.24	0.24	23	0.64	0.68 *
		L	4.88 ± 1.04	0.18	21	5.08 ± 1.23	0.24	24	0.87	0.68 *
Mean Velocity (m/s)		R	1.44 ± 0.2	0.04	15	1.46 ± 0.24	0.04	16	0.73	0.62 *
		L	1.28 ± 0.26	0.04	18	1.31 ± 0.30	0.05	17	0.90	0.82 *
Peak Force (N)		R	500 ± 91	16	18	542 ± 101	20	18	0.87	0.79 *
		L	544 ± 147	26	27	573 ± 132	23	25	0.73	0.57 *
Peak Power (W)		R	774 ± 237	41	30	824 ± 175	34	21	0.67	0.57 *
		L	747 ± 245	43	32	817 ± 162	35	22	0.68	0.52 *
Peak Power (W/kg)		R	10.1 ± 2.4	0.42	23	10.3 ± 1.8	0.37	18	0.53	0.36
		L	9.75 ± 2.63	0.46	27	10.2 ± 2.1	0.38	19	0.61	0.43
Peak Velocity (m/s)		R	2.23 ± 0.35	0.06	16	2.30 ± 0.31	0.06	15	0.70	0.66 *
		L	2.01 ± 0.36	0.06	18	2.04 ± 0.39	0.07	19	0.92	0.86 *
Total Work (kJ)		R	0.18 ± 0.03	0.00	20	0.17 ± 0.04	0.00	22	0.77	0.88 *
		L	0.22 ± 0.08	0.01	31	0.19 ± 0.06	0.01	24	0.50	0.35
Height (m)	T	R	0.54 ± 0.08	0.01	15	0.57 ± 0.08	0.01	14	0.48	0.77 *
		L	0.56 ± 0.07	0.02	13	0.58 ± 0.12	0.02	16	0.79	0.72 *
Mean Force (N)		R	132 ± 97	17	73	122 ± 106	21	87	0.97	0.99 *
		L	126 ± 96	17	70	117 ± 103	20	87	0.98	0.99 *
Mean Power (W)		R	328 ± 104	18	31	376 ± 129	26	34	0.53	0.55 *
		L	321 ± 96	17	30	340 ± 86	17	26	0.90	0.82 *
Mean Power (W/kg)		R	4.32 ± 1.19	0.21	27	4.73 ± 1.49	0.30	31	0.69	0.53 *
		L	4.22 ± 1.07	0.19	25	4.30 ± 1.00	0.19	23	0.89	0.81 *
Mean Velocity (m/s)		R	1.32 ± 0.21	0.03	16	1.42 ± 0.28	0.05	19	0.61	0.46 *
		L	1.21 ± 0.28	0.05	23	1.28 ± 0.29	0.06	21	0.93	0.87 *
Peak Force (N)		R	515 ± 85	15	16	553 ± 84	17	15	0.79	0.65 *
		L	543 ± 102	18	23	571 ± 119	23	20	0.69	0.53 *
Peak Power (W)		R	880 ± 258	45	25	982 ± 302	61	30	0.74	0.59 *
		L	850 ± 297	53	35	910 ± 294	67	32	0.76	0.61 *
Peak Power (W/kg)		R	11.5 ± 2.85	0.50	24	12.3 ± 3.45	0.70	27	0.69	0.52 *
		L	11.1 ± 3.67	0.71	31	11.4 ± 3.39	0.64	26	0.75	0.48
Peak Velocity (m/s)		R	2.41 ± 0.38	0.06	16	2.54 ± 0.44	0.09	17	0.73	0.57 *
		L	2.20 ± 0.45	0.08	20	2.26 ± 0.49	0.09	21	0.92	0.77 *
Total Work (kJ)		R	0.16 ± 0.05	0.01	35	0.19 ± 0.06	0.01	34	0.55	0.40
		L	0.20 ± 0.11	0.01	41	0.23 ± 0.09	0.01	39	0.57	0.41 *

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 2. Intra-rater reliability of landmine punch throw test with 25 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
			1st			2nd				
Height (m)	NT	R	0.41 ± 0.10	0.01	17	0.42 ± 0.06	0.01	15	0.86	0.76 *
		L	0.42 ± 0.07	0.01	18	0.42 ± 0.08	0.01	20	0.77	0.63 *
Mean Force (N)		R	177 ± 131	23	73	156 ± 137	26	87	0.99	0.99 *
		L	173 ± 128	22	73	156 ± 136	26	87	0.99	0.99 *
Mean Power (W)		R	370 ± 107	18	28	385 ± 97	19	25	0.84	0.72 *
		L	327 ± 98	17	30	346 ± 84	16	24	0.88	0.78 *
Mean Power (W/kg)		R	4.85 ± 1.12	0.19	23	4.85 ± 0.99	0.19	20	0.76	0.62 *
		L	4.25 ± 0.84	0.14	19	4.32 ± 0.73	0.14	17	0.73	0.57 *
Mean Velocity (m/s)		R	1.27 ± 0.27	0.04	21	1.31 ± 0.27	0.05	20	0.88	0.79 *
		L	1.17 ± 0.20	0.03	19	1.21 ± 0.19	0.03	17	0.87	0.77 *
Peak Force (N)		R	521 ± 88	15	17	536 ± 90	17	16	0.79	0.66 *
		L	573 ± 110	25	21	600 ± 119	23	19	0.78	0.68 *
Peak Power (W)		R	692 ± 190	33	27	750 ± 183	36	24	0.83	0.71 *
		L	687 ± 187	36	27	717 ± 195	39	29	0.77	0.62 *
Peak Power (W/kg)		R	9.05 ± 1.99	0.35	21	9.43 ± 1.82	0.35	19	0.77	0.62 *
		L	8.85 ± 1.67	0.30	18	8.96 ± 1.45	0.29	17	0.84	0.78 *
Peak Velocity (m/s)		R	1.93 ± 0.42	0.07	22	2.03 ± 0.39	0.07	19	0.90	0.82 *
		L	1.88 ± 0.21	0.04	19	1.96 ± 0.29	0.05	18	0.85	0.75 *
Total Work (kJ)		R	0.24 ± 0.04	0.00	23	0.20 ± 0.04	0.00	24	0.85	0.74 *
		L	0.20 ± 0.03	0.01	24	0.22 ± 0.06	0.01	25	0.83	0.70 *
Height (m)	T	R	0.55 ± 0.08	0.01	16	0.57 ± 0.09	0.01	15	0.77	0.62 *
		L	0.53 ± 0.07	0.01	14	0.58 ± 0.10	0.02	18	0.77	0.82 *
Mean Force (N)		R	161 ± 119	21	73	144 ± 125	24	87	0.99	0.99 *
		L	142 ± 120	23	87	139 ± 126	25	90	0.97	0.98 *
Mean Power (W)		R	317 ± 89	19	34	325 ± 80	15	24	0.79	0.68 *
		L	290 ± 66	11	22	321 ± 75	15	23	0.73	0.57 *
Mean Power (W/kg)		R	4.15 ± 1.18	0.20	28	4.11 ± 0.80	0.15	19	0.72	0.58 *
		L	3.78 ± 0.68	0.12	19	4.02 ± 0.69	0.13	17	0.75	0.67 *
Mean Velocity (m/s)		R	1.18 ± 0.29	0.05	25	1.26 ± 0.24	0.04	19	0.82	0.69 *
		L	1.22 ± 0.19	0.04	18	1.23 ± 0.20	0.04	17	0.91	0.85 *
Peak Force (N)		R	526 ± 95	16	18	560 ± 78	15	14	0.82	0.68 *
		L	590 ± 88	21	20	540 ± 75	14	18	0.78	0.69 *
Peak Power (W)		R	832 ± 214	42	28	886 ± 224	43	25	0.86	0.76 *
		L	821 ± 230	43	27	798 ± 242	48	30	0.69	0.62 *
Peak Power (W/kg)		R	10.9 ± 2.67	0.49	24	11.2 ± 2.35	0.46	20	0.77	0.63 *
		L	10.5 ± 2.85	0.51	25	10.9 ± 2.62	0.42	21	0.77	0.67 *
Peak Velocity (m/s)		R	2.12 ± 0.51	0.09	21	2.26 ± 0.41	0.08	18	0.90	0.81 *
		L	1.88 ± 0.36	0.06	19	1.78 ± 0.37	0.07	21	0.81	0.78 *
Total Work (kJ)		R	0.20 ± 0.10	0.01	44	0.24 ± 0.09	0.01	37	0.83	0.74 *
		L	0.23 ± 0.09	0.01	39	0.26 ± 0.12	0.04	42	0.63	0.46 *

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 3. Intra-rater reliability of landmine punch throw test with 30 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
				1st			2nd			
Height (m)	NT	R	0.51 ± 0.07	0.01	24	0.40 ± 0.09	0.01	23	0.48	0.32
		L	0.48 ± 0.12	0.02	39	0.38 ± 0.13	0.02	35	0.40	0.33
Mean Force (N)		R	182 ± 159	31	87	161 ± 159	31	87	0.99	0.99 *
		L	180 ± 157	30	87	181 ± 158	31	87	0.96	0.98 *
Mean Power (W)		R	399 ± 110	23	27	370 ± 102	20	27	0.95	0.86 *
		L	337 ± 75	14	22	334 ± 75	14	26	0.92	0.85 *
Mean Power (W/kg)		R	5.05 ± 0.87	0.21	20	4.65 ± 0.94	0.18	20	0.85	0.72 *
		L	4.23 ± 0.62	0.12	14	4.21 ± 0.70	0.13	21	0.82	0.69 *
Mean Velocity (m/s)		R	1.14 ± 0.22	0.04	19	1.14 ± 0.23	0.04	20	0.89	0.75 *
		L	1.20 ± 0.22	0.04	18	1.12 ± 0.21	0.04	20	0.88	0.79 *
Peak Force (N)		R	603 ± 90	24	21	567 ± 89	17	15	0.77	0.66 *
		L	608 ± 101	19	22	602 ± 91	18	17	073	0.67 *
Peak Power (W)		R	721 ± 209	36	25	712 ± 202	39	28	0.82	0.67 *
		L	666 ± 120	24	33	729 ± 144	29	30	0.79	0.70 *
Peak Power (W/kg)		R	9.61 ± 1.77	0.39	23	8.93 ± 1.96	0.38	21	0.80	0.76 *
		L	8.31 ± 1.73	0.33	20	8.61 ± 1.44	0.35	21	0.78	0.73 *
Peak Velocity (m/s)		R	1.80 ± 0.36	0.07	23	1.76 ± 0.36	0.07	20	0.81	0.68 *
		L	1.61 ± 0.23	0.06	17	1.68 ± 0.29	0.06	17	0.91	0.84 *
Total Work (kJ)		R	0.27 ± 0.10	0.01	35	0.23 ± 0.06	0.01	27	0.61	0.55 *
		L	0.25 ± 0.05	0.01	21	0.28 ± 0.07	0.01	27	0.60	0.55 *
Height (m)	T	R	0.54 ± 0.11	0.02	22	0.55 ± 0.08	0.01	15	0.61	0.43 *
		L	0.54 ± 0.08	0.01	19	0.52 ± 0.07	0.02	16	0.79	0.69 *
Mean Force (N)		R	178 ± 148	29	83	172 ± 150	29	87	0.99	0.99 *
		L	171 ± 149	30	81	166 ± 150	30	80	0.96	0.97 *
Mean Power (W)		R	307 ± 71	15	23	312 ± 72	14	23	0.88	0.79 *
		L	297 ± 53	10	17	299 ± 64	12	20	0.89	0.80 *
Mean Power (W/kg)		R	3.90 ± 0.76	0.15	21	3.95 ± 0.75	0.14	19	0.82	0.68 *
		L	3.74 ± 0.49	0.09	13	3.85 ± 0.67	0.11	15	0.84	0.73 *
Mean Velocity (m/s)		R	1.04 ± 0.19	0.03	19	1.07 ± 0.20	0.04	19	0.86	0.75 *
		L	0.92 ± 0.16	0.03	16	0.99 ± 0.16	0.03	18	0.91	0.84 *
Peak Force (N)		R	569 ± 68	13	12	588 ± 92	18	15	0.77	0.74 *
		L	641 ± 104	25	23	598 ± 99	22	18	0.71	0.71 *
Peak Power (W)		R	808 ± 225	47	30	843 ± 226	44	27	0.75	0.79 *
		L	825 ± 176	30	22	891 ± 184	34	25	0.84	0.78 *
Peak Power (W/kg)		R	10.23 ± 2.54	0.51	24	10.63 ± 2.50	0.49	23	0.82	0.69 *
		L	10.05 ± 2.21	0.47	26	8.72 ± 1.81	0.32	27	0.68	0.59 *
Peak Velocity (m/s)		R	1.92 ± 0.38	0.07	20	1.97 ± 0.36	0.07	18	0.90	0.83 *
		L	1.70 ± 0.30	0.06	18	1.89 ± 0.31	0.06	19	0.81	0.73 *
Total Work (kJ)		R	0.25 ± 0.17	0.02	41	0.28 ± 0.10	0.01	38	0.62	0.44
		L	0.22 ± 0.12	0.02	31	0.29 ± 0.16	0.02	41	0.39	0.57 *

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 4. Intra-rater reliability of landmine punch throw test with 35 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
			1st			2nd				
Height (m)	NT	R	0.46 ± 0.10	0.02	22	0.41 ± 0.06	0.01	16	0.58	0.59 *
		L	0.40 ± 0.05	0.01	14	0.46 ± 0.06	0.01	17	0.57	0.61 *
Mean Force (N)		R	211 ± 184	36	87	210 ± 183	38	87	0.99	0.99 *
		L	205 ± 179	35	83	203 ± 180	36	86	0.98	0.99 *
Mean Power (W)		R	368 ± 133	26	36	359 ± 124	24	34	0.80	0.73 *
		L	331 ± 102	20	30	345 ± 123	23	34	0.80	0.74 *
Mean Power (W/kg)		R	4.63 ± 1.56	0.37	41	4.58 ± 1.67	0.32	38	0.72	0.65 *
		L	4.12 ± 1.22	0.23	30	4.44 ± 1.55	0.30	32	0.75	0.73 *
Mean Velocity (m/s)		R	1.10 ± 0.26	0.06	24	1.06 ± 0.27	0.05	25	0.74	0.58 *
		L	1.04 ± 0.20	0.04	22	1.03 ± 0.19	0.03	21	0.87	0.79 *
Peak Force (N)		R	613 ± 137	26	22	598 ± 107	21	17	0.71	0.66 *
		L	658 ± 112	25	20	615 ± 100	20	16	0.72	0.78 *
Peak Power (W)		R	696 ± 241	47	34	882 ± 255	50	37	0.75	0.69 *
		L	678 ± 231	44	31	860 ± 224	45	34	0.77	0.80 *
Peak Power (W/kg)		R	8.76 ± 2.87	0.56	32	8.61 ± 3.35	0.65	38	0.76	0.68 *
		L	8.19 ± 2.87	0.55	30	8.42 ± 3.20	0.57	36	0.76	0.65 *
Peak Velocity (m/s)		R	1.63 ± 0.40	0.07	24	1.61 ± 0.42	0.08	26	0.80	0.66 *
		L	1.33 ± 030	0.06	21	1.62 ± 0.34	0.07	22	0.78	0.73 *
Total Work (kJ)		R	0.27 ± 0.11	0.02	41	0.25 ± 0.08	0.01	34	0.53	0.48
		L	0.28 ± 0.05	0.01	26	0.27 ± 0.08	0.01	31	0.47	0.33
Height (m)	T	R	0.55 ± 0.09	0.01	23	0.53 ± 0.16	0.02	19	0.61	0.43
		L	0.53 ± 0.07	0.01	19	0.46 ± 0.09	0.02	20	0.75	0.60 *
Mean Force (N)		R	199 ± 176	33	87	199 ± 174	34	87	0.99	0.99 *
		L	207 ± 172	34	83	208 ± 180	36	86	0.98	0.98 *
Mean Power (W)		R	291 ± 45	8	15	302 ± 67	13	22	0.73	0.62 *
		L	297 ± 50	11	17	310 ± 59	12	19	0.82	0.73 *
Mean Power (W/kg)		R	3.68 ± 0.41	0.08	11	3.84 ± 0.98	0.18	24	0.74	0.63 *
		L	3.57 ± 0.46	0.09	12	3.94 ± 0.98	0.17	26	0.69	0.54 *
Mean Velocity (m/s)		R	0.96 ± 0.20	0.03	21	0.98 ± 0.23	0.04	24	0.81	0.75 *
		L	0.82 ± 0.11	0.02	14	0.94 ± 0.17	0.03	18	0.82	0.76 *
Peak Force (N)		R	587 ± 68	13	11	586 ± 104	20	17	0.76	0.67 *
		L	606 ± 84	16	13	615 ± 100	20	16	0.77	0.78 *
Peak Power (W)		R	717 ± 157	30	21	742 ± 228	44	30	0.76	0.65 *
		L	654 ± 206	41	31	680 ± 221	45	32	0.78	0.70 *
Peak Power (W/kg)		R	9.06 ± 1.76	0.34	19	9.42 ± 3.01	0.59	32	0.69	0.60 *
		L	8.16 ± 2.01	0.46	22	8.44 ± 1.89	0.49	23	0.78	0.66 *
Peak Velocity (m/s)		R	1.72 ± 0.37	0.07	21	1.75 ± 0.41	0.08	23	0.81	0.85 *
		L	1.62 ± 0.23	0.06	21	1.52 ± 0.34	0.06	22	0.83	0.74 *
Total Work (kJ)		R	0.26 ± 0.11	0.02	45	0.27 ± 0.10	0.02	38	0.61	0.56 *
		L	0.31 ± 0.11	0.02	38	0.27 ± 0.08	0.01	32	0.68	0.51 *

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 5. Test–retest reliability of landmine punch throw test with 20 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
				1st			2nd			
Height (m)	NT	R	0.44 ± 0.06	0.01	13	0.46 ± 0.07	0.01	15	0.56	0.56 *
		L	0.43 ± 0.06	0.01	14	0.40 ± 0.12	0.02	30	0.38	0.32 *
Mean Force (N)		R	149 ± 110	19	73	139 ± 109	19	73	0.97	0.97 *
		L	145 ± 107	18	73	147 ± 101	18	73	0.99	0.99 *
Mean Power (W)		R	413 ± 131	23	31	418 ± 124	22	30	0.94	0.85 *
		L	374 ± 109	19	29	369 ± 104	21	31	0.81	0.75 *
Mean Power (W/kg)		R	5.39 ± 1.26	0.22	23	5.44 ± 1.30	0.29	24	0.87	0.76 *
		L	4.88 ± 1.04	0.18	21	4.84 ± 1.10	0.25	22	0.86	0.65 *
Mean Velocity (m/s)		R	1.44 ± 0.21	0.04	15	1.41 ± 0.29	0.04	16	0.85	0.79 *
		L	1.28 ± 0.26	0.04	18	1.19 ± 0.23	0.05	20	0.77	0.63 *
Peak Force (N)		R	500 ± 91	16	18	503 ± 92	16	18	0.91	0.86 *
		L	544 ± 147	26	27	543 ± 150	27	27	0.92	0.86 *
Peak Power (W)		R	774 ± 237	41	30	760 ± 220	36	30	0.84	0.68 *
		L	747 ± 245	43	32	723 ± 225	41	30	0.84	0.73 *
Peak Power (W/kg)		R	10.1 ± 2.41	0.42	23	10.3 ± 3.39	0.51	31	0.73	0.64 *
		L	9.75 ± 2.63	0.46	27	8.84 ± 2.33	0.53	26	0.75	0.59
Peak Velocity (m/s)		R	2.23 ± 0.35	0.06	16	2.28 ± 0.50	0.09	18	0.89	0.76 *
		L	2.01 ± 0.36	0.06	18	1.81 ± 0.35	0.08	19	0.76	0.66 *
Total Work (kJ)		R	0.18 ± 0.03	0.00	20	0.20 ± 0.04	0.02	31	0.68	0.73 *
		L	0.22 ± 0.08	0.01	31	0.19 ± 0.09	0.02	40	0.55	0.38
Height (m)	T	R	0.54 ± 0.08	0.01	15	0.62 ± 0.11	0.02	21	0.55	0.73 *
		L	0.56 ± 0.07	0.02	13	0.50 ± 0.07	0.03	22	0.59	0.69 *
Mean Force (N)		R	132 ± 97	17	73	131 ± 94	16	73	0.99	0.99 *
		L	126 ± 96	17	70	130 ± 95	18	70	0.97	0.93 *
Mean Power (W)		R	328 ± 104	18	31	320 ± 120	21	33	0.76	0.65 *
		L	321 ± 96	17	30	297 ± 99	19	31	0.87	0.81 *
Mean Power (W/kg)		R	4.32 ± 1.19	0.21	27	4.28 ± 1.23	0.25	30	0.74	0.52
		L	4.22 ± 1.07	0.19	25	3.89 ± 1.03	0.23	27	0.75	0.55 *
Mean Velocity (m/s)		R	1.32 ± 0.21	0.03	16	1.35 ± 0.23	0.03	18	0.80	0.72 *
		L	1.21 ± 0.28	0.05	23	1.15 ± 0.25	0.05	23	0.88	0.79 *
Peak Force (N)		R	515 ± 85	15	16	525 ± 101	20	21	0.77	0.66 *
		L	543 ± 102	18	23	520 ± 106	21	26	0.78	0.72 *
Peak Power (W)		R	880 ± 258	45	25	896 ± 230	40	21	0.82	0.61 *
		L	850 ± 297	53	35	812 ± 260	46	31	0.84	0.74 *
Peak Power (W/kg)		R	11.5 ± 2.85	0.50	24	11.9 ± 3.11	0.56	30	0.71	0.68 *
		L	11.1 ± 3.67	0.71	31	9.80 ± 2.46	0.56	25	0.72	0.68 *
Peak Velocity (m/s)		R	2.41 ± 0.38	0.06	16	2.36 ± 0.43	0.07	20	0.76	0.65 *
		L	2.20 ± 0.45	0.08	20	2.07 ± 0.40	0.08	19	0.92	0.77 *
Total Work (kJ)		R	0.16 ± 0.05	0.01	35	0.21 ± 0.06	0.02	45	0.30	0.21
		L	0.20 ± 0.11	0.01	41	0.15 ± 0.06	0.01	21	0.38	0.36

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 6. Test–retest reliability of landmine punch throw test with 25 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
			1st			2nd				
Height (m)	NT	R	0.41 ± 0.10	0.01	17	0.51 ± 0.20	0.02	28	0.36	0.24
		L	0.42 ± 0.07	0.01	18	0.44 ± 0.08	0.02	27	0.44	0.26
Mean Force (N)		R	177 ± 131	23	73	181 ± 128	22	73	0.98	0.92 *
		L	173 ± 128	22	73	172 ± 122	21	73	0.96	0.97 *
Mean Power (W)		R	370 ± 107	18	28	360 ± 105	16	27	0.90	0.80 *
		L	327 ± 98	17	30	319 ± 102	23	32	0.93	0.87 *
Mean Power (W/kg)		R	4.85 ± 1.12	0.19	23	5.01 ± 1.41	0.23	25	0.85	0.74 *
		L	4.25 ± 0.84	0.14	19	4.16 ± 0.91	0.20	21	0.81	0.68 *
Mean Velocity (m/s)		R	1.27 ± 0.27	0.04	21	1.31 ± 0.34	0.04	22	0.92	0.85 *
		L	1.17 ± 0.20	0.03	19	1.14 ± 0.24	0.03	20	0.91	0.85 *
Peak Force (N)		R	521 ± 88	15	17	511 ± 101	23	22	0.75	0.62 *
		L	573 ± 110	25	21	527 ± 123	28	23	0.83	0.76 *
Peak Power (W)		R	692 ± 190	33	27	714 ± 198	35	31	0.79	0.66 *
		L	687 ± 187	36	27	675 ± 170	33	24	0.86	0.80 *
Peak Power (W/kg)		R	9.05 ± 1.99	0.35	21	10.02 ± 2.23	0.44	29	0.77	0.64 *
		L	8.85 ± 1.67	0.30	18	8.23 ± 1.92	0.45	23	0.71	0.78 *
Peak Velocity (m/s)		R	1.93 ± 0.42	0.07	22	1.98 ± 0.50	0.12	24	0.92	0.87 *
		L	1.88 ± 0.21	0.04	19	178 ± 0.19	0.03	19	0.94	0.91 *
Total Work (kJ)		R	0.24 ± 0.04	0.00	23	0.20 ± 0.05	0.01	28	0.71	0.69 *
		L	0.20 ± 0.03	0.01	24	0.24 ± 0.05	0.01	29	0.49	0.35
Height (m)	T	R	0.55 ± 0.08	0.01	16	0.61 ± 0.13	0.02	22	0.44	0.31
		L	0.53 ± 0.07	0.01	14	0.63 ± 0.10	0.03	23	0.29	0.14
Mean Force (N)		R	161 ± 119	21	73	159 ± 113	20	73	0.99	0.99 *
		L	142 ± 120	23	87	150 ± 123	24	87	0.98	0.99 *
Mean Power (W)		R	317 ± 89	19	34	305 ± 85	18	32	0.89	0.84 *
		L	290 ± 66	11	22	283 ± 88	20	31	0.88	0.83 *
Mean Power (W/kg)		R	4.15 ± 1.18	0.20	28	4.05 ± 0.91	0.16	22	0.84	0.77 *
		L	3.78 ± 0.68	0.12	19	3.55 ± 0.65	0.28	28	0.75	0.60 *
Mean Velocity (m/s)		R	1.18 ± 0.29	0.05	25	1.19 ± 0.25	0.05	24	0.92	0.87 *
		L	1.22 ± 0.19	0.04	18	1.12 ± 0.21	0.04	22	0.83	0.75 *
Peak Force (N)		R	526 ± 95	16	18	511 ± 90	15	15	0.82	0.70 *
		L	590 ± 88	21	20	548 ± 75	20	21	0.80	0.75 *
Peak Power (W)		R	832 ± 214	42	28	854 ± 224	44	30	0.85	0.77 *
		L	821 ± 230	43	27	803 ± 187	36	25	0.83	0.70 *
Peak Power (W/kg)		R	10.9 ± 2.67	0.49	24	9.99 ± 2.24	39	19	0.83	0.72 *
		L	10.5 ± 2.85	0.51	25	9.29 ± 2.33	0.53	26	0.82	0.67 *
Peak Velocity (m/s)		R	2.12 ± 0.51	0.09	21	2.11 ± 0.52	0.09	21	0.95	0.92 *
		L	1.88 ± 0.36	0.06	19	1.84 ± 0.32	0.05	20	0.90	0.83 *
Total Work (kJ)		R	0.20 ± 0.10	0.01	44	0.15 ± 0.05	0.01	22	0.45	0.30
		L	0.23 ± 0.09	0.01	39	0.20 ± 0.08	0.01	30	0.48	0.51

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 7. Test–retest reliability of landmine punch throw test with 30 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
			1st			2nd				
Height (m)	NT	R	0.51 ± 0.07	0.01	24	0.44 ± 0.05	0.01	17	0.56	0.40
		L	0.48 ± 0.12	0.02	39	0.42 ± 0.06	0.01	16	0.28	0.20
Mean Force (N)		R	182 ± 159	31	87	187 ± 149	30	87	0.99	0.99 *
		L	180 ± 157	30	87	181 ± 154	30	87	0.99	0.98 *
Mean Power (W)		R	399 ± 110	23	27	356 ± 102	20	24	0.89	0.88 *
		L	337 ± 75	14	22	331 ± 89	19	29	0.86	0.85 *
Mean Power (W/kg)		R	5.05 ± 0.87	0.21	20	4.59 ± 0.95	0.23	23	0.85	0.82 *
		L	4.23 ± 0.62	0.12	14	4.29 ± 0.87	0.20	21	0.84	0.82 *
Mean Velocity (m/s)		R	1.14 ± 0.22	0.04	19	1.09 ± 0.33	0.05	24	0.80	0.85 *
		L	1.20 ± 0.22	0.04	18	1.17 ± 0.18	0.03	15	0.80	0.81 *
Peak Force (N)		R	603 ± 90	24	21	596 ± 91	24	22	0.89	0.81 *
		L	608 ± 101	19	22	591 ± 98	18	20	0.85	0.89 *
Peak Power (W)		R	721 ± 209	36	25	711 ± 189	33	24	0.87	0.76 *
		L	666 ± 120	24	33	649 ± 117	23	32	0.90	0.84 *
Peak Power (W/kg)		R	9.61 ± 1.77	0.39	23	8.67 ± 2.01	0.46	25	0.86	0.75 *
		L	8.31 ± 1.73	0.33	20	7.73 ± 1.56	0.30	18	0.80	0.76 *
Peak Velocity (m/s)		R	1.80 ± 0.36	0.07	23	1.73 ± 0.33	0.06	21	0.83	0.74 *
		L	1.61 ± 0.23	0.06	17	1.48 ± 0.19	0.05	14	0.85	0.78 *
Total Work (kJ)		R	0.27 ± 0.10	0.01	35	0.24 ± 0.09	0.01	30	0.52	0.34
		L	0.25 ± 0.05	0.01	21	0.28 ± 0.06	0.01	24	0.57	0.40
Height (m)	T	R	0.54 ± 0.11	0.02	22	0.61 ± 0.14	0.03	30	0.60	0.66 *
		L	0.54 ± 0.08	0.01	19	0.52 ± 0.09	0.02	24	0.41	0.36
Mean Force (N)		R	178 ± 148	29	83	176 ± 139	28	83	0.99	0.99 *
		L	171 ± 149	30	81	173 ± 145	30	81	0.99	0.98 *
Mean Power (W)		R	307 ± 71	15	23	287 ± 62	14	22	0.84	0.82 *
		L	297 ± 53	10	17	281 ± 68	13	20	0.87	0.77 *
Mean Power (W/kg)		R	3.90 ± 0.76	0.15	21	3.71 ± 0.57	0.13	19	0.79	0.72 *
		L	3.74 ± 0.49	0.09	13	3.65 ± 0.42	0.08	11	0.78	0.69 *
Mean Velocity (m/s)		R	1.04 ± 0.19	0.03	19	0.98 ± 0.22	0.05	22	0.74	0.60 *
		L	0.92 ± 0.16	0.03	16	0.87 ± 0.19	0.04	22	0.83	0.70 *
Peak Force (N)		R	569 ± 68	13	12	555 ± 75	16	16	0.80	0.83 *
		L	641 ± 104	25	23	579 ± 121	29	27	0.75	0.79 *
Peak Power (W)		R	808 ± 225	47	30	733 ± 201	38	23	0.77	0.80 *
		L	825 ± 176	30	22	734 ± 156	26	17	0.75	0.71 *
Peak Power (W/kg)		R	10.23 ± 2.54	0.51	24	9.62 ± 2.85	0.60	29	0.78	0.74 *
		L	10.05 ± 2.21	0.47	26	8.64 ± 2.14	0.51	24	0.78	0.79 *
Peak Velocity (m/s)		R	1.92 ± 0.38	0.07	20	1.87 ± 0.42	0.08	25	0.84	0.89 *
		L	1.70 ± 0.30	0.06	18	1.65 ± 0.38	0.07	21	0.85	0.73 *
Total Work (kJ)		R	0.25 ± 0.17	0.02	41	0.18 ± 0.06	0.01	34	0.33	0.26
		L	0.22 ± 0.12	0.02	31	0.20 ± 0.06	0.01	27	0.61	0.24

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

Table 8. Test–retest reliability of landmine punch throw test with 35 kg.

Outcome Measure		Side	Mean ± SD	SEM	CV	Mean ± SD	SEM	CV	ICC	r
			1st			2nd				
Height (m)	NT	R	0.46 ± 0.10	0.02	22	0.43 ± 0.06	0.01	15	0.69	0.68 *
		L	0.40 ± 0.05	0.01	14	0.43 ± 0.06	0.01	11	0.58	0.42 *
Mean Force (N)		R	211 ± 184	36	87	209 ± 180	35	87	0.99	0.99 *
		L	205 ± 179	35	83	203 ± 175	35	83	0.98	0.99 *
Mean Power (W)		R	368 ± 133	26	36	388 ± 120	22	32	0.85	0.78 *
		L	331 ± 102	20	30	351 ± 79	21	22	0.88	0.88 *
Mean Power (W/kg)		R	4.63 ± 1.56	0.37	41	4.82 ± 0.99	0.28	31	0.79	0.69 *
		L	4.12 ± 1.22	0.23	30	4.32 ± 1.59	0.31	38	0.75	0.71 *
Mean Velocity (m/s)		R	1.10 ± 0.26	0.06	24	1.21 ± 0.18	0.05	16	0.78	0.63 *
		L	1.04 ± 0.20	0.04	22	0.97 ± 0.16	0.04	18	0.86	0.74 *
Peak Force (N)		R	613 ± 137	26	22	600 ± 121	22	19	0.81	0.77 *
		L	658 ± 112	25	20	635 ± 97	25	16	0.80	0.80 *
Peak Power (W)		R	696 ± 241	47	34	713 ± 210	45	30	0.83	0.73 *
		L	678 ± 231	44	31	643 ± 159	32	24	0.77	0.75 *
Peak Power (W/kg)		R	8.76 ± 2.87	0.56	32	9.01 ± 1.78	0.49	26	0.78	0.64 *
		L	8.19 ± 2.87	0.55	30	7.91 ± 1.65	0.45	20	0.71	0.65 *
Peak Velocity (m/s)		R	1.63 ± 0.40	0.07	24	1.74 ± 0.39	0.06	23	0.92	0.85 *
		L	1.33 ± 030	0.06	21	1.43 ± 0.24	0.06	16	0.82	0.72 *
Total Work (kJ)		R	0.27 ± 0.11	0.02	41	0.24 ± 0.07	0.02	31	0.64	0.61 *
		L	0.28 ± 0.05	0.01	26	0.26 ± 0.05	0.02	28	0.66	0.59 *
Height (m)	T	R	0.55 ± 0.09	0.01	23	0.51 ± 0.12	0.02	29	0.41	0.25
		L	0.53 ± 0.07	0.01	19	0.50 ± 0.10	0.02	24	0.52	0.36
Mean Force (N)		R	199 ± 176	33	87	202 ± 179	33	87	0.98	0.97 *
		L	207 ± 172	34	83	205 ± 171	34	83	0.98	0.99 *
Mean Power (W)		R	291 ± 45	8	15	304 ± 53	14	17	0.77	0.69 *
		L	297 ± 50	11	17	302 ± 43	11	14	0.75	0.79 *
Mean Power (W/kg)		R	3.68 ± 0.41	0.08	11	3.48 ± 0.59	0.09	15	0.82	0.74 *
		L	3.57 ± 0.46	0.09	12	3.74 ± 0.39	0.10	10	0.82	0.80 *
Mean Velocity (m/s)		R	0.96 ± 0.20	0.03	21	1.08 ± 0.16	0.04	15	0.75	0.66 *
		L	0.82 ± 0.11	0.02	14	0.86 ± 0.23	0.04	20	0.73	0.73 *
Peak Force (N)		R	587 ± 68	13	11	605 ± 74	20	12	0.84	0.72 *
		L	606 ± 84	16	13	619 ± 74	12	20	0.81	0.69 *
Peak Power (W)		R	717 ± 157	30	21	746 ± 160	32	23	0.85	0.75 *
		L	654 ± 206	41	31	705 ± 170	47	24	0.85	0.78 *
Peak Power (W/kg)		R	9.06 ± 1.76	0.34	19	9.94 ± 2.13	0.59	21	0.75	0.76 *
		L	8.16 ± 2.01	0.46	22	8.69 ± 1.64	0.45	17	0.70	0.66 *
Peak Velocity (m/s)		R	1.72 ± 0.37	0.07	21	1.85 ± 0.34	0.07	20	0.90	0.85 *
		L	1.62 ± 0.23	0.06	21	1.52 ± 0.22	0.06	17	0.87	0.81 *
Total Work (kJ)		R	0.26 ± 0.11	0.03	45	0.18 ± 0.09	0.02	43	0.18	0.10
		L	0.31 ± 0.11	0.02	38	0.22 ± 0.09	0.02	39	0.21	0.13

*—p value < 0.05; SD—standard deviation; CV—coefficients of variation; SEM—standard error of measurement; ICC—intraclass correlation coefficients; r—Pearson correlation coefficient; NT—no throw; T—throw; R—right; L—left.

4. Discussion

The most important observation from this study is that the GymAware linear transducer may be a reliable tool for evaluating the strength, power, and velocity of the barbell during the LPT test. All applied barbell loads and both forms of the LPT test (with and without throw) for most variables (including force, power, and velocity) demonstrated good to excellent reliability. In this study, there was a noticeable tendency towards worsening reliability as the load of the barbell increased. Additionally, the LPT test performed with a barbell throw showed some lower ICC and r values compared to the test without a throw.

Velocity-based training (VBT) is becoming more and more popular; thus, methods allowing for the precise selection of training loads based on force, power, and velocity measurements are considered better and safer than classic 1RM assessment [7,13,14]. The main advantage of this approach is that it provides accurate, indirect estimations of 1 RM without the need to perform a maximal lift [1,7,13,14]. Moreover, the wide accessibility of velocity-based technology makes VBT attractive to coaches [7,21]. It has been previously reported that controlling barbell velocity is a good way to monitor resistance training intensities [1,4,20]. The LPT test is applied to assess the ability to produce high velocities in a movement pattern similar to a rear-hand punch. Due to the fact that movement during the LPT test is similar to punching movement patterns, which occur in combat sports (e.g., in boxing), it may be suggested that the LPT, in conjunction with the linear position transducer, may be a useful tool in the assessing the speed-strength component of punching and monitoring training loads in combat sports [23–25]. It was reported that for boxers, the maximal and explosive strength of the upper body are strongly related to punch impact force [21,22].

There are many methods of assessing punch performance, but none are considered good enough [7,19,23]. However, linear transducers are thought of by many authors as the gold standard for the measurement of barbell velocity [1,33]. Fritschi et al. [18] tested various kinds of devices on separate days and reported high between-measurement correlations of mean and peak velocity for linear transducers such as GymAware (r = 0.90–1), Quantum (r = 0.88–1), and Vmaxpro (r = 0.92–0.99). In their study, the Push Band (r = 0.69–0.96) and Flex (r = 0.60–0.94) devices showed poorer validity (especially for higher-velocity exercises). Other authors also confirmed these observations, noting that GymAware appeared to be the most valid among other linear transducers used [40,41]. Additionally, the Push device was found to be less valid than GymAware [1,7]. In our study, the GymAware linear transducer also demonstrated very high and significant correlations between measurements for the same day as well as for different days.

We suggested that the results from the current study are of great applicative value for coaches and athletes. Since in most of the papers, barbell velocity was evaluated during more classical strength exercises, i.e., the bench press, back squat, and bench pull [1,7,12], our study is the first in which the reliability of the barbell force, power, and velocity were assessed during the LPT test applying various loads.

Orange et al. [42] examined 29 youth rugby league players who performed the squat and bench press exercises with loads between 20 and 90% of 1RM at two different testing sessions. The authors found good to excellent reliability of velocity and power assessed by the GymAware system at loads within the 40–90% 1RM range [42]. Additionally, the inter-repetition reliability for the one testing session was high for the bench press, bent-over-row, and squat [42]. The reliability of the GymAware system observed in our study was similar to that noted by Orange et al. [42]. For all loads and both LPT test types, the reliability of mean and peak force, power, and velocity ranged from good to excellent. Moreover, intra-rater reliability was similar to test–retest, which may indicate that this device provided comparable results not only during one session but even on separate days.

Chéry et al. [43] used the deadlift exercise and loads ranging between 20 and 100% of 1RM for assessing velocity and power. They reported that reliability starts to decrease at loads below 30% of 1RM. In the study by Orange et al. [42] a decrease in ICC was observed at lower barbell loads. The authors reported good reliability at loads of 60, 80, and 90% of 1RM. Reliability of velocity and power tended to be lower at 20% of 1RM [42]. Contrarily, in our study, such a decrease in reliability was observed when the barbell load increased. This discrepancy was probably present because they examined professional athletes, but in our work, the participants comprised students. Therefore, the subjects in our work were probably weaker and less fit, so their performance was better at lower loads. Moreover, Orange et al. [42] used squat and bench press exercises, which may require different movement skills than the landmine punch throw. Bench press and squat are simple, one-plane exercises commonly used in strength training by both athletes and recreational amateurs. Therefore, this movement could finally provide higher reliability, even in the case of heavy loads. LPT, on the other hand, is a complex multi-plane movement requiring more motor skills and greater control for precise execution with a heavy load. In our study, series were performed progressively increasing the load to refusal, so the participants were subjected to loads from 30–40% of 1 RM (20 kg) to 90–100% of 1 RM (35 kg). Therefore, we used a similar spectrum of loads and also observed good to excellent inter-rater and test–retest reliability for force, power, and velocity.

In numerous studies, the validity or reliability of velocity parameters provided by various VBT mobile devices have been assessed. Generally accepted are parameters of mean and peak concentric velocity, which are usually obtained by linear position transducers [17,29,44]. Our study is the first in which more variables than power and velocity have been reported, which provides a fuller and broader picture of barbell movement during the LPT test. Such information can be used by coaches as well as athletes in VBT.

This study has some limitations which should be addressed. We evaluated young male students who were not professional athletes. Therefore, this study should be extended to professional athletes, especially from combat sports. Additionally, the reliability of the LPT test may be further evaluated by other velocity-based devices for comparison. Additionally, only young men were included in the present study; therefore, research should also include the participation of women and people above the age of 30. Moreover, it is worth assessing the reliability of the LPT test, taking the circadian cycle into account, by comparing measurements taken in the morning with those obtained in the afternoon.

5. Conclusions

In conclusion, these results support the use of the GymAware linear transducer to track barbell velocity during the LPT test. This device could have valuable practical applications for strength and conditioning coaches. Therefore, we suggest that LPT assessed with the GymAware linear transducer may be a useful method for evaluating upper limb strength and power during the performance of a boxing punch.

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