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The acute effect of strength exercises at different intensities on intraocular pressure

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Abstract
Background This study aimed to determine the effect of two basic strength exercises with progressive loads on intraocular pressure (IOP).
Methods Seventeen (out of 20 recruited) physically active male military officers (46 ± 4.77 years) performed the jump squat and the ballistic bench press exercises, in counterbalanced order, with four and five progressive loads, respectively. IOP was measured with a rebound tonometer before and after each of the corresponding loads.
Results IOP linearly increases with heavier loads for the jump squat (r = 0.976) and the ballistic bench press (r = 0.991) exercises. A significant IOP elevation was observed during the jump squat test ($p < 0.001$), and Bonferroni-Holm correction revealed that ~75% of one repetition maximum (RM) was able to promote significant changes in IOP with respect to the other three loads (all corrected p values <0.05), whereas the load corresponding to ~65%RM and ~60%RM induced a significant IOP rise when compared with the load of ~50%RM (corrected p-values of 0.43 in both cases). For its part, IOP significantly increases with the bench press test ($p < 0.001$), and performing the ~50%RM load was enough to induce significant IOP changes (corrected p-value <0.01).
Conclusions Acute performance of jump squat and ballistic bench press lead to a significant increase of IOP, and 5 min of rest are enough to recover baseline IOP values. There is a strong linear association between the increase in load and the IOP rise for both exercises, and bench press execution produces a significantly higher IOP increase when compared with the jump squat for the same relative loads.

Keywords Intraocular pressure · Exercise intraocular pressure · Exercise intensity · Rebound tonometer

Note: These results have not been presented at any conference.

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Introduction

Intraocular pressure (IOP) fluctuations are strongly implicated in the development of glaucoma, and the key factor to prevent ocular damages is IOP reduction and stabilization [1]. Different circumstances such as circadian variations [2], physical activity [3, 4], cognitive processing [5], Valsalva maneuver [6], and daily activities [7] have been shown to promote IOP changes. Therefore, understating IOP behavior as consequence of all these factors must be taken into account in order to preserve ocular health.

Strength training has proven to be effective in improving individuals' health status [8, 9]. For example, Warburton et al. [10] concluded that intervention programs designed specifically to enhance muscular strength, muscular endurance, muscular power, and flexibility helped to improve several indicators of health status [10]. For this reason, these types of training programs are recommended to be performed at least twice a week in order to maintain functional status and enhance quality of life [11]. However, special care should be taken when strength training is undertaken by populations with certain cardiovascular pathologies or risk factors as there may be undesirable side-effects [12].

Recent studies have focused on the acute effect of strength training on IOP, which could have relevance on IOP management for glaucoma patients or those at high risk of glaucoma. In this regard, Vieira et al. [13] investigated the effect of four repetitions at 80% of one repetition maximum (RM) of the bench press exercise with and without holding the breath, finding significant IOP increases following the bench press protocol, and even greater increases when participants held their breath [13]. Similarly, Rüfer et al. [4] found that upper limb physical anaerobic effort (20 repetitions with 65%RM on the butterfly machine) induced a significant IOP rise, whereas the leg curl exercise did not promote any significant change in IOP after performing 20 and 10 repetitions at 65%RM and 75%RM, respectively [14]. Although further research is required, it seems that the part of the body mainly involved and the exercise intensity have relevance in IOP changes during strength training. The five basic resistance training exercises are the squat, deadlift, bench press, pull-ups, and military press. Surprisingly, although these exercises are key in any resistance training programme, there is no information regarding the effect of the intensity (%RM) of lifting in these exercise on IOP behavior.

To address the problem discussed above, we determined IOP values before and after each of four and five progressive loads performed in the bench press and jump squat exercises, respectively. The aims of the present study were to (1) examine the effect of the intensity (%RM) of the exercise on IOP, and (2) compare IOP values between the ballistic bench press and jump squat exercises for the same relative loads. We hypothesized that (1) IOP could linearly increase with load as a consequence of higher muscular requirements and longer time under muscular tension, and also that (2) the bench press would elicit higher IOP values than the jump squat for the same relative load because this exercise is performed in supine position [14].

Methods

Participants

We conducted the study in conformity with the Code of Ethics of the World Medical Association (Declaration of Helsinki), and permission was provided by the university institutional review board (IRB approval 112/CEIH/2016). Twenty male military officers belonging to the Spanish Army Training and Doctrine Command (Granada, Spain) were enrolled in this study. All participants had a recent verification of good health and successfully underwent the annual physical tests of the Spanish Army, and all of them were free of medication. They had normal or corrected to normal vision (monocular and binocular visual acuity ≤0 log MAR) and were free of any ocular disease. We imposed as inclusion criteria 1) baseline IOP readings below 21 mmHg, and 2) all candidates were able to attain a peak velocity ≥ 1.5 $m{\cdot}s^{-1}$ for all the incremental loads with the exception of bench press 1-RM.Additionally, on the day of testing, all pilots were instructed to avoid alcohol and caffeine consumption [15, 16], and perform any exercise. Also, they were asked to sleep adequately the night prior to testing. We excluded two participants because they declined to participate in the squat test due to previous injuries, and other participant did not finish the entire protocol because he was not able to move the bar at the peak velocity required. As a result, we analyzed data from 17 out of 20 participants (M ± SD: 46 ± 4.77 years).

Materials and measurements

Jump squat

The warm-up included jogging, joint mobility, dynamic stretching, six countermovement jumps without additional weight, and one set of five jumps lifting 17 kg in the assessed exercise. Participants then performed an incremental loading test at four different intensities of the countermovement jump exercise performed in a Smith machine. The loads used were 20, 40, 60, and 80% of body weight. Participants performed two repetitions as quickly as possible with each load and rested for 1 min between trials with the same load and 5 min between different loads. Two trained spotters were present on each side of the bar during the protocols to ensure safety, as well as verbally to encourage the participants throughout the test.

Ballistic bench press

The warm-up included dynamic stretching, arm and shoulder mobilization, and one set of four repetitions during the Smith machine bench press throw with an external load of 17 kg. Thereafter, an incremental loading test at four different intensities of the ballistic bench press exercise was performed in a Smith machine. Initial load was set at 20 kg for all participants. This load was progressively increased by 2.5, 5, or 10 kg based on the maximum velocity of the bar recorded by a linear velocity transducer (T-Force System; Ergotech, Murcia, Spain). The load increase was proportional to the recorded velocity of the bar in such a way that the last load of the protocol was always performed at a maximum velocity of ≈ 1.4 $m{\cdot}s^{-1}$. Participants performed two repetitions with each load using the standard “touch-and-go” protocol in which the bar was lowered slowly to touch the chest before being lifted immediately at the maximum possible speed. The rest period was 1 min between trials with the same load and 5 min between different loads. Two trained spotters were present on each side of the bar during the protocols to ensure safety, as well as verbally to encourage the participants throughout the test.

The load corresponding to a maximum velocity equal to 1.5 $m \cdot s^{-1}$ (≈50% of 1RM according to García-Ramos et al. [17]) was doubled to determine the bench press 1RM. If the participants were able to lift this load at a mean velocity ≤ 0.25 $m \cdot s^{-1}$ it was considered their real 1RM. The load was reduced (if subjects were not able to complete the repetition) or incremented (if subjects lifted the load faster than 0.25 $m \cdot s^{-1}$) from 1 to 5 kg until determining their 1RM was determined. Participants needed an average of 1.9 ± 0.6 attempts to achieve their 1RM.

Intraocular pressure

Firstly, we performed biomicroscopic examination and direct ophthalmoscopy to check the anterior and posterior ocular structures in order to check possible undetected ocular pathologies [18]. We measured IOP with a portable rebound tonometer (ICare, Tiolat Oy, Inc. Helsinki, Finland) in a randomily selected eye, using the same eye for all subsequent IOP measures. This apparatus has shown good intra- and interobserver reproducibility, and it has been used in similar investigations [4]. Participants were instructed to look at distance while the probe of the tonometer was held at a distance of 4 to 8 mm, and perpendicular to cornea. Six rapid consecutive measurements were performed against the central cornea and the mean reading was displayed digitally in mmHg on the LCD screen. The apparatus indicates if differences between measures are acceptable or if the standard deviation (SD) is too large and a new measurement is recommended; we always obtained values with low SD (ideal measure).

Procedure

Firstly, participants signed the consent form and filled in the demographic questionnaire. Thereafter, participants were instructed to warm-up. At this point, we explained to the participants how to execute correctly the two strength exercises, and instructions were given to participants in order to prevent the Valsalva maneuver while performing physical efforts. After this, we measured IOP and they began with the corresponding test. We measured IOP right before and after the second repetition of each incremental load in a standing position with the exception of bench press 1-RM where just one repetition was carried out with the corresponding load. Participants were instructed to adopt a standing position after each repetition in order to collect the IOP value right after physical exertion (2–5 s approximately). After the first incremental test, participants were asked to rest for 10 min, and then we followed the same protocol for the second test (counterbalanced order). Finally, to avoid diurnal fluctuation that can affect physical performance [19] and IOP measures [2], all experimental sessions were conducted between 10 am and noon (12 pm).

Experimental design and statistical analysis

A repeated-measures design was used to examine the effect of an incremental loading test in the bench press and jump squat exercises on intraocular pressure. A two-way repeated measures ANOVA was separately applied for the jump squat (four loads: 1, 2, 3, and 4) and bench press (five loads: 1, 2, 3, and 4, and 1RM), using the intensity (four and five loads, respectively) and the point of measure (pre and post) as the within-participants factors, to examine the effect of the load on IOP. Additionally, the effect of the type of exercise on IOP was assessed through a repeated measures ANOVA (exercise [Squat vs. Bench press] × intensity [50%RM vs. 60%RM] × point of measure [pre vs. post]). When significant F values were achieved, pairwise differences between means were identified using Bonferroni-Holm post hoc procedures.

Results

Jump squat

The four consecutive absolute loads used during the test were 96.44 ± 8.33 kg (50.75 ± 4.69%RM), 110.96 ± 11.52 kg (58.33 ± 5.66%RM), 126.29 ± 12.55 kg (66.38 ± 6.17%RM), and 139.26 ± 12.94 kg (73.19 ± 6.1%RM). The two-way ANOVA conducted on IOP values during the jump squat incremental loading test demonstrated to be significant for the intensity, $F(3, 48) = 16.09$, $p < 0.001$, $\eta_p^2 = 0.501$, for the point of measure $F(1, 16) = 7.62$, $p = 0.014$, $\eta_p^2 = 0.323$, as well as for the interaction intensity x point of measure, $F(3, 48) = 19.61$, $p < 0.001$, $\eta_p^2 = 0.551$ (see Table 1, and Fig. 1 [panel a]). The increase in the load was strongly associated with a linear increase in IOP ($r = 0.976$; Fig. 1 [panel a]). Bonferroni-Holm post hoc procedures revealed that the highest intensity (~75%RM) was able to promote significant differences in IOP with respect to the other three loads ($p = 0.025$ for the ~65%RM, $p = 0.002$ for the ~60%RM, and $p = 0.001$ for the ~50%RM), whereas the load corresponding to ~65%RM and ~60%RM induced a significant IOP in comparison to the load of ~50%RM (corrected p-values of 0.43 in both cases). There was no cumulative effect of fatigue as demonstrated the one-way ANOVA for the pre-effort IOP measures, $F(3, 48) = 0.158$, $p = 0.924$, $\eta_p^2 = 0.01$.

Bench press

For the bench press test, the external loads used were 19.53 ± 1.94 kg (30.88 ± 4.61%RM), 26.65 ± 3.33 kg

Table 1 Intraocular pressure values before and after each intensity for the jump squat and the bench press exercise

	Pre (M ± SD)	Post (M ± SD)	*p*-value	ES
Jump squat				
50%RM	14.29 ± 2.47	14.18 ± 3.11	0.86	−0.04
60%RM	14.47 ± 2.18	15.18 ± 2.70	0.46	0.29
65%RM	14.41 ± 1.94	15.95 ± 2.49	0.08	0.70
75%RM	14.35 ± 1.58	17.94 ± 2.84	<0.01	1.62
Bench press				
30%RM	14.24 ± 2.66	14.76 ± 3.01	0.24	0.18
40%RM	14.18 ± 2.48	15.47 ± 2.32	0.04	0.54
50%RM	14.35 ± 2.52	16.76 ± 1.95	<0.01	1.08
60%RM	14.41 ± 2.35	18.18 ± 1.85	<0.01	1.80
1-RM	14.41 ± 2.18	19.82 ± 2.90	<0.01	2.13

M Mean, *SD* Standard Deviation, *p-value* Holm-Bonferroni correction, *ES* Effect Size, *IOP* Intraocular pressure, *RM* repetition maximum

(41.8 ± 3.97%RM), 32.41 ± 4.89 kg (50.65 ± 4.46%RM), 37.53 ± 5.6 kg (58.67 ± 5.25%RM), and 64.35 ± 10.65 kg (1RM). The two-way ANOVA revealed statistical significance for the intensity, $F(4, 64) = 36.66$, $p < 0.001$, $\eta_p^2 = 0.696$, for the point of measure, $F(1, 16) = 54.11$, $p < 0.001$, $\eta_p^2 = 0.772$, and for the interaction intensity x point of measure, $F(4, 64) = 38.34$, $p < 0.001$, $\eta_p^2 = 0.706$, when executing the bench press incremental loading test (see Table 1, and Fig. 1 [panel b]). Similar to the jump squat test, we found that IOP linearly increases with external loads ($r = 0.991$; Fig. 1 [panel b]). The multiple comparison analysis showed that ~50 RM% was enough to produce significant changes in IOP in comparison with the lightest load (~30%RM) ($p = 0.006$ for ~50%RM, $p < 0.001$ for ~60%RM, and $p < 0.001$ for the 1RM). Additionally, a separate analysis for the pre-exercise IOP values corroborated no significant changes between the five IOP measures before the bench press, $F(4, 64) = 1.148$, $p = 0.342$, $\eta_p^2 = 0.067$, showing that 5 min of rest between loads are enough to recover baseline IOP levels.

Jump squat vs. bench press

The repeated measures ANOVA revealed significant main effects for exercise, $F(1,16) = 15.79$, $p < 0.001$, $\eta_p^2 = 0.497$), intensity, $F(1,16) = 18$, $p = 0.001$, $\eta_p^2 = 0.529$), and the point of measure, $F(1,16) = 14.84$, $p = 0.001$, $\eta_p^2 = 0.481$), but the interaction did not show statistical differences ($F < 1$). IOP values were significantly higher for the bench press than the jump squat for the same relative intensities (Fig. 2).

Discussion

IOP is sensitive to homeostatic disturbances caused by physical tasks among other types of activities. However the effect of exercise, mainly anaerobic, on IOP is not firmly established. We tested two of the main basic and popular resistance training exercises (jump squat and bench press) with several progressive loads. Our results show that, as hypothesized, the acute performance of strength training exercises increases IOP. The magnitudes of the changes in IOP are dependent on both the intensity and the exercise type. The increase in the load is associated with an increase in IOP, and for the same relative load (%RM) the increase in IOP is higher during the bench press throw than during the jump squat. Our results also prove that 5 min of rest between loads were enough to recover baseline IOP values. These findings support the idea that physical efforts that interfere the regular interchange of respiratory gases (e.g. Valsalva maneuver, which occurs with a closed glottis) and promote homeostatic variations cause an IOP rise.

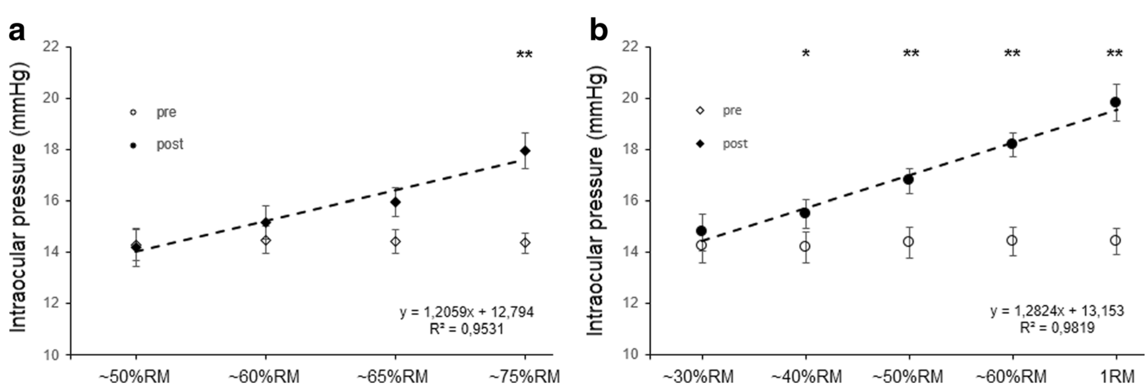

Fig. 1 **a**) Effects of performing jump squats at different intensities on intraocular pressure, and **b**) effects of performing bench press at different intensities on intraocular pressure. All resistances are calculated as a percentage of one repetition maximum (RM). The pre-exercise values for each resistance are represented with *open diamonds* and *circles*, and the post-exercise values with *black-filled diamonds* and *circles*, respectively. The *black dashed lines* illustrated the linear tendency of intraocular pressure with the different loads implemented. * and ** indicate statistically significant differences between the pre-exercise and post-exercise measures (Bonferroni-Holm corrected *p*-value <0.05 and <0.01, respectively). Errors bars represent the standard error (SE). All values are calculated across participants ($n = 17$)

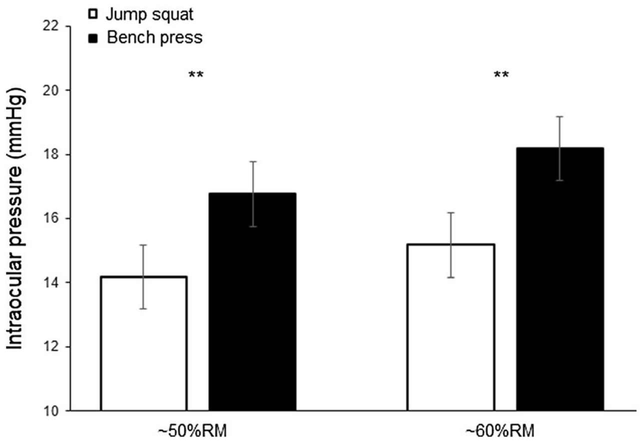

Fig. 2 The effect of the type of exercise on IOP at the same relative intensities. Average intraocular pressure values for each exercise (jump squat vs. bench press) at 50 and 60% of one repetition maximum (RM). Data from the squat exercise are represented in *white* and from the ballistic bench press in *black*. Pre-exercise IOP values are not showed in this figure, all pre-exercise values are very similar (see the Results section. ** indicates statistically significant differences between the two exercises (Bonferroni-Holm corrected *p*-value <0.01). Errors bars represent the Standard Error (SE). All values are calculated across participants ($n = 17$)

The performance of low-intensity exercise has been associated with a decrease or unchanged IOP [3, 4, 20–23]. In contrast, high-intensity physical exercise leads to a considerable IOP rise [13, 24]. There are different theories to explain the IOP rise during resistance exercise. For example, it has been documented that IOP changes transiently in parallel with blood pressure during isometric exercise. The increase in blood pressure and IOP has been speculated to be related to the strength of contraction and also to the size of muscle mass involved during exercise [25]. Therefore, the intensity and the metabolic demands of exercise seem to influence those IOP variations. In addition, other activities that involve variations in respiratory gas exchange, such as playing wind instruments, have shown to promote rises in IOP and this change was correlated with the degree of exhalation [26]. Similarly, Dickerman et al. [24] reported that individuals producing maximal isometric contractions while holding their breath experience a mean IOP increment of 15 mmHg, and Vieira et al. [13] found that four repetitions of a bench press exercise lead to IOP increase, with greater IOP values when the participant held their breath. Moreover, the Valsalva maneuver seems to play an important role in the IOP behavior during physical efforts.

Regarding the effect of the type of exercise performed on IOP changes, Rufer et al. [4] found that upper limb exercises promoted a significant IOP increment whereas lower limb exercises did not induce any significant variation in IOP. It was suggested that this difference could result from an involuntary Valsalva maneuver while using the butterfly machine or, could be associated with increased facial muscle tension (facial congestion) during muscular effort [27]. We asked participants to avoid making a Valsalva maneuver during effort and IOP measurements, but we cannot discard the possibility that it occurred unintentionally. Previous studies have shown that executing intensive resistance exercise while lying down cause an IOP rise due to the consequences of the Valsalva maneuver [13]. Both the supine posture and the performance of upper-body resistance training exercises contribute to the higher IOP rise when compared to the jump squat exercise with the same load. For example, when exercising at 60%RM, a mean IOP elevation of 0.89 mmHg and 3.94 mmHg was measured in jump squat and bench press respectively, which represents approximately 6% and 28% of baseline mean value. The cumulative effect of long-term intermittent IOP elevation during anaerobic exercise performance may result in glaucomatous damage as has already been shown by playing high resistance wind instruments [26]. Thus, to prevent IOP fluctuations, exercising the upper-body in a supine position seems to be less desirable than resistance exercise in standing position or exercising the lower body. It has been stated in a previous investigation that exhausting effort could be a potential risk factor for the development and progression of glaucoma [11]. However, the IOP variations in our study were observed over short periods of time so we cannot establish the long-term effect on ocular health. Further research is required to clarify this.

The present findings must be interpreted cautiously in clinical patients since our experimental sample is formed by healthy individuals, and therefore, this study should be replicated with glaucoma patients or suspects due to the possible disturbance in their IOP autoregulatory control [28]. Also, the technique for IOP assessment must be considered since repeated IOP measurements by applanation or indentation tonometry significantly diminish IOP on remeasurement, and this methodological bias can explain the IOP-lowering effect of exercise [25]. Our decision to use rebound tonometry to measure IOP was based on the fact that it has been demonstrated to show no learning effect is rapid and does not require the use of topical anesthetic [4, 29]. The recent development of the contact-lens sensor for continuous IOP monitoring could offer a better alternative for recording the impact of physical effort on IOP [30]. This technology avoids the inconvenience of IOP measurement devices that require the head and eyes to be motionless and has obvious practical advantages when outside the laboratory environment. It is our hope that future studies into the effect of resistance exercise and the long-term effect of strength training on IOP management will consider the effect of body position during resistance exercise, implement continuous IOP monitoring and include both female subjects and people with glaucoma.

In conclusion, the results of the present study indicate that the acute performance of basic resistance training exercises increases IOP. Regardless of the type of exercise (jump squat or bench press throw), the increase in the load was strongly associated with a linear increase in IOP. Interestingly, the increase in IOP was significantly higher in the bench press throw compared to the jump squat for the same relative load (%RM). The supine position of the bench press compared to the standing position of the squat could be responsible of the higher increase in IOP during the bench press throw. Based on these results, two basic recommendations can be provided to avoid undesirable IOP fluctuations in at-risk populations, involved in resistance training programs, particularly glaucoma patients or those at high risk of glaucoma: 1) the use of low-moderate loads (<50%RM), and 2) the avoidance of resistance training exercises performed in a supine position. Future studies should evaluate the effect of anaerobic exercise in a clinical population.

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Compliance with ethical standards

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Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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