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Effects of four consecutive one-repetition maximum testing days on neuromuscular performance, muscle soreness and perceived recovery

Efectos de cuatro días consecutivos de prueba de una repetición máxima sobre el rendimiento neuromuscular, el dolor muscular y la recuperación percibida

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Abstract. Purpose: The aim of this study was to evaluate the reliability of the one-repetition maximum (1RM) test and to assess the potential negative effects of this test on subsequent neuromuscular performance and perceived recovery. Method: A cross-sectional study in which subjects attended four consecutive days to perform an incremental 1RM test in the bench press. During each testing session, 1RM value, movement velocity against a submaximal (50% 1RM) load, perceived recovery, muscle soreness (DOMS), and rating of perceived exertion (RPE) were recorded. The analysis was performed by sorting the subjects into two groups (stronger: ≥ 1.2 1RM/bodyweight; and weaker: < 1.2 1RM/ bodyweight). Results: The reliability of 1RM values was good to excellent ($ICC_{3,1}$ = 0.83-0.99), while SEm values were low (< 6%). The results showed no significant changes either in 1RM values or in movement velocity against 50% 1RM load over the days. The reported RPE values were high (6.5 to 8) but remained unchanged across sessions. Perceived recovery was only affected in the stronger group from the third day, despite the reported values being between "moderately" and "well recovered." DOMS were significantly higher during the third and fourth testing days in both groups but remained low in values (< 3.3 in a 0 to 10 scale). Conclusions: Consecutive days of 1RM testing did not significantly affect neuromuscular performance, and only slight effects were found on perceived muscle soreness and perceived recovery.
Keywords: strength; testing; reliability

Resumen. Propósito: El objetivo de este estudio fue evaluar la confiabilidad de la prueba de una repetición máxima (1RM) y evaluar los posibles efectos negativos de esta prueba sobre el rendimiento neuromuscular posterior y la recuperación percibida. Método: Estudio transversal en el que los sujetos asistieron durante cuatro días consecutivos para realizar una prueba incremental de 1RM en press de banca. Durante cada sesión de test, se registró el valor de 1RM, la velocidad de movimiento contra una carga submáxima (50% de 1RM), la recuperación percibida, el dolor muscular (DOMS) y la calificación del esfuerzo percibido (RPE). El análisis se realizó clasificando a los sujetos en dos grupos (más fuertes: ≥ 1,2 1RM/peso corporal; y más débiles: < 1,2 1RM/peso corporal). Resultados: La confiabilidad de los valores de 1RM fue de buena a excelente ($ICC_{3,1}$= 0,83-0,99), mientras que los valores de SEm fueron bajos (< 6%). Los resultados no mostraron cambios significativos en los valores de 1RM ni en la velocidad de movimiento frente a una carga de 50% de 1RM a lo largo de los días. Los valores de RPE informados fueron altos (6,5 a 8) pero se mantuvieron sin cambios entre las sesiones. La recuperación percibida sólo se vio afectada en el grupo más fuerte a partir del tercer día, a pesar de que los valores informados estaban entre "moderadamente" y "bien recuperados". Los DOMS fueron significativamente más altos durante el tercer y cuarto día de test en ambos grupos, pero se mantuvieron bajos en valores (<3,3 en una escala de 0 a 10). Conclusiones: El test de 1RM en días consecutivos no afectó significativamente el rendimiento neuromuscular, y sólo se encontraron efectos leves sobre el dolor muscular percibido y la recuperación percibida.
Palabras clave: fuerza; pruebas; fiabilidad

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Introduction

Resistance training is the most widely used method to increase muscular strength and to obtain its associated benefits (ACSM, 2009). Exercise prescription during resistance training programs is usually based on the participants' maximal strength values. In addition, the efficacy of a training intervention is commonly assessed through the improvements in maximal strength. Due to the importance of maximal strength assessment, it is mandatory to use tests as sensitive and reliable as possible (Grgic, Lazinica, Schoenfeld, & Pedisic, 2020). Although maximal strength can be assessed via isometric and isokinetic muscle actions, dynamic muscle actions are the most commonly selected (ACSM, 2009).

Among these methods, one-repetition maximum (1RM) has been historically considered the gold standard for training prescription and athlete strength assessment. The good reliability of 1RM values has been widely reported in athletes with experience in resistance training (Hakkinen, 1993; LeBrasseur, Bhasin, Miciek, & Storer, 2008), although more controversial results have been shown in subjects with low training experience (Faigenbaum et al., 2012; Levinger et al., 2009; Martínez-Cava, Morán-Navarro, & García Pallarés, 2017). Some authors have suggested that both the early improvement in strength levels and lifestyle factors could affect the reliability of 1RM assessment in inexperienced subjects (McBurnie et al., 2019). However, a recent topic review concluded that the inter-test reliability of 1RM is consistent regardless of training level, showing similar reliability scores when data were grouped according to participants' training status (Grgic et al., 2020).

In addition to potential reliability issues, increases in injury risk, physiological stress and delayed muscle soreness associated with the 1RM test have been proposed as limitations of this assessment method.

In this line, Di Fabio (2001) and Barnard et al. (1999) reported injury incidences and muscle soreness in elderly people and populations with heart disease when performing a 1RM test. (DiStasio, 2014; Dohoney, Chromiak, Lemire, Abadie, & Kovacs, 2002; Goulart et al., 2020). However, several researches have shown no adverse effects either in young or in healthy adult athletes (Comfort & Mcmahon, 2015; Faigenbaum et al., 2012; García-Ramos et al., 2018). Another theoretically potential limitation of 1RM assessment relates to the neuromuscular fatigue caused by the test. According to Hakkinen (1993), exacerbated neuromuscular fatigue could affect the athlete's ability to train on successive days. In line with this, previous research has shown decreases in neuromuscular performance (e.g., jumping ability) after resistance training to failure using submaximal loads (Goulart et al., 2020; Ide et al., 2011). Nevertheless, the possible negative effect of a single resistance training session consisting in maximal loads performed to failure subsequently (e.g., next day/s) has received little attention. Therefore, the direct 1RM test may not negatively influence performance as long as the athlete carries out only a few failure-repetitions over 90% of 1RM (Smilios, 1998).

Therefore, the aims of the present study were (I) to evaluate the test–retest reliability of 1RM assessment; and (II) to assess the potential negative effects of this test on subsequent neuromuscular performance and perceived recovery.

Methods

Experimental approach to the problem

This study used a within-subject mixed observational cohort design. Subjects attended for four consecutive days to perform the 1RM test in the bench press exercise. Every day, subjects reported their perceived recovery and muscle soreness before the warm-up. Neuromuscular performance was assessed by measuring movement velocity against a submaximal load (50% 1RM). Rating of perceived exertion (RPE) was also registered in each experimental session.

Subjects

Seventeen handball players (17.6 ± 0.4 years) volunteered for the study. All players had at least 1 year of experience in the use of scales for monitoring training and resistance training, including the bench press exercise in their habitual training program. All of them were assessed from their 1RM in the previous month as a regular measure of training fitness. Subjects exhibiting endocrine or metabolic diseases, cardiopathies, upper torso injuries, or who were under any medical treatment, were excluded. All of them were requested not to train in the course of the study period. For statistical analysis, subjects were divided into different groups according to their relative 1RM/Bodyweight (i.e., stronger ≥ 1.2 and weaker < 1.2) (Hernández Davó, Botella Ruiz, & Sabido, 2017). The participants' characteristics are shown in Table 1.

This study was approved by the Ethics Committee of the University following the tenets of the Declaration of Helsinki. Each participant or their guardians (in the case of <18 years old players) provided written informed consent before participating in the study.

Table 1.
Descriptive characteristics by group

	Bodyweight (kg)	Height (cm)	1RM/BW[a]
Stronger (n = 9)	82.77 ± 10.73	178.06 ± 5.33	1.30 ± 0.15
Weaker (n =8)	75.45 ± 10.9	182.81 ± 8.72	0.96 ± 0.10
Total (n = 17)	79.32 ± 11.12	18.29 ± 7.31	1.14 ± 0.22

[a] The ratio obtained in the first measurement.

Testing procedures

Warm-up

After a general warm-up of 5 minutes cycling at a free cadence, subjects performed a specific warm-up consisting of a single set of eight repetitions at 50% 1RM and four repetitions at 70% of 1RM, with one minute rest between them. For the bench press, subjects were instructed to perform the exercise keeping five points of support during each repetition (head, shoulder and buttocks on the bench and feet on the floor). In addition, the bar had to touch the subjects' chest before the maximum extension of the elbow.

Movement velocity against a submaximal load

After the specific warm-up, the subjects assessed movement velocity against a submaximal load. This test consisted of a single set of six repetitions using the 50% 1RM load. Subjects were fully encouraged to lift the bar as fast as possible. Mean propulsive velocity (MPV) was recorded in each repetition using a linear position transducer (Chronojump, Boscosystem, Barcelona) with a sampling rate of 1000 Hz. The validity and reliability of this device has been previously reported (Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca, & García-Ramos, 2019). The greater MPV value of the set was used for statistical analysis.

1RM assessment

An incremental test was used to assess the 1RM bench press every day. The subjects performed three sets of one repetition at 80, 85 and 90% of 1RM, with a 3-minute rest break between them. These loads were calculated based on the first testing day and used for all sessions. According to the predicted 1RM obtained by using the mean propulsive velocity attained at 90% 1RM load each day, a direct 1RM load attempt was performed (Jidovtseff, Harris, Crielaard, & Cronin, 2011). To ensure the real 1RM, the researchers confirmed that every attempt was performed below 0.2 $m \cdot s^{-1}$ (González-Badillo & Sánchez-Medina, 2010).

Perceived recovery status (PRS)

Immediately after the general warm-up ended, subjects reported their perceived recovery status (PRS scale) (PRS; Laurent et al., 2011). They were asked, "How do you feel you have recovered?", defined between extremely tired (= 0) and highly energetic (= 10).

Muscle soreness

Delayed onset muscular soreness (DOMS) was reported

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by the subjects 24 hours after every session. Subjects were asked, "How much pain do you feel in your chest muscles?" rating their subjective feeling on a 0 to 10 scale (0 = no pain; 10 = a lot of pain) (Ojala & Häkkinen, 2013). Besides, the researchers recorded any injuries that could rise as the origin of muscle pain during the implementation.

Rating of perceived exertion (RPE)

Rating of perceived exertion values was obtained using the OMNI-RES scale. This scale aims to define exercise intensity between "extremely easy" (0) and "extremely hard" (10). Subjects were asked, "How hard do you feel the exercise was?" immediately after the last set of the 1RM test.

Statistical analysis

The relative reliability of the 1RM successive measures was analyzed using an intraclass correlation coefficient of two-way mixed effects for an absolute agreement based on a single rate ($ICC_{3,1}$) (Koo & Li, 2016). $ICC_{3,1}$ was set up with 95% confidence limits (CI). The $ICC_{3,1}$ values were interpreted according to (Portney & Watkins, 2002) as poor (< 0.5) moderate (0.5–0.74), good (0.75–0.89) and excellent (> 0.90). The relative and absolute reliability values were obtained using the equation proposed for standard error of the measurement based on $ICC_{3,1}$ (SEm) (Hopkins, 2000, 2015). Minimal detectable change (MDC) was calculated through the formula $(1.96 \times SEm \times \sqrt{2})$. A Kolgomorov–Smirnov test was used to confirm data normality. A two (strength level) by four (testing days) mixed ANOVA was performed to analyze 1RM, MPV, RPE, PRS and DOMS. Hedges'g index (g) was used to estimate the effect size between different days. The g values were interpreted as trivial ($g < 0.2$), small ($g < 0.5$), moderate ($g < 0.8$) and large ($g \geq 0.8$). Statistical differences were set at $p < 0.05$.

Results

The 1RM value showed a good to excellent relative reliability on all days in both the stronger ($ICC_{3,1}$ = 0.83–0.96, [CI = 0.41–0.99]) and the weaker group ($ICC_{3,1}$ = 0.93–0.99, [CI = 0.73–1.00]), and a good absolute reliability in both groups (SEm < 6%). The effect sizes for the differences in 1RM values between days were trivial (range -0.14 to 0.06). Data are shown in Table 2.

Table 2.
Reliability scores of 1RM bench press across days

	Stronger				Weaker			
	SEm (%)	SEm (kg)	MDC	$ICC_{3,1}$ (95%CI)	SEm (%)	SEm(kg)	MDC	$ICC_{3,1}$ (95%CI)
Day 1–2	3.62 (1.82, 5.43)	3.71	10.27	.89 (.63, .97)	1.80 (0.84, 2.76)	1.21	3.36	.99 (.97, 1)
Day 1-3	2.60 (1.30, 3.89)	2.65	7.36	.95 (.79, .99)	5.60 (2.62, 8.59)	3.78	10.47	.94 (.74, .99)
Day 1-4	2.57 (1.29, 3.84)	2.63	7.30	.94 (.78, .99)	5.97 (2.79, 9.14)	3.96	10.98	.93 (.73, .99)
Day 2–3	4.82 (2.42, 7.22)	4.89	13.55	.83 (.41, .96)	5.37 (2.51, 8.24)	3.61	9.99	.95 (.76, .99)
Day 2-4	4.10 (2.06, 6.14)	4.17	11.56	.86 (.51, .97)	5.75 (2.69, 8.82)	3.80	10.55	.94 (.75, .99)
Day 3–4	2.41 (1.21, 3.61)	2.46	6.81	.96 (.82, .99)	3.83 (1.79, 5.88)	2.54	7.03	.97 (.88, .99)

SEm = standard error of the measurement; MDC = minimal detectable change; ICC = intraclass correlation coefficient.

There was a significant main effect of groups on 1RM ($p < 0.05$) reflecting that 1RM was greater in the stronger group. No significant main effect of day, or group-by-day interaction was found. For MPV, no significant effect of group ($p = 0.482$), day ($p = 0.446$), or group-by-day interaction ($p = 0.069$) was found. The 1RM and MPV with a submaximal load across days in each group are shown in Figures 1 and 2. The ES for between-day differences was trivial (range -0.10 to 0.09) in both groups.

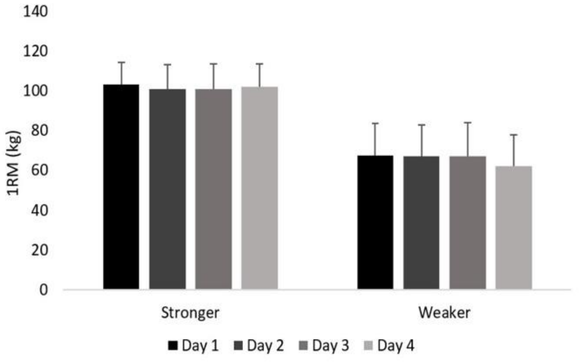

Figure 1. 1RM bench press values over days by group.

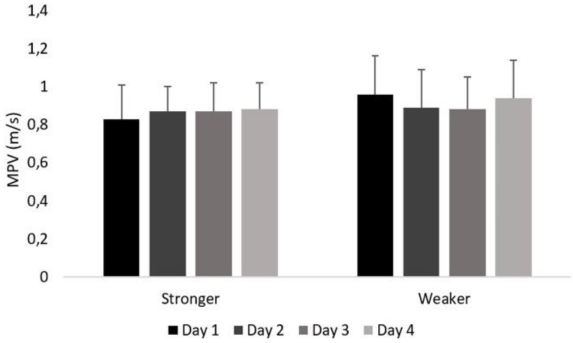

Figure 2. MPV against the 50% 1RM load on different days by group.

Data of perceived variables are shown in Figure 3 (stronger group) and Figure 4 (weaker group). There was a main effect of time ($p < 0.05$) on PRS values. Specifically, PRS on the third and fourth days was lower than on the second day ($p < 0.05$) in the stronger group. No effects of group ($p = 0.333$) or time by group interaction were found ($p = 0.927$). The ES values were small to moderate (range -0.40 to 0.78) in the stronger group, and trivial to small (range -0.12 to 0.37) in the weaker group. Regarding DOMS, a main effect of time ($p = 0.002$) and group ($p = 0.024$) was found. In particular, DOMS on the first and second day was lower than on the third and fourth day in

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the stronger group, while DOMS on the first day was significantly lower than on the second, third and fourth days in the weaker group. No group-by-time interaction was found in DOMS values ($p = 0.178$). In addition, DOMS on the first and second days was significantly higher in the weaker than in the stronger group. The ES values were small to large (range 0.35 to 1.48) in the stronger group and small to moderate (range 0.47 to 0.59) in the weaker groups. Finally, RPE showed a main effect on the group ($p = 0.041$), with the stronger group showing greater values. No effects of time ($p = 0.479$) or group-by-time interactions ($p = 0.368$) were found. ES was small (range 0.24 to 0.35) in the stronger group and trivial to moderate (range 0.09 to 0.56) in the weaker group.

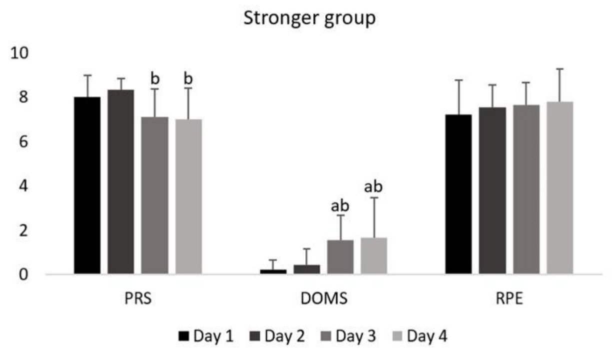

Figure 3. Perceptual variables scores over days in the stronger group.
* a = significantly different from day 1; b = significantly different from day 2.

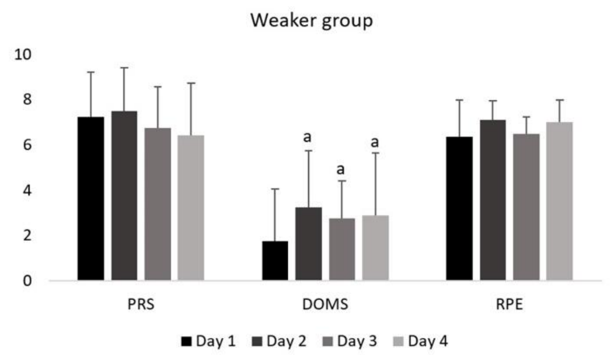

Figure 4. Perceptual variables scores over days in the weaker group.
* a = significantly different from day 1.

Discussion

In the last few years, the 1RM test has been questioned for reasons such as low reliability, potential risk of injury and associated fatigue. This study aimed to shed light on these questions by assessing the reliability of 1RM bench press on consecutive days and analyzing the potential negative effects on neuromuscular and perceptual variables. The main findings of the present study showed no differences in 1RM values over four consecutive days, and good to excellent absolute and relative reliability was found. In addition, neuromuscular performance assessed by movement velocity against a submaximal load was not affected across days. Perceived recovery and muscle soreness significantly increased over testing days, but the values can be considered practically irrelevant.

The 1RM assessment has been widely used for training prescription and performance evaluation in both research and professional fields. According to several authors (Benton, Raab, & Waggener, 2013; García-Ramos et al., 2018; LeBrasseur et al., 2008), the 1RM test shows consistent values over the days. However, other authors have suggested that strength level plays a role in 1RM reliability, with inexperienced athletes showing lower reliability scores (Faigenbaum et al., 2012; Levinger et al., 2009; Martínez-Cava et al., 2017). In the present study, changes in the limit of agreement between 1RM values across days were smaller than expected, suggesting that individual variability in 1RM was negligible across participants. In this regard, these results disagree with the assumption that strength level mediates in 1RM reliability, as the weaker group showed similar (or slightly higher) reliability scores to the stronger group. It seems, therefore, that the 1RM test is a reliable way to assess subjects' strength level, independently of their resistance training experience.

Movement velocity against a submaximal load has been used as a marker of neuromuscular status (e.g., fatigue state) (Sánchez-Medina & González-Badillo, 2011). To assess the possible fatigue induced by consecutive days of 1RM assesment, MPV against a submaximal load (50% 1RM) was measured. The analysis showed no differences in MPV values over days, either in the stronger or in the weaker group, which suggests that 1RM testing sessions did not lead to significant neuromuscular fatigue on subsequent days. These results are in line with those reported by Smilios (1998). It can be argued that despite the great level of effort required to lift a maximal load, the low training volume associated with a 1RM test could prevent performance impairments in the days after the test. Despite the unpractical fact of performing a 1RM assessment over consecutive days, the present results reinforce the idea that neuromuscular performance is not affected on the day after a 1RM testing protocol is conducted, and therefore, this can be removed as a limitation linked to this kind of assessment.

The use of perceived scales such as the PRS and the RPE to assess both subjective recovery (Beier, Earp, & Korak, 2019; Wilson et al., 2013) and exercise exertion (Helms, Cronin, Storey, & Zourdos, 2016; Hernández Davó et al., 2017) has increased in popularity in the resistance training field over the last few years. In the present study, perceived recovery was negatively affected on the third and fourth days only in the stronger group. However, the reported PRS values ranged on all days between moderately and well recovered (i.e., 6 to 8), highlighting that the perceived level of recovery was generally good. Again, these results can be partially explained by the low training volume associated with the testing sessions. In this regard, resistance sessions with a high training volume have been linked to increased muscle damage (Sikorski et al., 2013). The low number of total repetitions performed during the sessions used in the current study could have hampered a high muscle damage and the associated muscle soreness and low perceptions of recovery. Regarding muscle soreness, DOMS values were higher in the subjects in the weaker group than in the stronger group, which makes sense as muscle soreness is often associated with unaccustomed physical activity (Cheung, Hume, & Maxwell, 2003). In addition, both groups showed a significant increase in DOMS values starting on the second–third day, suggesting that subjects experienced some muscle damage. Despite this increase, the higher DOMS value reported in both groups were 3.25 in the 0 to 10 scale, which can be considered clinically negligible (Mueller-Wohlfahrt et al., 2013). Although usually explained after eccentric and isometric exercise, it can be hypothesized that the lack of greater increases in DOMS values over the successive testing days is due to the repeated bout effect (Nosaka, 2008). Thus, the repetition of the same exercise on consecutive days works as a protective mechanism against increased muscle pain (Nosaka, 2008; Nosaka & Newton, 2002).

Practical applications

The present study suggests that 1RM testing can be used as a reliable assessment of subjects' strength independently of their training status. This has been proven even in a "non-real" schedule with a consecutive 1RM test over four days. Despite some perceptual scores of recovery and slightly increased DOMS over the days, the reported values suggested an appropriate athletes' recovery and negligible muscle pain. In fact, neuromuscular performance assessed by movement velocity against a submaximal load was not affected any day. Finally, no injuries were recorded during the experimental procedures. Altogether, this study allows for the conclusion that the 1RM test is consistent and reliable, and subsequent performance is not affected by the testing protocol.

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