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PII: S1440-2440(18)30141-5
DOI: https://doi.org/10.1016/j.jsams.2018.05.007
Reference: JSAMS 1847

To appear in: *Journal of Science and Medicine in Sport*

Received date: 22-1-2018
Revised date: 25-4-2018
Accepted date: 8-5-2018

Please cite this article as: Moras Gerard, Fernández-Valdés Bruno, Vázquez-Guerrero Jairo, Tous Julio, Exel Juliana, Sampaio Jaime.Entropy measures detect increased movement variability in resistance training when elite rugby players use the ball.*Journal of Science and Medicine in Sport* https://doi.org/10.1016/j.jsams.2018.05.007

Full Title: Entropy measures detect increased movement variability in resistance training when elite rugby players use the ball.

Running Title: Movement variability in resistance training

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Abstract

Objectives: This study described the variability in acceleration during a resistance training task, performed in horizontal inertial flywheels without (NOBALL) or with the constraint of catching and throwing a rugby ball (BALL). **Design** and **Methods**: Twelve elite rugby players (mean ± SD: age 25.6 ± 3.0 years, height 1.82 ± 0.07 m, weight 94.0 ± 9.9 kg) performed a resistance training task in both conditions (NOBALL AND BALL). Players had five minutes of a standardized warm-up, followed by two series of six repetitions of both conditions: at the first three repetitions the intensity was progressively increased while the last three were performed at maximal voluntary effort. Thereafter, the participants performed two series of eight repetitions from each condition for two days and in a random order, with a minimum of 10 min between series. The structure of variability was analysed using non-linear measures of entropy. **Results**: Mean changes (%; ±90%CL) of 4.64; ±3.1 g for mean acceleration and 39.48; ±36.63 a.u. for sample entropy indicated likely and very likely increase when in BALL condition. Multiscale entropy also showed higher unpredictability of acceleration under the BALL condition, especially at higher time scales. **Conclusions**: the application of match specific constraints in resistance training for rugby players elicit different amount of variability of body acceleration across multiple physiological time scales. Understanding the non-linear process inherent to the manipulation of resistance training variables with constraints and its motor adaptations may help coaches and trainers to enhance the effectiveness of physical training and, ultimately, better understand and maximize sports performance.

Keywords: accelerometry; rugby; resistance training; entropy

Introduction

Sprinting ability is essential in many invasion team sports, such as rugby[1]. One of its most important components is acceleration, which is the capacity of increasing and/or maintaining speed[2]. Considering that the neuromuscular system is movement and velocity-dependent[3], it seems consensual that training specificity is a key issue to develop the sprinting ability. In invasion team sports, particularly, there are strong demands on players performance when carrying, passing, receiving, kicking or throwing balls to their teammates while sprinting, which adds substantial complexity to the tasks[4]. However, gym-based resistance training programs traditionally aim to improve sprinting ability and moving on multiple planes, prioritizing the use of weights in vertical actions, and rarely incorporate the use of a ball[5].

The recent literature on skill acquisition encourages the use of constraint-led approaches, in order to improve specificity and develop challenging training environments, which increases movement variability and adaptability[6]. What is yet unknown is how these constraints caused by specific, but complex, motor demands affect the underlying dynamics of kinematic variables and, ultimately, the performance outcomes. Most probably, the conventional approaches that describe variability using linear measures, may not be able to reveal these relationships, once it provides very limited information about how the motor control system responds to changes, either within or between individuals[7].

The analysis of human movement has evolved to assess the variability of a measure targeting the detection of changes in fluctuations and spatiotemporal characteristics of outcomes. Within the past 20 years, entropy analysis has become relatively popular as a measure of system complexity and used to describe changes in postural control[8], assessment of running[9], human walking data[10], and tactical behaviour in soccer[11]. However, to our knowledge, entropy analysis has not been applied to understand how the manipulations of resistance training constraints affects the amount of complexity of physical outcomes in team sports.

The multiscale entropy analysis has been suggested as a proper method to address the complexity inherent to the biological signals, allowing to deal with the multiple spatial and temporal scales in a time series, reflecting the multiscaled characteristic of the biological system operation[12,13]. In fact, multiscale entropy integrates the sample entropy (SampEn) method, which quantifies point-to-point fluctuations of a time series in a single time scale, but over a broad range of time scales through a coarse graining procedure[13,14]. The advantages on this method lies on the additional information on the relationship between the levels of a biological system, as well as the organization of athlete’s movement from a dynamical system perspective[15].

Therefore, the aim of this study was to identify the differences in the acceleration during a resistance horizontal forward-backward task without (NOBALL) or with the constraint of catching and throwing a rugby ball in the forward phase (BALL). It was hypothesized that during the resistance training task, the addition of a ball as a constraint, there might be changes in the resultant acceleration of the players that can be detected and described by a non-linear approach.

Methods

Twelve elite rugby players that integrate a professional team at the Spanish league volunteered to participate in this study (mean ± *SD*: age 25.6 ± 3.0 years, height 1.82 ± 0.07 m, weight 94.0 ± 9.9 kg). The team training schedule included four gym-based resistance training sessions per week. The procedures complied with the Declaration of Helsinki (2013) and were approved by the local ethics committee (11/2015/CEICEGC).

The inertial flywheel device (Byomedic System SCP, Barcelona, Spain) consists of a metal flywheel (diameter: 0.42 m) with up to 16 weights (0.421 kg), which can be added along the top edge of the flywheel perimeter. The device is comprised of a cone attached above a flywheel, and as the flywheel and cone spin, a rope winds and unwinds around the cone. The concentric action unwinds the rope and the eccentric action occurs during rewinding. The force applied in the eccentric action to bring the flywheel to a stop will depend on the kinetic energy generated during the concentric action[16]. To change the resistance to movement, the moment of inertia can be modified by adding any number of the 16 weights to the edge of the flywheel and also by selecting one of the four positions (P1, P2, P3 or P4). For this study, the Position 1 and the 16 weights were selected, in order to generate the highest levels of mean force[17]. The moment of inertia for the device was 0.27 $\text{kg}\cdot\text{m}^2$.

The protocol was performed during four different days. Day one was prior to the experiment, where the participants underwent to a familiarization session with the inertial flywheel device during the horizontal movement. When performing the BALL condition, an expert player made a pass from the right side, two meters away. The evaluated player caught the ball during the forward movement, synchronized with the first step. Then, during the second step the subject passed the ball to another expert player standing two meters away at the other side. Emphasis was placed on the proper technique and the importance of keeping the rope of the device tight. In day two, the experimental protocol began with a standardized warm-up, after which the optimal length of the rope for performing horizontal movements with three steps backwards and three steps forwards was obtained for each player. Thereafter, the participants performed two series of four repetitions of the NOBALL condition, with maximal voluntary effort, with a minimum of 10 min between series. The average time duration (T_{mean}) of the four repetitions was calculated and converted to the movements rate (R) in beats per minute for each player, as in equation 1[18].

$$R = (60/T_{mean})/2 \qquad (1)$$

Subjects were instructed to synchronize the forward and backward horizontal movements with the rate established using the metronome. Days three and four were dedicated to the task. Each player had five minutes of a standardized warm-up, followed by two series of six repetitions of both conditions. The intensity of the first three repetitions was progressively increased, while the last three repetitions were performed at maximal voluntary effort. Afterwards, the participants performed two series of eight repetitions of each condition (for two days and in a random order) with a minimum of 10 min rest between series. During data collection, players did not receive any verbal information on the quality of the movement or the outcome of the test.

The acceleration of the rugby players under both conditions was measured using an inertial measurement unit (WIMU, Realtrack Systems, Almeria, Spain), with a 16 Hz processing capability, that consists of a 5 Hz Galileo GPS positioning device, a 3D accelerometer 100G recording at 1000 Hz, a 3D gyroscope recording at 1000 Hz, a 3D magnetometer recording at 100 Hz, and a barometer at 120 kPa. The accelerometer was attached to the player using an elastic waist belt close to the sacrum. This position provided the best indication of whole body movement, as the location is close to the player’s center of mass[19]. A portable high-speed camera (Casio Exilim EX-ZR100) recording at 240 fps was also used to synchronize the accelerometry signal with the movement phases.

Four repetitions obtained from both conditions were considered for the analysis. The acceleration time-series data were divided into two consecutive intervals for each repetition (forward and backward movement) and analysed separately for each subject. Mean acceleration, sample entropy (SampEn) and multiscale entropy for the acceleration of the global, forward and backward movement were calculated.

The acceleration (*at*) was calculated by the equation 2:

$$at = \sqrt{z^2 + y^2 + x^2} \tag{2}$$

The calculation of SampEn and multiscale entropy was done according to Goldberger et al.[20] and through dedicated routines programmed in Matlab® (The MathWorks, Massachussets, USA).

A Mann-Whitney non-parametric test was used to compare the SampEn of the original time series and its surrogates, in order to verify if the variability found in the data is not only the product of random noise[7]. Magnitude-based inferences and precision of estimation were used to analyse the data[21]. Prior to the comparisons, all processed variables were log-transformed to reduce the non-uniformity of error. A descriptive analysis was performed using mean and standard deviations for the mean and maximal acceleration, as well as SampEn (the presented mean is the back-transformed mean of the log transform).

Differences between the different constraints and movement directions were expressed in percentage units with 95% confidence limits. Smallest worthwhile differences were estimated from the standardized units multiplied by 0.2. Uncertainty in the true differences of the scenarios was assessed using non-clinical magnitude-based inferences. Also, the comparisons were assessed via standardized mean differences and respective 95% confidence intervals. Thresholds for effect 4 sizes statistics were 0.2, trivial; 0.6, small; 1.2, moderate; 2.0, large; and >2.0, very large[22].

Results

Rugby players reached peak acceleration values (mean ± standard deviation) of 3.28 ± 1.16 g, 2.97 ± 1.24 g, 2.77 ± 0.6 g for NOBALL global, forward and backwards movements and 3.2 ± 0.57 g, 3.19 ± 0.58 g, 2.53 ± 0.3 g for BALL global, forward and backwards movements, respectively. The peak acceleration for NOBALL global, forward and backwards movements were 1.11 ± 0.06 g, 1.07 ± 0.04 g, 1.12 ± 0.11 g, respectively, while for BALL global, forward and backwards movements were 1.1 ± 0.05 g, 1.1 ± 0.06 g, 1.17 ± 0.07 g, respectively. SampEn of the NOBALL for global was 0.21 ± 0.08, for forward was 0.23 ± 0.16 and 0.21 ± 0.08 for backwards. SampEn of the BALL was 0.27 ± 0.07 for global, 0.28 ± 0.09 for forward and 0.28 ± 0.07 for backwards movement.

The SampEn values calculated for all original time series were statistically lower than the mean values obtained for its surrogates ($p<0.001$), indicating meaningfulness of the variability intrinsic to the data.

When peak acceleration was compared among tasks in the NOBALL constraint, it seems that the backwards movements required higher peak acceleration of rugby players when the constraint was NOBALL, by the moderate and large standardized differences (Figure 1b). In the BALL constraint, worthwhile differences among movements in this variable were small or trivial. Mean acceleration in both constraints showed small or trivial differences for global and forward movements, which, although higher than backwards, was considered unclear in terms of practical inferences. The acceleration complexity was trivially different when SampEn was compared among the three movements (Figure 1a).

**** Figure 1 near here ****

The results when the effect of NOBALL and BALL in the different movement parts showed that peak acceleration is not clearly affected by the constraint, opposite to mean acceleration and SampEn (Figure 2). For both variables, when the ball is added to the task, global and forward movements very likely/likely present an increase of acceleration and complexity.

**** Figure 2 near here ****

The multiscale entropy curves obtained for the constraints and across all sets are presented in figure 3. The values for the different set are consistent across all time scales. Global, forward and backwards tasks show increasing multiscale entropy values towards the highest time scales and similar range of values. However, the BALL tasks show higher multiscale entropy values when compared to the NOBALL tasks.

**** Figure 3 near here ****

Discussion

This study aimed to identify the differences in the acceleration during a resistance horizontal forward-backward task without (NOBALL) or with the constraint of catching and throwing a rugby ball in the forward phase (BALL). The main findings suggest that the ball constraint affected the acceleration produced by the players.

In the global set of the resistance task there was a decreased in peak acceleration when comparing the forward with the backward movement. The mean acceleration in the global and backwards sets of the movement were lower than forward, especially under NOBALL condition. Previous research suggested that forward and backward running are regulated by the same neural circuitry, but backwards running presents higher degrees of freedom to be managed, translating to a higher amount of coordination variability[23]. Although the authors did not find an effect of running speed to the coordination variability in either tasks, in the present study, the sprinting ability, or the capacity to accelerate over time, seem to have been influenced by the higher degrees of freedom in backwards movement.

Additionally, in the BALL situation, although mean acceleration at backwards movement showed an unclear effect of the constraint, with a small-standardized difference, the peak acceleration at backwards movements likely decreased under this condition. Although these results do not corroborate with previous work on sprint training considering BALL and NOBALL situations[24], slower performance in constrained tasks have already been reported for joint kinematics coordination, as well as the speed of overall sprinting technique of field hockey players, when performing tasks constrained by hockey sticks[25]. Thus, the manual constraint applied to the resistance task seems to affect the players' linear acceleration during the sprint performance in different directions.

Sprinting ability training for team sports can integrate equipment constraints in the training protocols, in order to elicit adequate physiological and mechanical demands of the specific skills. Thus, the other point of the present study was to show how simple but sport-specific gym-based resistance training tasks can promote improvements beyond the peak acceleration. When confronting entropy analysis between the original acceleration time series in each condition and the entropy of its surrogates, it was shown that the amount of variability obtained contains meaningful structural richness[13]. The SampEn values did not indicate a clear relationship in the amount of regularity present in the acceleration at each different movement of the resistance task. On the other hand, there is a likely increase in the BALL SampEn of all sets of the task. These results indicate that the constraint applied to the resistance training task not only requires from the players higher acceleration as discussed above, but also induces a change in system coordination patterns or establishes certain combination of movement stability and adaptability[26]. This is an evidence of how specificity issues can foster the adaptive aspects of movement variability. The association of the degree of variability with skill and health is changing[27]. It has been shown that some degree of motor variability is beneficial as it allows a more adaptive system to internal and external perturbations that constantly act on the body. The results associated to the players mentioned above may indicate detrimental movement control or coordination when a manual task is added, as to catch and throw a ball while run aiming increased body acceleration. Previous studies have already associated decreased variability to compromised athletic condition and lower skill level[28], motor learning/adaptation to the task, pain free movement[27]. As previously mentioned, there are results on sprint training using the ball as a constraint that did not find any differences between BALL and NOBALL situation[24]. However, it seems likely that these ball constraint effects are better identified at a non-linear level, as presented in this study.

At the level of time scales, entropy across multiple temporal scales was also calculated through multiscale entropy analysis, as SampEn is calculated considering only a single scale. This method reveals the dependency of the entropy measures on the different temporal scales[12]. The advantages are in the assessment of acceleration variability during the resistance task, accounting to its diverse dynamical interactions within and between physiological levels of the system during a task. Throughout the perception-action cycle, the task demands from the system to attune to the environment as the constraints change[15]. All the conditions presented higher multiscale entropy values towards the highest time scales. This monotonic increase in higher time scales indicates that acceleration becomes more complex than those corresponding to lower scales. Current results also suggest that multiscale entropy values among the tasks are similar but BALL condition presented higher multiscale entropy than NOBALL, especially from the time scale 12 towards 20. This might indicate that changes in the system imposed by the task constraint might occur at higher-level (macro-scale) process or in a systemic fashion, which reflects the integration of the lower-level processes, i.e. molecular, cellular tissue[15]. The ball constraint probably acts at the postural system level during resistance training tasks. The BALL condition implies higher anticipatory and compensatory adjustments due to the external perturbation of posture, once players must rotate the trunk sideways to catch and throw the ball. During catching and throwing movements (forward BALL**)**, the central nervous system had to modulate the anticipatory and compensatory activities of the distal and proximal muscles in a different way to forward NOBALL, in order to accomplish the task. Athletic trainers and physical therapists often use postural perturbations such as standing on one leg in different postural controlling conditions and/or throwing, catching or kicking a ball[29]. These tasks aim to increase difficulty by reducing the reliability of somatosensory information. However, the present study shows how manipulating constraints in motor tasks during physical training acts on players' adaptive capacity, although is not commonly used in practice. Traditional resistance training tasks might be excessively static in opposition to the fact that players need to constantly adjust their actions according to the inherent changes in performance environments[30]. Further studies can focus on how the learning process inherent to a period of resistance or sprint training using ball constraints would change the variability of the acceleration and affect performance.

Conclusions

The use of specific constraints in resistance training for rugby players elicits different structure of variability in body acceleration across multiple physiological time scales, particularly towards higher level scales (physiological systems). Thus, the sprinting ability and passing performance in rugby players might benefit from careful planning of how motor tasks are performed during resistance training. Understanding the non-linear process inherent to the manipulation of gym-based resistance training variables with constraints and its motor adaptations may help coaches and trainers to enhance the effectiveness of training.

Practical Implications

- Team sports players need to constantly adjust their actions to extremely dynamic environments. Using the ball during gym-based resistance training tasks can change the structure of movement variability and, therefore, compensate for the low variability observed in traditional resistance training performed at the gym.
- Sprinting ability and passing performances should benefit from these different structures of movement variability.
- Using the ball in resistance training increases variability inter-repetitions, elicits a wider area of the muscle tissue and reduces the risk of injury.

Acknowledgements

We thank the rugby players who took part in the study and Mr. Jacob González a rugby physical trainer from FC Barcelona. This work was supported by the Ministry of Education, Culture and Sport and the National Institute of Physical Education of Catalonia (INEFC), center of Barcelona. Bruno Fernández-Valdés is the recipient of a predoctoral fellowship from the Ministry of Education, Culture and Sport (FPU15/03235). Project NanoSTIMA: Macro-to-Nano Human Sensing: Towards Integrated Multimodal Health Monitoring and Analytics, NORTE-01-0145-FEDER-000016, co-financed by Fundo Europeu de Desenvolvimento Regional (FEDER) - NORTE 2020.

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Figure 1. (a) Table containing the magnitude-based inferences of each variable across the different movements of a resistance training tasks. (b) Standardised Cohen's differences for acceleration characteristics compared across the different movements of a resistance training task. Error bars indicate uncertainty in true mean changes with 90% confidence intervals.

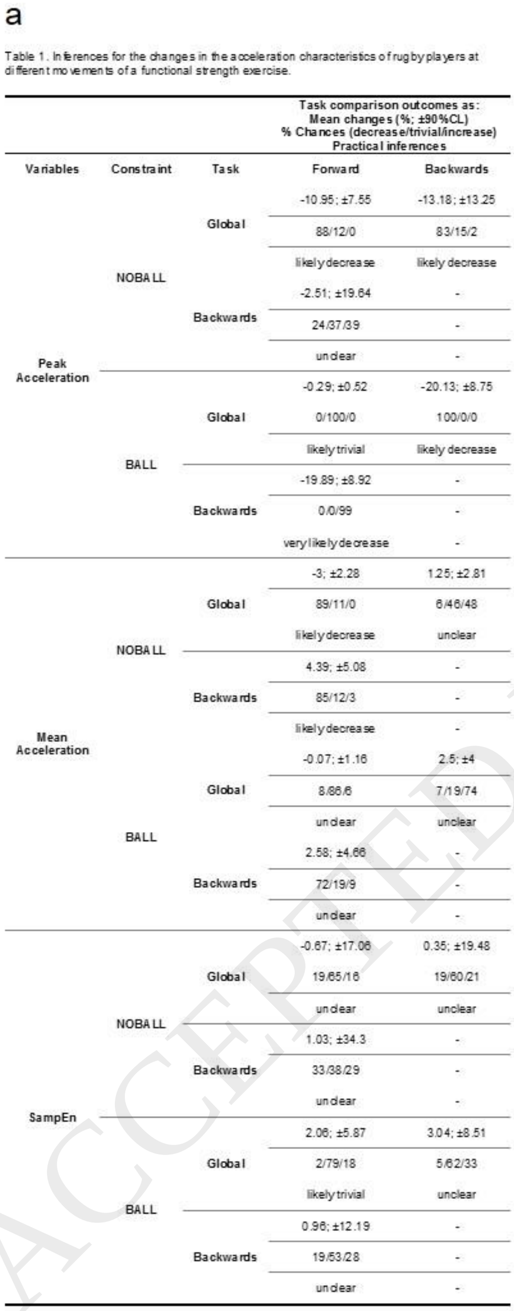

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Table 1. Inferences for the changes in the acceleration characteristics of rugby players at different movements of a functional strength exercise.

			Task comparison outcomes as: Mean changes (%; ±90%CL) % Chances (decrease/trivial/increase) Practical inferences	
Variables	**Constraint**	**Task**	**Forward**	**Backwards**
Peak Acceleration	**NOBALL**	**Global**	-10.95; ±7.55	-13.18; ±13.25
			88/12/0	83/15/2
			likely decrease	likely decrease
		Backwards	-2.51; ±19.64	-
			24/37/39	-
			unclear	-
	BALL	**Global**	-0.29; ±0.52	-20.13; ±8.75
			0/100/0	100/0/0
			likely trivial	likely decrease
		Backwards	-19.89; ±8.92	-
			0/0/99	-
			very likely decrease	-
Mean Acceleration	**NOBALL**	**Global**	-3; ±2.28	1.25; ±2.81
			89/11/0	6/46/48
			likely decrease	unclear
		Backwards	4.39; ±5.08	-
			85/12/3	-
			likely decrease	-
	BALL	**Global**	-0.07; ±1.16	2.5; ±4
			8/86/6	7/19/74
			unclear	unclear
		Backwards	2.58; ±4.66	-
			72/19/9	-
			unclear	-
SampEn	**NOBALL**	**Global**	-0.67; ±17.06	0.35; ±19.48
			19/65/16	19/60/21
			unclear	unclear
		Backwards	1.03; ±34.3	-
			33/38/29	-
			unclear	-
	BALL	**Global**	2.06; ±5.87	3.04; ±8.51
			2/79/18	5/62/33
			likely trivial	unclear
		Backwards	0.96; ±12.19	-
			19/53/28	-
			unclear	-

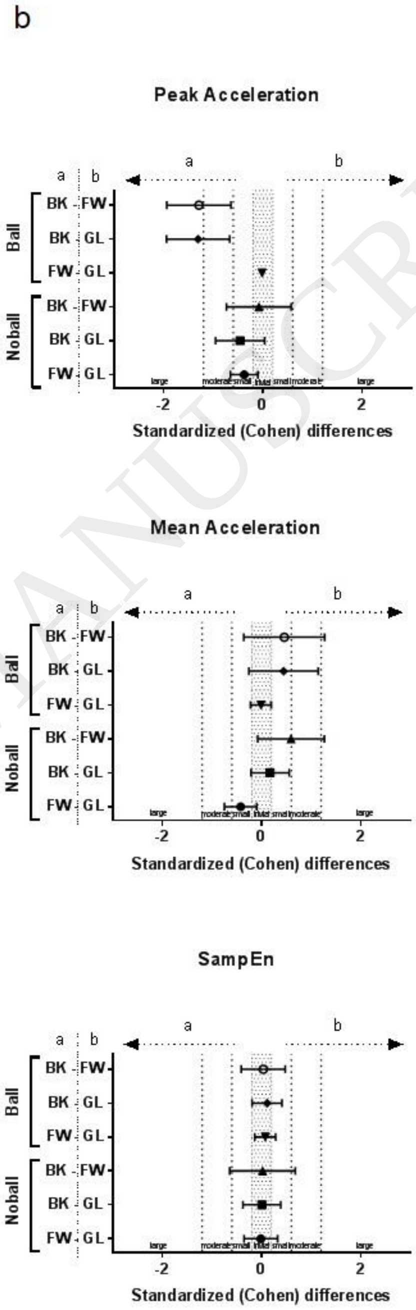

Figure 2. (a) Table containing the magnitude-based inferences of each variable across the different ball constraints applied to the resistance training task. (b) Standardised Cohen's differences for acceleration characteristics compared between different ball constraints during a resistance training task. Error bars indicate uncertainty in true mean changes with 90% confidence intervals.

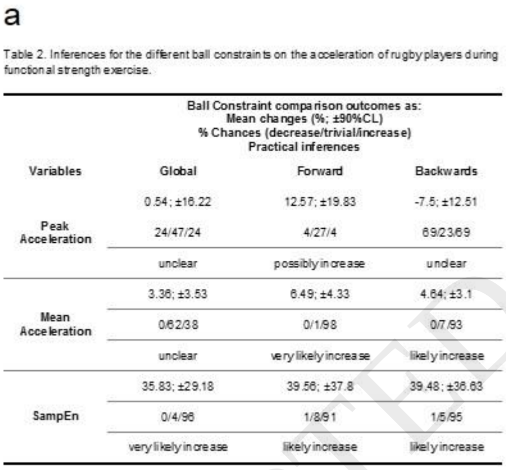

Table 2. Inferences for the different ball constraints on the acceleration of rugby players during functional strength exercise.

	Ball Constraint comparison outcomes as: Mean changes (%; ±90%CL) % Chances (decrease/trivial/increase) Practical inferences		
Variables	**Global**	**Forward**	**Backwards**
Peak Acceleration	0.54; ±16.22	12.57; ±19.83	-7.5; ±12.51
	24/47/24	4/27/4	69/23/69
	unclear	possibly increase	unclear
Mean Acceleration	3.36; ±3.53	6.49; ±4.33	4.64; ±3.1
	0/62/38	0/1/98	0/7/93
	unclear	very likely increase	likely increase
SampEn	35.83; ±29.18	39.56; ±37.8	39.48; ±36.63
	0/4/96	1/8/91	1/5/95
	very likely increase	likely increase	likely increase

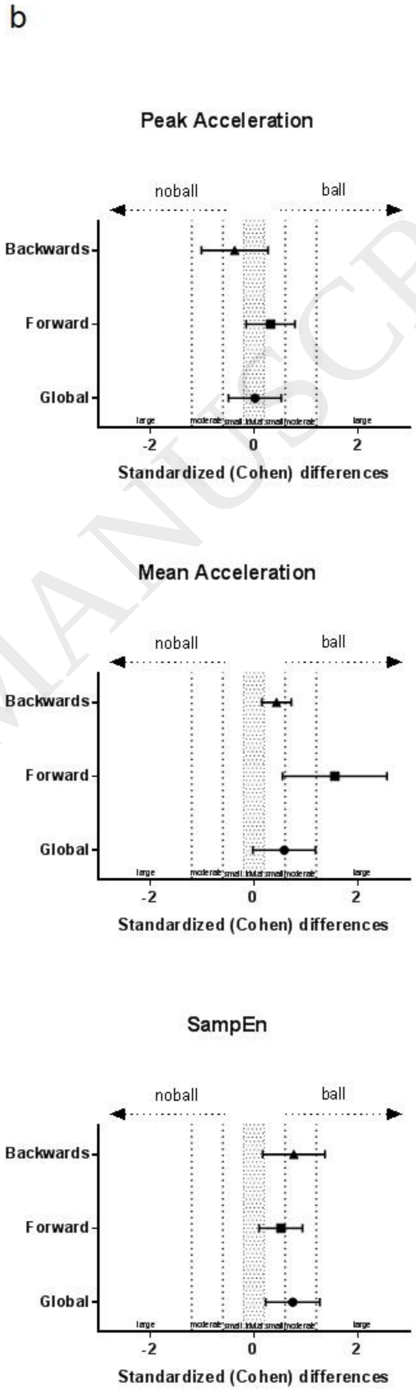

Figure 3. Multiscale entropy values for the different parts of horizontal resistance training movements with (BALL) or without (NOBALL) the constraint of using the ball, across different time scales.