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Title page

Title: Physical Characteristics underpinning Repetitive Lunging In Fencing

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Abstract:
Given the repetitive demand to execute lunging and changes in direction within fencing, the ability to sustain these at maximal capacity is fundamental to performance. The aim of this study was threefold. Firstly to provide normative values for this variable referred to as repeat lunge ability (RLA) and secondly to identify the physical characteristics that underpin it. Thirdly, was to establish if a cause and effect relationship existed by training the associated characteristics. Assessment of lowerbody power, reactive strength, speed, change of direction speed (CODS) and a sportspecific RLA were conducted on senior and junior elite male fencers (n = 36). Fencers were on average (± SD) 18.9 ± 3.2 years of age, 174.35 ± 10.42 cm tall, 70.67 ± 7.35 kg in mass, and 8.5 ± 4.2 years fencing experience. The RLA test had average work times of 16.03 s ± 1.40 and demonstrated "large" to "very large" associations with all tested variables, but in particular CODS (r = .70) and standing broad jump (SBJ; r = -68). Through linear regression analysis, these also provided a two-predictor model accounting for 61% of the common variance associated with RLA. A cause and effect relationship with SBJ and CODS was confirmed by the training group, where RLA performance in these fencers improved from 15.80 ± 1.07 s to 14.90 ± 0.86 s, with the magnitude of change reported as "moderate" (ES = 0.93). Concurrent improvements were also noted in both SBJ (216.86 cm ± 17.15 vs. 221.71 ± 17.59 cm) and CODS (4.44 ± 0.29 s vs. 4.31 ± 0.09 s) and while differences were only significant in SBJ, magnitudes of change were classed as "small" (ES = 0.28) and "moderate" (ES = 0.61)respectively. In conclusion, to improve RLA strength and conditioning coaches should focus on improving lower-body power and reactive strength, noting that jump training and plyometrics designed to enhance horizontal propulsion may be most effective, and translate to improvement in CODS also.

Keywords: lunging, speed, endurance

INTRODUCTION

Fencing involves a series of explosive lunges and changes in direction, spaced by low-intensity movements with varying recovery periods, predominately taxing anaerobic metabolism (Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014). Given the repetitive demand to effectively execute lunging and changes in direction within each bout, the ability to sustain these at maximal capacity, referred to as repeat lunge ability (RLA), should be considered fundamental to performance. The need for fencers to demonstrate RLA is clear when noting that the lunge is the most common form of attack (Aquili & Tancredi, 2013), usually delivered after several changes in direction (and feints) (Roi & Bianchedi, 2008), used to evade and disguise the hit. For example, during each bout, a fencer may cover between 250-1000 m, attack 140 times and change direction nearly 400 times in women's epee and around 170 times in men's epee and foil (Roi & Bianchedi, 2008). In sabre, there are on average 21 lunges, 7 changes in direction and 14 attacks per bout (Aquili & Tancredi, 2013). The work to rest ratios vary between swords, but it is clear that as the competition progresses and fencers reach the elimination bouts, the intensity and anaerobic nature of fights increase, with lactate values rising from around 4 mmol/L in the preliminary bouts, to being consistently above this (and as high as 15.3 mmol/L) during the elimination bouts (Cerizza & Roi, 1994).

As of yet, RLA has not been reported on in the literature, and subsequently nor have the physical characteristics that underpin this vital movement; such information will greatly inform the strength and conditioning training of fencers. The aim of this study therefore was threefold. Firstly to report normative values on this variable and secondly to identify the physical characteristics that underpin it. Thirdly, was to

identify if training these characteristics did indeed improve its score, noting that associations from this may not be cause and effect. Because the RLA test involves lunging and change of direction speed, it was hypothesised that similar associations to those identified previously (Guilhem, Giroux, Chollet, & Rabita, 2014; Tsolakis, Kostaki, & Vagenas, 2010; Turner, et al., In press) would be noted; these centred on lower body power, reactive strength and speed.

METHODS

Experimental Approach to the Problem

Given the repetitive demand to effectively execute lunging and changes in direction within each bout, normative data within elite athletes for RLA, as well as establishing the physical characteristics associated with its performance, could help support the training programmes of fencers. The assumed physical demands of the RLA, based on previous investigations in to lunging and CODS tests, suggested appropriate independent variables would be various measures of lower body power, including horizontal and vertical jumping, reactive strength index and speed (linear and with changes in direction). Given the number of athletes available within both the senior and junior elite squads, it was possible to run a multiple linear regression analysis, in addition to bivariate correlations, and thus the possibility of explaining larger shared variances in the dependent variable (i.e., RLA). Finally, any theoretical associations uncovered could be explored via a training group consisting of Podium Potential athletes, as these trained full-time, receiving structured strength and conditioning supervision.

Participants

The identification of RLA scores and the determination of physical characteristics that underpin them, involved thirty-six male elite senior and junior fencers, averaging (± SD) 18.9 ± 3.2 years of age, 174.35 ± 10.42 cm tall, 70.67 ± 7.35 kg in mass, and 8.5 ± 4.2 years fencing experience. The training of any identified physical characteristics and subsequent re-testing of RLA (to evaluate any associations found) used a sample of these. Several senior fencers (n = 7) comprised the training group (TG) as they were full-time athletes receiving supervised strength and conditioning training (subject characteristics as follows: 20.6 ± 2.4 years of age, 177.71 ± 4.37 cm tall, 74.41 ± 6.93 kg in mass, and had 10.0 ± 3.8 years fencing experience). The junior fencers (n = 8) were the control group (CG) and those that remained within the programme thus able to report for subsequent re-testing; this group received no supervised strength and conditioning training (subject characteristics as follows: 17.7 ± 1.4 years of age, 178.43 ± 9.25 cm tall, 72.71 ± 6.63 kg in mass, and had 8.1 ± 3.6). All fencers were familiar with the testing protocol as it was regularly completed throughout their season, and all were healthy and in good fitness. All speed, agility and RLA testing was conducted on a metal competition *piste* to increase validity of results, and all tests were conducted on the same day. Fencers were also asked to eat according to their normal diet and avoid eating and drinking substances other than water one hour prior to each test session. Fencers preceded testing with their individualised ~ 15 min warm-up, consisting of CODS drills that gradually increased in speed, lunging drills that gradually increased in speed and distance, and various mobility drills that typically concentrate on the hip and ankle joints. The institutional ethics committee in accordance with the declaration of Helsinki granted ethical

approval and each fencer provided written informed consent before taking part in the research.

Anthropometric data

Body mass was measured to the nearest 0.1 kg with an accurately pre-calibrated electronic weighing scale (Seca Alpha 770, Birmingham, UK). Participants were instructed to stand in the centre of the weighing scale's platform, barefoot and with minimum clothes (Eston & Reilly, 2009). Stature was measured to the nearest 0.1 cm with a stadiometer (Seca 220, Birmingham, UK). Participants were asked to stand barefoot in an erect position with heels together, arms hanging relaxed at sides and their upper back, buttocks and cranium against the stadiometer They were also instructed to fully inhale, stretch up and orientate their head in the Frankfort plane upon measurement (Eston & Reilly, 2009). The measurement was taken as the maximum distance from the floor to the highest point (vertex) on the skull.

Lower-body Power

Jump height was measured in the countermovement jump (CMJ) and single leg-countermovement jump (SLCMJ) for both front (or lead) and back legs. Reactive strength index (RSI) was measured following a drop jump from a box height of 30cm (Flanagan & Comyns, 2008). During the test, fencers were instructed to minimize ground contact time and then jump as high as possible. The RSI was calculated as flight time in milliseconds divided by ground contact time in milliseconds. For all jumps (drop jump, CMJ, SLCMJ), fencers were instructed to keep their hands in contact with their hips for the duration of the test. Any movement of the hands away

from the hips would have resulted in the jump being disqualified. Following take-off, fencers were also instructed to maintain full extension until contact had been made with the floor upon landing. All scores were recorded to the nearest 0.01cm (or to two decimal places in the case of RSI) and were measured using an optical measurement system (Optojump, Microgate, Italy). Compared to force plate measures, Optojump has shown intraclass correlation coefficients (ICCs) for validity of r = 0.997-0.998. Furthermore, test-retest reliability had ICCs ranging from 0.982 to 0.989 with low coefficients of variation (2.7%) (Glatthorn, Gouge, Nussbaumer, Stauffacher, Impellizzeri, & Maffiuletti, 2011). The standing broad jump was measured using a flexible tape measure, placed along the ground. Fencers had to jump as far forward as possible, keeping their hands on their hips as per other jump tests. If the fencers fell forward at landing, causing their feet to change position, the jump was disqualified. Scores were recorded to the nearest 0.1 cm, and in line with the heel of the foot furthest back.

Speed

Using fencing footwork, fencers had to travel between two sets of timing gates (Brower timing systems, Utah, USA) positioned at hip height and spaced 7 m apart. Fencers' speed was tested going forward (SPDFwd) as well as going backwards (SPDBk). The test was immediately stopped if the athlete used footwork deemed by the fencing coach to be unrepresentative of proper form, or if the beam was broken at the start or finish line with any part of their body other than their hips.

Change of direction speed

The CODS was measured using a 4-2-2-4 m shuttle (Turner, et al., In press). For this, fencers started behind one set of timing gates (Brower timing systems, Utah, USA) set at hip height. Using fencing footwork, they travelled as fast as they could up to a 4 m line, ensuring their front foot crossed the line, they then travelled backwards ensuring the front foot crossed the 2 m line. Again they travelled forward to the 4 m line, before moving backwards past the start line. The test was immediately stopped if the athlete used footwork deemed by the fencing coach to be unrepresentative of proper form, if the beam was broken at the start or finish line with any part of their body other than their hips, or if the athlete failed to pass either line with their toes or lunged in order to reach the line.

Repeat Lunge Ability

Using fencing footwork, fencers travelled 7 m towards a mannequin where they performed a lunge to hit either its chest or head guard. They then changed direction, traveling backwards until their lead toe was behind a 4 m line. From here they continued to hit the mannequin a further 4 times, traveling back to the 4 m line between hits; only following the last hit (5^{th}) did they then travel back past the start line (positioned 7 m from the mannequin). This was repeated 5 times with 10 s rest between intervals, with the score recorded as the average time across the 5 intervals. Timing gates (Brower timing systems, Utah, USA) were positioned at hip height at the start line, which fencers broke to both start and conclude each interval. Due to the unreliable data noted in pilot testing due to fencers continually breaking the beam of light gates within a test (resulting in intraclass correlations of $r < 0.6$), the start line was set a further 3 m back from the mannequin relative to the within-interval shuttle

line (4 m line); between day intraclass correlations improved to $r = 0.83$. The test was void if the fencer used footwork or a lunge technique deemed by the fencing coach to be unrepresentative of proper form, or if the fencer failed to pass either line with their toes. This test was considered valid on account of fencers having to cover an 8 m distance (4 m to and 4 m back from target) between hits, which is a short enough distance to be specific to the sport, but long to ensure several steps prior to each lunge. Because elimination bouts (of all swords) induce high levels of blood lactate, the test must also include (several) work intervals long enough to stimulate the onset of blood lactate accumulation, and thus challenge the fencers to work in the presence of high concentrations of hydrogen ions. Without the psychological arousal associated with competitions, this therefore required deviating from the established work to rest ratios of the sport (Roi & Bianchedi, 2008; Aquili & Tancredi, 2013), with the recovery from each lunge and the continuous changing of direction considered to largely contribute to fatigue. Pilot testing of the RLA revealed blood lactate values of 6.7 ± 1.8 mmol/L.

Strength and Conditioning Training

The TG fencers performed approximately two strength and power sessions and two conditioning sessions a week for 16-weeks before being re-tested. Strength and power training consisted of various squats and weightlifting exercises and derivatives, coupled with plyometrics such as jump to box, drop jumps and hurdle jumps. These exercises are well supported in their ability to increase jump and CODS performance (Asci & Acikada, 2007; Peterson, Alvar, & Rhea, 2006) and have been shown to improve movement time in fencers (Redondo, Alonso, Sedano, & de Benito, 2014). Conditioning sessions consisted of high intensity interval training, designed to induce

high levels of blood lactate (Baker, 2011). Work to rest ratios of 1:1 were used, usually 30 s in length and performing a total of 6 repetitions (therefore totalling 6 min). Exercises consisted of cross training activities such as bike and rowing ergometer sprints, sled pulls and battle ropes. An "off-feet" approach was chosen as the sport of fencing subjects its athletes to a high frequency of lower limb impacts, which present as a risk to injury (Harmer, 2008); It was felt that conditioning activities should not exacerbate the issue further.

Statistical Analysis

Measures of normality were assessed using the Shapiro-Wilk statistic. To determine the reliability of all tests of lower-body power, three trials were conducted and single measures ICC (two-way random with absolute agreement) between trials were conducted; the highest score of each trial was used for subsequent analysis. Pearsons Product Moment correlation analysis was used to identify relationships between variables and a stepwise multiple linear regression was used to identify the best predictors of RLA. Differences in pre and post RLA, SBJ and CODS scores for TG and CG fencers was investigated using a paired-samples *t*-test, with differences also reported as effect sizes (Hopkins, 2004) and interpreted according to Rhea (2004), with athletes classed as "highly trained". Differences between the TG and GC were also explored by way of independent samples *t*-tests. All statistical analysis was conducted using SPSS version 21 with the level of significance set at $p < 0.05$.

RESULTS

All data was normally distributed and intraclass correlations demonstrated a high level of reliability between trials of all variables (**Error! Reference source not found.**). Results for all tests are illustrated in **Error! Reference source not found.** and correlations are illustrated in Table 2. Due to sample size, only four variables were entered into the regression model: RSI, CODS, SPDBk (as it had a higher correlation with RLA than SPDFwd) and SBJ (on account of it having the highest correlation with RLA of all lower-body power tests). Results reveal that all variables are strongly correlated with RLA, but in particular CODS and SBJ. Furthermore, linear regression analysis revealed that these two variables best predict RLA scores, collectively accounting for 61% of the common variance in the score (**Error! Reference source not found.**).

********** Table 1, 2 and 3 about here **********

Following strength and conditioning programming to improve SBJ and CODS scores in TG fencers, RLA significantly ($p < 0.05$) improved from 15.80 ±1.07 s to 14.90 ±0.86 s, with the magnitude of change reported as "moderate" (ES = 0.93). Similarly, improvements were noted in both SBJ (216.86 cm ± 17.15 *vs.* 221.71 ± 17.59 cm) and CODS (4.44 ± 0.29 s *vs.* 4.31 ± 0.09 s) and while differences were only significant in SBJ, magnitudes of change were classed as "small" (ES = 0.28) and "moderate" (ES = 0.61) respectively. In contrast, the CG fencers made non-significant ($p > 0.05$) improvements in RLA (15.90 ± 1.53 s to 15.57 ± 1.61), with the magnitude of change reported as "trivial" (ES = 0.21). Improvements (albeit non-significant) were also

noted in both SBJ (203.63 ± 12.99 *vs.* 204.75 cm ± 13.75 cm) and CODS (4.43 ± 0.21 s *vs.* 4.42 ± 0.22 s), with magnitudes of change again classed as "trivial" in both (ES = 0.08 and 0.03 respectively).

Finally, when examining differences between the TG and CG, no significant differences in SBJ, CODS and RLA were found during initial testing. However, "large" effect size differences were noted in SBJ (ES = 17.71), but trivial in CODS and RLA (ES = 0.05 and 0.07 respectively). During post testing however, both SBJ and RLA scores were significantly better in the TG, with differences classed as "large" and "moderate" (ES = 17.66 and 0.52) respectively. While CODS scores were not significantly different, they were classed as moderately different (ES = 0.67) and again in favour of the TG.

DISCUSSION

The RLA test had average work times of 16.03 s (± 1.40) and was correlated to all other tested variables, but in particular CODS (r = 0.70) and SBJ (r = -0.68), where associations are classed as "large" and "very large" respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). Through linear regression analyses, these variables provided a two-predictor model accounting for 61% of the common variance associated with RLA. Based on these findings, a fencer's ability to repetitively lunge and change direction, with maximal intensity throughout each bout, can be facilitated by increasing CODS, linear speed (forward and backward) and lower-body power including RSI. Furthermore, when investigating the trainability of RLA and specifically, if increases in CODS and SBJ improved its performance (in accordance with the multiple regression analysis), significant improvements were noted (from

15.80 ±1.07 s to 14.90 ±0.86 s). This mirrored improvements in CODS and SBJ, however, only in the latter were improvements significant, but nevertheless, changes in CODS scores were considered “moderate” using effect size analysis. Analysis within the CG also revealed improvements in these variables, however, these changes were non-significant and classed as “trivial”. It therefore appears reasonable to suggest that larger improvements in SBJ and/or agility would also result in larger improvements in RLA. The concept of increasing fencing specific movements such as lunging and CODS through strength and power training have also been advocated elsewhere (Guilhem, Giroux, Chollet, & Rabita, 2014; Redondo, Alonso, Sedano, & de Benito, 2014; Turner, et al., In press; Tsolakis, Kostaki, & Vagenas, 2010).

The correlations herein, between a sport specific speed endurance test and various anaerobic power tests, have been reported in numerous other investigations of repeat sprint ability (Da Silva, Guglielmo, & Bishop, 2010; Pyne, Montgomery, Hewitt, & Sheehan, 2008; Sant'Ana Pereira, Sargeant, Rademaker, de Haan, & Van Mechelen, 1996), and the associations here may act to further support fencing as an anaerobic power-based sport (Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014; Turner, et al., 2014). That said, no measures of aerobic capacity were taken to further qualify this statement, but given that the TG contained elite athletes in the middle of the competitive season, this was not possible. Also, only 61% of the common variance in RLA scores was predicted using the two-predictor model (Table 3), leaving 39% unaccounted for. It may be that this would be further explained by a fencer’s anthropometry and aerobic capacity or, in the opinions of the authors’ (and given the RLA protocol), their lactate deflection points and buffering capacity. That is, conditioning designed to enable fencers to work at higher intensities before reaching the onset of blood lactate accumulation, as well as working in the

presence of hydrogen ion accumulation, would achieve greater scores still. Therefore it is likely that the conditioning work undertaken by these athletes, and the physiological improvements made consequent to this, may also be responsible for the noted improvement in RLA scores of the TG fencers. Again, due to the fencers being in full training, it was not possible to exclude conditioning work to better highlight the associations with lower body power; future research should attempt to validate this, along with the affect of the conditioning activities used.

When comparing the TG and CG, it is interesting to note that significant differences were only noted following the intervention; that is the difference between level of fencer (i.e., senior *vs*. junior) does not appear to be defined by physicality, and probably serves to highlight the highly technical and tactical demand of the sport. That said, following the intervention, significant differences were evident between the groups for RLA and SBJ and classed as "moderate" and "large" differences respectively. While the difference in CODS was not significant, it was deemed to be "moderate". In summary, fencing training albeit at a high level, may plateau in its carryover to indirect measures of fitness and lower body. At this stage, strength and conditioning based training can enhance these physical characteristics and subsequently improve specific and fundamental abilities to fencing, namely RLA; this has also been preciously shown in measures of fencing specific movement time (Redondo, Alonso, Sedano, & de Benito, 2014).

Finally, the technical footwork incorporated within the CODS test that inevitably dictate a large part of the score, is beyond the remit of the strength and conditioning coach, and is thus better affected indirectly. Noting that measures of lower-body power are correlated to these, one such method may be by virtue of increasing this physical attribute. Similar relationships have been reported by Tsolakis *et al.*, (2010)

who found a relationship between CMJ and RSI, and scores derived from a shuttle test, where fencers moved as fast as possible between 5 m cones, covering a total distance of 30 m (average score 12.43 s). Here they reported correlations of r = - 0.63 and - 0.44 for CMJ and RSI respectively. Similarly, Turner *et al.*, (In press) reported correlations between a CODS (4-2-2-4 m) and CMJ, SBJ and RSI (r = - 0.49, - 0.65 and – 0.41 respectively). Also, it is interesting to note that SPDBk is better correlated to RLA (and CODS) than SPDFwd (r = .48 and .40 respectively), and may highlight the need to further expose athletes to this type of training within fencing coaching sessions.

CONCLUSIONS AND PRACTICAL APPLICATIONS

Strength and power training is advocated to improve RLA and thus the ability to sustain attacking actions within a fencing bout. Strength and conditioning coaches should focus on improving lower-body power and reactive strength, noting that jump training and plyometrics designed to enhance horizontal propulsion may be most effective and translate to improvement in CODS also. Furthermore, given the high levels of lactate expected to be generated in fencers as they progress in the competition, and the assumed validity of the RLA test, conditioning training designed to enable fencers to work at higher intensities before reaching OBLA, as well as working in the presence of hydrogen ion accumulation, would further improve performance through enhanced speed and power endurance. Finally, as shown when examining the differences between the TG and CG, strength and conditioning training is required to improve scores in fencing specific tests above that which can be gained from fencing practice alone.

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Table 1 Test results presented as means (±SD) with associated reliability scores using single measures intraclass correlations (ICC) and 95% confidence intervals (95%CI).

Test	Mean	SD	ICC	95%CI
Countermovement Jump (cm)	40.13	7.76	0.96	0.94 - 0.98
Single-leg jump Front foot (cm)	23.01	4.79	0.96	0.93 - 0.98
Single-leg jump back foot (cm)	20.57	4.78	0.93	0.84 - 0.96
Reactive strength index	1.65	0.44	0.92	0.85 - 0.96
Standing broad jump (cm)	204.17	26.22	0.96	0.90 - 0.98
Agility (s)	4.65	0.41	0.98	0.97 - 0.99
Speed forward (s)	1.98	0.24	0.98	0.96 - 0.99
Speed backward (s)	2.10	0.24	0.98	0.97 - 0.99
Repeat lunge ability (s)	16.03	1.40		

Table 2. Correlations between tested variables associated with RLA

	CMJ	SLJFr	SLJBk	RSI	SBJ	Agility	SPDFwd	SPDBk
SLJFr	.83**							
SLJBk	.77**	.89**						
RSI	.75**	.79**	.70**					
SBJ	.79**	.70**	.64**	.61**				
Agility	-.57**	-.54**	-.53**	-.56**	-.58**			
SPDFwd	-.53**	-.57**	-.57**	-.45**	-.39*	.62**		
SPDBk	-.54**	-.55**	-.51**	-.59**	-.44**	.76**	.79**	
RLA	-.60**	-.58**	-.57**	-.53**	-.68**	.70**	.40*	.48**

Key: CMJ = countermovement jump; SLJFr = single leg jump front foot; SLJBk = single leg jump back foot; RSI = reactive strength index; SBJ = standing broad jump; SPDFwd = speed forward; SPDBk = speed back; RLA = repeat lunge ability; * Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

Table 3 Multiple regression models to predict repeat lunge ability

	B	**SE *B***	**β**
Step 1			
Constant	4.91	2.03	
Agility	2.47	0.44	0.70*
Step 2			
Constant	13.55	3.35	
Agility	1.63	0.48	0.46*
Standing broad jump	-0.02	0.01	-0.42*

Note: R^2 = .49 for step 1, Δ R^2 = .61 for step 2 (p < .001). * p < 0.001.