Title: Effect of wearing different types of face masks during dynamic and isometric resistance training on intraocular pressure

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Running title: Exercise-induced IOP changes with face masks

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Abstract

Clinical relevance: The use of face masks has demonstrated to be an effective strategy to prevent transmission of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2). Wearing face masks, mainly FFP2 (Filtering Face Piece 2) masks, during exercise practice has demonstrated to affect several physiological measures, but its impact on intraocular pressure (IOP) remains unknown.

Background: This study was aimed at assessing the IOP behavior during the execution of the dynamic and isometric biceps-curl exercise with a surgical and FFP2 face mask.

Methods: 22 physically active young adults performed sets of 10 repetitions against the 10-RM (repetition maximum) load and 1-minute isometric effort against a load 15% lower than the 10-RM load with the FFP2 and surgical mask and without any mask. A total of six exercise sets (3 experimental conditions [FFP2, surgical and control] × 2 exercise modalities) were performed. A rebound tonometer was used to measure IOP before, during (10 measurements), and after (30-seconds of passive recovery) each training set.

Results: At rest, there were not statistically significant IOP differences ($p=0.222$). During dynamic exercise, IOP showed a progressive IOP rise ($p<0.001$), observing a higher IOP response with the FFP2 than without mask (corrected p-value=0.003). For the isometric exercise, there was a greater IOP response as a function of accumulated effort ($p<0.001$), which was dependent of the face mask used (FFP2>surgical>control; corrected p-values<0.01).

Conclusions: FFP2 masks cause a heightened IOP response during the execution of dynamic and isometric biceps-curl exercise, suggesting that, when possible, glaucoma patients may limit the use of FFP2 masks during resistance training.

Keywords: COVID-19, resistance training, ocular health, glaucoma management.

The irruption of the coronavirus disease 2019 (COVID-19) has dramatically changed the way of living. There is scientific evidence that the spread of droplets and aerosol particles is the main mode of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) transmission.[1,2] Based on this evidence, physical distancing (6 feet / 2 meters), avoiding crowded indoor spaces, wearing face masks, vaccination and hygiene are demonstrably some of the most effective preventive measures.[3] Some of these preventive measures, such as the use of face masks when people are indoors, are expected to remain in place for a long time in some countries. Therefore, it is important to analyse the physiological effects of wearing face masks during indoor activities that are commonly performed without masks (e.g., resistance training).

There exist some claims that the use of face masks may influence the cardiopulmonary functioning and perceived levels of breathing resistance, mainly while performing physically demanding tasks.[4–8] Nevertheless, the magnitude and validity of these results have been scientifically questioned.[9–12] In this regard, Law and colleagues (2021)[13] recently found that wearing a surgical mask during functional magnetic resonance imaging caused mild hypercapnia. However, Epstein et al. (2020)[5] observed minor effects of wearing a surgical mask on physiological variables during a strenuous workout, but a significant increase in end-tidal carbon dioxide levels was observed when a N95 mask, which is comparable to a FFP2 (Filtering Face Piece 2) mask, was used. Taken together, the effects of wearing face masks on the human physiology is still a matter of debate by the scientific community and are likely to differ between different face masks (e.g., surgical or FFP2/N95 masks).

It has been demonstrated that physical training positively impacts numerous health conditions, including some ocular diseases.[14] Notably, the association between physical exercise and glaucoma has been extensively researched in the last years due to the high prevalence of this ocular condition worldwide (i.e., approximately 76 million people in 2020).[15] Specifically, low-intensity endurance exercise (e.g., walking, jogging, or cycling) reduces intraocular pressure (IOP) levels,[16,17] and this is important because IOP reduction is the only proven strategy for the prevention and management of glaucoma.[18] On the contrary, the execution of resistance training against heavy loads provokes an acute IOP rise,[19–23] and this effect is exacerbated when the interchange of gases is compromised.[24,25] In the same line, the exposure to hypoxia and hypercapnia conditions has been shown to induce a significant IOP rise.[26,27] Remarkably, a recent study showed that using a FFP2 mask counteracts the IOP lowering-effect of low-intensity aerobic exercise on glaucoma patients.[28] Therefore, it is plausible to expect an increase in IOP when face masks are used during resistance training.

Due to the fact that wearing face masks is one of the most effective strategies for preventing COVID-19 transmission, mainly in indoor facilities (e.g., fitness centers), being its use is mandatory in most countries, this study has been designed to assess the impact of wearing surgical and FFP2 masks during resistance training on IOP. In particular, the objective of this study was to assess the IOP behavior during the execution of the biceps-curl exercise while wearing surgical and FFP2 face masks. Complementarily, a further objective of this investigation was to determine these effects when the biceps-curl exercise is performed in dynamic (i.e., 10 repetitions against the 10-RM [repetition maximum] load) and isometric (i.e., 1-minute isometric effort against a load 15% lower than the 10RM load) conditions. Recent evidence suggests that FFP2 masks cause an IOP rise in comparison to the same physical activity (400-m walking protocol) without using any face mask in glaucoma patients.[28] However, based on the mixed results observed in the scientific literature about the impact of wearing face masks on the human physiology, we had no basis on which to formulate specific hypotheses. The results of this study would permit to determine the impact of using face masks during resistance training on IOP levels, and it will be of special interest for eye care specialists in order to provide evidence-based recommendations for glaucoma patients or those at risk.

METHODS

Participants and ethical approval

First, an a-priori sample size calculation for an analysis of variance (ANOVA) with within factors using the G* Power 3.1 software was performed.[29] For this analysis, an effect size of 0.20, alpha of 0.05, power of 0.90, and level of correlation between repeated measures of 0.5 were considered, which projected that the inclusion of 22 participants was required to achieve the desired level of accuracy. As a result, 22 physically active and healthy sport science university students took part in this study (see **Table 1** for a description of the experimental sample). All volunteers were free of any physical limitation that could compromise testing performance and had no history of any ocular condition (checked by slit-lamp and direct ophthalmoscopy examination), cardiovascular disease, or surgery. Participants were physically active through their standard academic curriculum, which included ~6 physical activity classes per week, but none of them was an active athlete (7.6 ± 2.1 hours per week). The study protocol adhered to the guidelines of the World Medical Association (Declaration of Helsinki), and was approved by the Institutional Review Board. All participants read and signed an informed consent form.

Experimental design and procedure

This cross-sectional study was designed to explore the short-term effects of using face masks during the execution of upper-body resistance training on the IOP behavior of healthy young adults. All participants performed the dynamic and isometric biceps-curl exercise under three conditions: (i) wearing a FFP2 face mask (MZC-KZ, Mezorrison Health Science & Technology Co. Ltd, Shenzhen, China), (ii) wearing a surgical face mask (3PLY, KRAPE SA, Madrid, Spain), and (iii) without wearing a face mask (control condition). The six exercise sets (3 experimental conditions [control, surgical, and FFP2] × 2 exercise modalities [dynamic and isometric]) were randomly performed in the same experimental session. Consecutive sets were separated by 5 min of passive recovery. The isometric effort always lasted 1 minute, and the duration of the dynamic effort (10 repetitions against the 10RM load) was also close to 1 minute. Therefore, the total duration of the exercise sequence was of approximately 31 minutes (6 minutes of exercise plus 25 minutes of rest). The dependent variable was the IOP, which was assessed before each set, during exercise performance (a total of 10 measurements in each set), and after 30 seconds of passive recovery.

Testing procedures

The session began with a standardized warm-up consisting of 5 minutes of jogging and upper-body dynamic stretching exercises. Afterwards, the 10-RM load (i.e., the load with which participants can perform a maximum of 10 repetitions) was individually determined by an experienced strength and conditioning researcher through an incremental loading test. Participants first performed a set against 50% of their self-perceived 10-RM load and they were told to stop after 5 repetitions when they or the examiner identified that more than 10 repetitions could be performed. The load was then incremented cooperatively between the participant and the researcher and a new set was performed after 3 min of passive rest. Participants needed between 3 and 5 sets to reach the 10-RM load. The load used in the isometric curl-exercise represented approximately 85% of the 10-RM load because in a pilot testing, this was the load that participants could hold at a 90º elbow angle for at least 1 minute. The biceps-curl exercise was always performed in a standing position and bilaterally using an EZ curl bar and weight discs. The standing isometric biceps curl exercise was performed at a 90º elbow angle.

Intraocular pressure assessment and data processing

IOP was measured with a portable rebound tonometer (Icare Ic100, Tiolat Oy, Inc. Helsinki, Finland) from the right eye. This device demonstrably obtains repeatable measures and provides comparable results to Goldmann applanation tonometry, which is considered as the gold standard for IOP measurement.[30] The use of the Icare tonometer allows measuring IOP in applied contexts since it is hand-held, does not require the instillation of topical anesthesia, enables acquiring repeated measures in a rapid manner, and is very well-tolerated.[31] For IOP data acquisition, participants were instructed to fixate on a distant target as consecutive measurements were taken against the central cornea by an experienced optometrist. Every six consecutive measurements, the mean value is displayed, and the examiner vocalized the IOP value to a research assistant for data logging. During dynamic exercise, IOP readings were acquired with the participant in standing position and immediately after completing each repetition (i.e., elbows extended at 180°). During isometric exercise, IOP measurements were semi-continuously taken during the 1-

min isometric effort (i.e., in an intermittent manner since it was not automatically performed) while the participant remained in supine position. In order to obtain a set of equally distributed IOP at regular intervals, a procedure based on multirate digital signal processing was employed.[32] This method has been thoroughly described in recent published articles.[24,33–35] Aiming to compare the dynamic and isometric biceps-curl sets, IOP readings obtained during the 1-minute isometric effort were polynomially interpolated (i.e., using polynomial functions to connect the known points) to achieve 10 discrete values for each subject and condition. Baseline and recovery IOP measurements were taken 15 seconds before and 30 seconds after each training set, respectively.

Statistical analysis

The normal distribution of the data and the homogeneity of variances were confirmed with the Shapiro-Wilk and Levene´s tests, respectively ($p > 0.05$). A two-way repeated measures ANOVA (exercise modality [dynamic and isometric] and face mask [control, surgical, and FFP2]) was carried out to check possible baseline differences on IOP. For the main analysis, a repeated measures ANOVA for IOP considering the exercise modality (dynamic and isometric), face mask (control, surgical, and FFP2), and point of measure (baseline, 1 to 10, and recovery [a total of 12 measurements]) was performed. The magnitude of the changes was reported by the partial eta squared (ηp^2) and Cohen´s *d* effect size (*d*) for F and T tests, respectively. The Holm-Bonferroni procedure was applied for multiple comparisons, and the level of statistical significance was established at 0.05.

RESULTS

The analysis of the possible differences between the baseline IOP readings did not exhibit statistically significant differences for the main effects of “exercise modality” ($F_{1,21} = 2.09$, $p = 0.163$) and “face mask” ($F_{2,42} = 1.56$, $p = 0.222$), as well as the interaction “exercise modality × face mask” ($F_{2,42} = 0.36$, $p = 0.704$).

The main analysis revealed statistically significant differences for the main effects of “exercise modality” ($F_{1,21} = 20.74$, $p < 0.001$, $\eta^2_p = 0.50$), “face mask” ($F_{2,42} = 17.47$, $p < 0.001$,

η^2_p = 0.45), and "point of measure" ($F_{11,231}$ = 155.67, p < 0.001, η^2_p = 0.88), as well as for the interactions "exercise modality × point of measure" ($F_{11,231}$ = 3.58, p < 0.001, η^2_p = 0.15) and "face mask × point of measure" ($F_{22,462}$ = 7.91, p < 0.001, η^2_p = 0.27). However, the interactions "exercise modality × face mask" ($F_{2,42}$ = 0.77, p = 0.468, η^2_p = 0.04) and "exercise modality × face mask × point of measure" ($F_{22,462}$ = 1.15, p = 0.292, η^2_p = 0.05) did not reach statistical significance. Subsequently, two separate repeated measures ANOVAs were performed for the dynamic and isometric exercise modalities.

For the dynamic condition, there was a statistically significant effect of the "face mask" ($F_{2,42}$ = 6.61, p = 0.003, η^2_p = 0.24), "point of measure" ($F_{11,231}$ = 105.41, p < 0.001, η^2_p = 0.83), and "face mask × point of measure" ($F_{22,462}$ = 3.94, p < 0.001, η^2_p = 0.16). Post-hoc analyses revealed greater IOP values while wearing the FFP2 mask in comparison to the control condition (corrected p-value = 0.003, d = 0.77), whereas the comparisons between the FFP2 and surgical masks (corrected p-value = 0.051, d = 0.49), as well as between the surgical mask and control condition (corrected p-value = 0.210, d = 0.27) were not statistically different (**Figure 1, panel A**). For the isometric condition, statistically significant differences were observed for the "face mask" ($F_{2,42}$ = 20.62, p < 0.001, η^2_p = 0.50), "point of measure" ($F_{11,231}$ = 97.71, p < 0.001, η^2_p = 0.8), and "face mask × point of measure" ($F_{22,462}$ = 5.50, p < 0.001, η^2_p = 0.21). Post-hoc comparisons demonstrated greater IOP values in the FFP2 condition in comparison to the surgical condition (corrected p-value = 0.004, d = 0.71) and the control condition (corrected p-value < 0.001, d = 1.37), and also, higher IOP vales were obtained while wearing the surgical mask in comparison to the control condition (corrected p-value = 0.004, d = 0.66) (**Figure 1, panel B**).

Regardless of the face mask condition, the IOP linearly increased during the execution of both dynamic and isometric efforts (all P-values < 0.001, and coefficients of determination ranging from 0.87 to 0.98). Lastly, higher IOP values were always observed for the isometric condition compared to the dynamic condition. The IOP differences observed between the dynamic and isometric modalities of the biceps-curl exercise with the different face masks are depicted in **Figure 2**.

DISCUSSION

There is consensus in the scientific community that wearing face masks is one of the most effective strategies to prevent infection from COVID-19, with FFP2/N95 masks providing a stronger protection from viral transmission.[3] However, having stated this, it is of interest to obtain data in relation to the impact of wearing face masks during resistance training on IOP, since qualitative and quantitative alterations of the exchange of gases during physical effort has been demonstrated to cause IOP fluctuations.[24–27] Data show a progressive IOP rise as a function of accumulated effort in the dynamic and isometric biceps-curl exercise, with these effects being more accentuated while wearing the FFP2 mask. In the dynamic condition, there were not meaningful differences for IOP values between the surgical mask and control condition, whereas this comparison reached statistical significance in the isometric biceps-curl exercise. Notably, baseline IOP readings did not differ across conditions, suggesting that wearing face masks does not alter IOP levels at rest. Also, IOP levels rapidly returned to baseline levels after exercise cessation in the three experimental conditions, showing that the IOP rise associated with the use of face masks during resistance training is transient. Taken together, the current results reveal that the use of FFP2 masks causes a heightened IOP response during the execution of dynamic and isometric upper-body resistance training and, thus, when possible, glaucoma patients or those at risk may consider to limit the use of FFP2 masks during resistance training.

The execution of resistance training has been commonly associated with IOP rises, with these effects being dependent on numerous factors such as exercise intensity,[34,36] exercise type,[35] accumulated effort,[20,37] or participants´ fitness level.[38,39] Within this range of factors, the quality and quantity of the breathing pattern has demonstrated to alter the IOP behavior during exercise performance and in resting conditions.[24–27] In this regard, recent studies suggest that masks could increase carbon dioxide retention (hypercapnia)[8,13] and airway resistance.[4,40,41] In addition, a recent work has found that performing a 400-m walking test with a FFP2 mask counteracts the IOP reduction linked to low-intensity aerobic in glaucoma.[28] This study shows that using a FFP2 provokes a greater IOP rise during the execution of dynamic and isometric bicep-curl training sets, which seems to support the relationship between alterations in the breathing pattern and IOP changes. In the current study, the impact of face masks on breathing resistance and gases concentration (i.e., carbon dioxide and oxygen levels) was not assessed, and thus, the specific physiological explanation for these findings require further investigation.

Overall, the available results in the scientific literature indicate that FFP2 models have a greater impact on the human physiology in comparison to surgical masks,[5,6] which is in line with the outcomes of this study. Remarkably, the average IOP differences between the FFP2 and control conditions were of approximately 1.7 and 2.3 mmHg for the dynamic and isometric exercises, respectively, whereas the differences between the surgical and control conditions were of approximately 0.5 and 1.0 mmHg for the dynamic and isometric exercises, respectively. Specifically, during the execution of resistance training with the FFP2 mask, the average IOP rise in the dynamic and isometric exercise when compared to the control condition was 84%. This IOP increment caused by the use of FFP2 masks is similar to the IOP changes associated with caffeine intake (i.e., 4 mg/kg of caffeine) or swimming goggles wear.[42,43] With that in mind, healthcare providers should consider the possible clinical relevance of these effects in order to provide recommendations about the most pertinent face mask for exercise practice in certain populations (e.g., glaucoma patients or those at risk).

Although it was not the primary objective of this investigation, the analysis of the IOP response with the different face masks between the dynamic and isometric biceps-curl exercises was carried out. There was a clear trend towards higher IOP values during the execution of isometric in comparison to dynamic biceps-curl exercise (effect size ranging from 0.39 to 0.52), with this finding being consistent in the FFP2, surgical and control conditions. This is the first study that has assessed the IOP response to isometric and dynamic resistance training in the same set of subjects. In this work, the average IOP rise obtained for the last measurement during physical effort in the control conditions were of approximately 4 mmHg and 6 mmHg for the dynamic and isometric sets, respectively. These results are in line with previous investigations, where an average IOP rise of 3-4 mmHg has been reported for the last repetition of the dynamic biceps-curl exercise against the same relative load used in this study,[25,37,44] and an average IOP peak of 4-6 mmHg in the isometric biceps-curl exercise.[24,35] Moreover, isometric resistance training sets lead to greater IOP values than dynamic exercises regardless of the face mask condition. From an applied perspective, the execution of dynamic resistance training should be prioritized to isometric efforts in individuals who need to minimize IOP peaks such as glaucoma patients or those at high risk of glaucoma onset. Also, due to the significant effect of FFP2 face masks on IOP levels during resistance training (i.e., reaching an IOP difference of 2.5 mmHg and 3.5 mmHg for the dynamic and isometric exercise in comparison to the control condition, respectively), eye care specialists should be aware of these effects in order to inform individuals who need to maintain stable IOP levels.

As previously stated, face masks, as well as other strategies such as vaccination, social distancing, avoiding enclosed spaces and hand hygiene, are an important preventive strategy for SARS-CoV-2 transmission.[3] However, the effects of wearing face masks during physical exercise on IOP have not been thoroughly investigated, and this is problematic due to the importance of maintaining low and stable IOP values for the prevention and management of glaucoma. From this study, it is possible to state that using FFP2 masks causes a heightened IOP rise to both dynamic and isometric biceps-curl exercise, but the IOP changes induced by surgical masks are almost insignificant. Based on this, surgical masks should be prioritized over FFP2 masks, when possible, during the execution of resistance training exercises against heavy loads in subjects who need to minimize IOP peaks. Nevertheless, this investigation is not exempt of limitations that must be acknowledged. First, the experimental sample was formed by healthy young adults, and the external validity of these results to other age groups or people with chronic health conditions needs to be tested in future investigations. Second, the IOP response to exercise has been demonstrated to be dependent on the exercise type (e.g., squat, bench-press, military press) and intensity, and this study only incorporated a specific exercise type (i.e., biceps curl) and intensity.[21,35] Future studies should determine the generalizability of the current findings to other exercise types and intensities. Third, participants were instructed about how to fit both masks to their face, however, possible differences in the adjustment of the masks may be considered as a limitation of the study. Forth, measures such as pulse pressure or ocular perfusion pressure have demonstrated to play an important role on glaucoma prevention and management.[45,46] cardiovascular measures (e.g., blood pressure) were not obtained in this study, and future studies should consider the inclusion of pulse pressure or ocular perfusion pressure in the experimental designs. Lastly, this cross-sectional study reveals that wearing FFP2 masks during highly demanding resistance training causes a heightened IOP response, however, the possible long-term effects of using face masks during exercise practice on the incidence and management of glaucoma require further research. The results of this study could help to provide personalized recommendations about the use of face masks during resistance training practice in subjects who need to minimize IOP fluctuations.

Conclusions

Wearing a FFP2 mask causes a significant IOP increment during the execution of both dynamic and isometric biceps-curl exercises in comparison to the surgical mask and control (i.e., without using any mask) conditions. Also, the IOP response to isometric effort was higher than during dynamic effort, with this effect being independent of the face mask used. The current findings suggest that, when possible, the use of surgical masks and dynamic resistance training should be prioritized by individuals who need to minimize IOP fluctuations (i.e., glaucoma patients or those at risk).

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Table 1. Descriptive (mean ± standard deviation) of the experimental sample.

	Total sample	**Women**	**Men**
Sample size	22	14	8
Age (years)	26.0 ± 5.6	24.4 ± 2.6	28.8 ± 8.3
Body mass (kg)	65.9 ± 13.3	59.2 ± 11.1	77.6 ± 7.3
Height (cm)	169.1 ± 7.9	164.5 ± 4.3	177.3 ± 6.0
10-RM load (kg)	17.1 ± 6.8	12.7 ± 2.3	24.8 ± 5.0
Isometric load (kg)	14.3 ± 4.9	11.0 ± 1.0	20.0 ± 3.5

Note: RM = repetition maximum.

Figure captions

Figure 1. Effects of performing dynamic sets of 10 repetitions to failure (panel A) and isometric efforts of 1-minute (panel B) during the biceps-curl exercise while using the different face masks. *, #, and $ denote statistically significant differences (corrected p-values < 0.05) for the comparisons FFP2 vs. control, FFP2 vs. surgical, and surgical vs. control, respectively. Error bars represent the standard error.

Figure 2. Standardized mean differences (Cohen´s d effect size) with 90% confidence intervals for the IOP values (average value from the 10 measurements taken during exercise) between the dynamic and isometric biceps-curl exercises. P-values have been corrected with the Holm-Bonferroni procedure. ES = effect size.