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Effects of Different Breathing Methods on Intraocular Pressure, Ocular Haemodynamics, and Cardiovascular Responses During Push-Ups and the Plank Exercise

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Abstract

Background. Modern sedentary lifestyle increases the risk of ocular disorders, while participation in resistance and bodyweight training continues to grow among young adults. Previous studies indicate that exercise-induced changes in intraocular pressure and ocular haemodynamics depend on exercise type, intensity, and breathing strategy, particularly during isometric efforts and the Valsalva manoeuvre (VM). However, evidence regarding the ocular and cardiovascular effects of different breathing techniques during common bodyweight exercises remains limited.

Aims. To evaluate the effects of different breathing techniques on intraocular pressure (IOP), ocular and systemic haemodynamics, pain, fatigue, and intensity perception during push-ups and the plank exercise.

Methods. The study included 40 physically active men and women (mean age 24.2 ± 5.1 years). Participants were tested before exercise, immediately after exercise, and at 5, 10, and 15 minutes after exercise. Retinal microcirculation was assessed using an "Optomed Aurora" eye fundus camera, IOP was measured with an "Icare" tonometer, arterial pressure was measured using an "Omron BP742N" Series 5 device, subjective muscle fatigue and pain were evaluated using a Visual Analogue Scale (VAS), and exercise intensity was assessed using the Borg Scale.

Results. During the static plank exercise, mean arterial pressure (MAP) increased by approximately 4% while breathing, whereas no increase and a slight decreasing trend was observed during the VM. Dynamic push-ups induced a 3–6% increase in MAP immediately after exercise, followed by a decrease at 10–15 minutes after exercise, particularly during the VM. Changes in IOP depended on exercise type: static exercises caused only a slight decrease, whereas push-ups resulted in a more pronounced, transient reduction in IOP, especially at 5–10 minutes after exercise. Dynamic exercises also had a greater effect on the arteriovenous ratio (AVR), due to increased sympathetic nervous system activation. Subjective sensations such as pain, fatigue, and tremor were minimal during the plank exercise, whereas during push-ups the VM tended to increase effort, although the differences were not statistically significant.

Conclusions. Dynamic exercises such as push-ups induce greater systemic and ocular physiological responses than static exercises, and the VM amplifies haemodynamic fluctuations and the subjective perception of effort. Changes in ocular parameters (IOP, AVR) are small, temporary, and primarily dependent on exercise type.

Keywords: Valsalva manoeuvre; push-ups; plank-exercise; mean arterial pressure; intraocular pressure; retinal microcirculation

1. INTRODUCTION

Breathing technique during physical exercise has a significant impact on the cardiovascular system and the haemodynamic response. The Valsalva manoeuvre (VM), characterised by increased intrathoracic pressure, is associated with a hypertensive response during exercise, manifested by increased arterial blood pressure (ABP). It has been noticed that athletes performing strength training exercises using the VM experience the greatest increases in ABP compared with other breathing strategies (Linsenbardt et al., 1992). Breathing patterns influence not only the cardiovascular system but also ocular physiology. Studies indicate that the VM during physical exertion may lead to an increase in IOP (Vera et al., 2021). A systematic review confirmed that breath-holding and the VM during resistance exercise are associated with statistically significant IOP spikes, particularly during high-intensity and prolonged efforts (Hackett et al., 2024).

It is important to emphasise that the VM is not just a technical or stability enhancing element. Although it may improve movement control, it simultaneously induces haemodynamic changes and may increase health risks (Hackett et al., 2013). Studies have shown that teaching participants to avoid the VM reduces ABP responses during isometric exercises. The VM, defined as breath-holding with an expanded thoracic cavity, induces temporary but significant haemodynamic fluctuations: an initial reduction in venous blood return and cardiac output, followed by a rapid increase in ABP and heart rate at the end of the manoeuvre (O'Connor et al., 1989). In contrast, controlled rhythmic breathing or exhalation during exertion significantly reduce the ABP response compared with breath-holding.

Isometric exercises, such as plank and other static loads, cause ABP responses. Although regular isometric training may reduce resting blood pressure, single exercises, especially when performed with the VM, can result in temporary but high increases in ABP (Jones et al., 2025). Changes in IOP during exercise depend on several interacting mechanisms, including elevations in systemic ABP, changes in venous blood pressure, mechanical compression of orbital tissues, and alterations in orbital haemodynamics. The VM and high intensity strength training exercises are frequently associated with pronounced but temporary increases in IOP. Studies indicate that strength training and isometric exercises may temporarily elevate IOP, however, values typically return rapidly to baseline after the exercise (Hackett et al., 2024; Krobot Cutura et al., 2024).

Despite these important insights, there remains a lack of studies examining how different breathing techniques simultaneously affect ocular haemodynamics (including IOP) and cardiovascular responses during static and semi-dynamic bodyweight exercises such as push-ups and plank. These gaps make it difficult to formulate evidence based and safe training and rehabilitation recommendations for individuals at increased risk of ocular or cardiovascular complications. Therefore, the aim of our study was to evaluate the effects of different breathing techniques on IOP, ocular haemodynamics, and cardiovascular responses during push-ups and the plank exercise.

2. METHODS

2.1. Study design and participants

Participants were assessed for eligibility to participate in the study. Inclusion criteria were age between 19 and 35 years, being physically active 2–3 times per week, not using medications that could affect the studied variables, absence of autonomic nervous system, metabolic, cardiovascular, or ocular diseases, and no history of ocular surgery or eye trauma. A total of 40 physically active participants met the inclusion criteria and agreed to take part in the study. Participants were randomly assigned to different groups. Baseline characteristics of the participants are presented in Table 1. All procedures were approved by the Regional Biomedical Research Ethics Committee (No. BE-2-69) and were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

2.2. Study procedure

The study was conducted under normal daily conditions. Experimental sessions were carried out between 17:00 and 19:00 and followed a predefined protocol. The mean ambient temperature during the study was 23°C, and relative humidity was 77%. Upon arrival, all participants were informed about the study aims and procedures.

Participants were instructed to refrain from physical activity and alcohol for 24 hours before the measurements, to avoid caffeinated and carbonated beverages for six hours, and to abstain from food for at least two hours prior to the study. Upon arrival at the laboratory, baseline anthropometric measurements were performed. ABP was measured, followed by retinal vessel photography and IOP assessment. Afterwards participants performed a standardised warm-up consisting of five minutes of cycling on an ergometer at 100 W while maintaining a cadence of 55–65 revolutions per minute, followed by stretching exercises.

Participants performed two exercises for one minute: the plank (Figure 1) and push-ups (Figure 2). During both exercises, participants applied two different breathing techniques: 1) normal breathing (cycles of 3 seconds of inhalation and 3 seconds of exhalation) and 2) a 10 second VM (cycles of 3 seconds of inhalation and 3 seconds of exhalation, followed by breath-holding for the final 10 seconds).

Figure 1. **Plank exercise**

Figure 2. **Push-up exercise**

Participants were instructed to perform a 10 second breath-hold corresponding to a VM. Prior to experimental testing, a familiarisation session was conducted where breathing technique was explained in detail and practiced under researcher supervision to ensure correct conduction. On the experimental day, all breathing instructions were repeated immediately before testing, and participants were reminded of the required breathing pattern before each trial. The experimental tasks consisted of one-minute isometric plank and push-up exercises, during which the use of a mouthpiece or manometer was not feasible, as it would have interfered with exercise conduction, head and body positioning, and measurement timing. Therefore, breathing patterns were standardised through instruction and familiarisation rather than expiratory pressure monitoring. This approach is consistent with previous studies examining the influence of breathing patterns on IOP during exercise (Vera et al., 2020).

ABP, retinal vessel photography, and IOP measurements were performed immediately after exercise. All parameters were then reassessed at 5, 10, and 15 minutes after exercise. Thirty minutes after exercise, participants' perceived exercise intensity, muscle fatigue during exercise, and subjective muscle pain were evaluated.

2.3. Measurements

Anthropometric measurements were obtained with participants wearing only underwear and barefoot. Height was measured using a Leicester Height Metre (*Invicta Plastics, Leicester, UK*), while body mass and body fat percentage were assessed using a TBF-300 body composition analyser (*Tanita, UK Ltd., West Drayton, UK*). Body mass index (BMI) was calculated as body mass in kilograms divided by height in meters squared.

Subjective perception of exercise intensity was assessed using the 20-point Borg Rate of Perceived Exertion Scale, where 0–7 indicates very, very light effort; 8–9 very light; 10–11 fairly light; 12–13 somewhat hard; 14–15 hard; 16–17 very hard; and 18–20 very, very hard (Borg, 1998). Muscle fatigue was evaluated using a Visual Analogue Scale (VAS), where 1 represented no fatigue and 10 indicated unbearable fatigue.

ABP was measured using an upper arm automatic oscillometric blood pressure monitor ("Omron BP742N", Series 5; *Omron Healthcare, Kyoto, Japan*). Mean arterial pressure was calculated using the formula: MAP = diastolic ABP + [1/3 × (systolic ABP – diastolic ABP)] (Choi & Kook, 2015).

Retinal vessel analysis. Participants were seated in a dimly lit room and a single image of right eye fundus was captured using a portable 45° colour non-mydriatic digital fundus camera (*Optomed Aurora, Optomed Plc, Oulu, Finland*). All images underwent pre-processing in ImageJ version 1.54 (*National Institutes of Health, Bethesda, USA*). Pre-processed images were further analysed with MONA REVA version 3.0.0 software (*VITO Health, Mol, Belgium*) by an experienced ophthalmologist. In the highest quality images, the diameters of the superior and inferior temporal retinal arterioles and venules at the margin of the optic disc were measured. AVR was calculated using the six largest arterioles and venules based on the modified formula (Knudtson et al., 2003).

IOP was assessed using a portable tonometer "Icare" (*Tiolat Oy, Helsinki, Finland*). Previous studies have demonstrated that Icare tonometry is suitable for screening in healthy individuals and that measurements are independent of age, sex, eye axial length, and central corneal thickness (Zhu et al., 2018). Following manufacturer guidelines and established protocols (Vera et al., 2020), an experienced ophthalmologist performed three consecutive IOP measurements while participants fixated sight on a target positioned 6 m away.

2.4. Data descriptive and comparative analysis

Data were analysed using IBM SPSS Statistics (version 30.0). Results are presented as means ± standard deviations (SD). The normality of data distribution was assessed using the Shapiro–Wilk test. As the data met the assumptions of normal distribution, parametric statistical analyses were performed. Paired and independent Student's t-tests were used to evaluate differences between pre- and post-exercise measurements and between intervention conditions, as appropriate. Effect sizes were calculated using Cohen's *d* to quantify the magnitude of observed differences. Statistical significance was set at $p < 0.05$.

3. RESULTS

Forty physically active participants' baseline characteristics are presented in Table 1.

Table 1. **Baseline characteristics of the participants (mean ± SD)**

	Characteristic	Age, years	Height, cm	Weight, kg	BMI, kg/m²	Body fat, %
Plank	Normal breathing group ($n = 10$)	23.6 ± 4.5	174.1 ± 14.2	77.4 ± 24.5	25.2 ± 6.1	25.3 ± 12.5
	Valsalva manoeuvre group ($n = 10$)	24.5 ± 5.5	174.1 ± 11.7	76.8 ± 18.5	25.0 ± 3.4	23.6 ± 6.6
	p value	0.62	1.00	0.88	0.84	0.73
Push-ups	Normal breathing group ($n = 10$)	26.1 ± 5.6	175.4 ± 14.7	76.4 ± 24.8	24.3 ± 4.5	21.0 ± 5.9
	Valsalva manoeuvre group ($n = 10$)	22.7 ± 4.8	174.8 ± 13.3	71.7 ± 18.8	23.1 ± 3.3	21.8 ± 8.3
	p value	0.23	0.93	0.63	0.45	0.81

The dynamics of MAP following exercise under different breathing techniques are presented in Table 2.

Table 2. **MAP values of participants (x ± SD), mmHg**

	Characteristic	Baseline, MAP	Directly after load, MAP	5 min after load, MAP	10 min after load, MAP	15 min after load, MAP
Plank	Normal breathing group	95.6 ± 9.6	99.8 ± 8.1*	98.8 ± 7.8	95.9 ± 8.9	94.8 ± 8.1
	Valsalva manoeuvre group	97.2 ± 7.4	96.1 ± 7.8	95.7 ± 5.9	94.6 ± 6.1	94.0 ± 6.5
Push-ups	Normal breathing group	97.6 ± 8.2	103.3 ± 10.6*	96.5 ± 10.7	92.7 ± 10.1*	92.4 ± 9.8*
	Valsalva manoeuvre group	92.9 ± 12.6	97.0 ± 10.7	87.1 ± 9.0*#	86.2 ± 7.6*#	84.3 ± 7.2*#

Note: MAP – mean arterial pressure; * – $p < 0.05$, statistically significant difference compared with baseline. # – $p < 0.05$, statistically significant difference between the plank and push-up groups.

During the plank exercise performed with normal breathing, baseline MAP was 95.6 ± 9.6 mmHg. Immediately after exercise, MAP increased by 4.3% ($p < 0.03$, Cohen's $d \approx 0.5$). However, at 5–15 minutes after exercise, MAP returned to baseline values and no statistically significant differences were observed compared with baseline ($p > 0{,}05$), with a reduced effect size ($d < 0.3$). During the plank exercise performed with the VM, baseline MAP was 97.2 ± 7.4 mmHg. After exercise, MAP decreased by 1.2% and continued to decrease over 15 minutes to a total reduction of 3.3%. These changes were not statistically significant ($p > 0.05$), and Cohen's d ranged from 0.1 to 0.3, indicating a small effect.

During the push-up exercise performed with normal breathing, baseline MAP averaged 97.6 ± 8.2 mmHg. Immediately after exercise, MAP increased by 5.8% ($p < 0.05$, Cohen's $d \approx 0.5$). At 5–15 minutes after exercise, MAP decreased by 1.2%. However, no significant difference was observed compared with baseline. At 10–15 minutes after exercise, a statistically significant decrease of 5.05% compared to baseline was observed ($p < 0.05$), with a reduced effect size ($d < 0.3$). During the push-up exercise performed with the VM, baseline MAP was 92.9 ± 12.6 mmHg. MAP slightly increased immediately after exercise by 4.4% but not statistically significantly. At 5–15 minutes after exercise, MAP decreased significantly by 9.3% ($p < 0.05$), with Cohen's d indicating small to moderate effect sizes (~0.3–0.5).

Between-group comparisons of MAP revealed no statistically significant differences. Immediately after exercise, MAP was higher in the push-up group with normal breathing compared with the plank group with normal breathing. However, these differences were not statistically significant ($p > 0.05$). When comparing the plank and push-up exercises performed with the VM, statistically significant differences were observed at 5–15 minutes after exercise ($p < 0.05$).

The dynamics of IOP following exercise under different conditions are presented in Table 3.

Table 3. **IOP values of participants (x ± SD), mmHg**

	Characteristic	**Baseline, IOP**	**Directly after load, IOP**	**5 min after load, IOP**	**10 min after load, IOP**	**15 min after load, IOP**
Plank	Normal breathing group	16.8 ± 3.4	15.7 ± 2.7	17.0 ± 2.3	17.4 ± 3.2	18.0 ± 3.0
	Valsalva manoeuvre group	17.4 ± 3.3	16.7 ± 3.5	17.3 ± 4.6	17.9 ± 5.0	17.7 ± 5.4
Push-ups	Normal breathing group	16.7 ± 2.9	16.3 ± 2,7	13.8 ± 3.9*#	14.3 ± 4.0*	15.7 ± 3.7
	Valsalva manoeuvre group	17.5 ± 3.3	16.6 ± 3.61	14.8 ± 3.5*	16.3 ± 4.0*#	16.2 ± 3.6

Note: IOP – intraocular pressure; * – $p < 0.05$, statistically significant difference compared with the baseline value; # – $p < 0.05$, statistically significant difference between the plank and push-up groups.

During the plank exercise with normal breathing, the baseline IOP was 16.8 ± 3.4 mmHg. Immediately after exercise, IOP non-significantly decreased by 6.6% ($d = 0.5$). After 5–15 min, there were no statistically significant changes. During the plank test with the VM, baseline IOP was 17.4 ± 3.3 mmHg. Immediately after the load, the decrease in IOP was statistically non-significant, 4.0% ($p > 0.05$, $d = 0.5$). Within 15 minutes, IOP gradually returned to baseline and did not result in significant IOP dynamics.

During the push-ups with normal breathing, the baseline IOP averaged 16.7 ± 2.9 mmHg, and immediately after exercising it decreased by 2.4% ($p > 0.05$). After 5–10 minutes, IOP significantly ($p < 0.05$) decreased by 17.4–14.4%, and after 15 minutes it returned to baseline (5.99%, $d = 0.3$). The greatest decrease in IOP occurred after 5 minutes ($p < 0.001$, $d = 0.75$) and 10 minutes after exercise ($p < 0.01$, $d = 0.84$) compared with the baseline value. During push-ups with the VM, the baseline IOP was 17.5 ± 3.3 mmHg. Immediately after exercise, IOP decreased by 5.14% ($p > 0.05$, $d = 0.27$). However, after 5 and 10 minutes IOP statistically significantly decreased ($p < 0.01$, $d = 0.52$). After 15 minutes recovered ($p > 0.05$, $d = 0.24$) but there were no statistically significant changes.

When comparing between groups, no statistically significant changes of IOP were observed immediately and 15 minutes after load. However, 5 minutes after load, IOP was statistically significantly higher ($p > 0.05$, $d = 1.01$) in the push-up with normal breathing group compared with the plank with normal breathing group. When comparing the plank exercise with the push-up exercise during the VM, statistically significant changes ($p < 0.05$) were observed at 10 minutes. However, after 15 minutes, no statistically significant changes were observed.

Data of the AVR under different breathing conditions are presented in Table 4.

Table 4. **Arteriovenous ratio values of participants (x ± SD)**

	Characteristic	Baseline, AVR	Directly after load, AVR	5 min after load, AVR	10 min after load, AVR	15 min after load, AVR
Plank	Normal breathing group	0.69 ± 0.03	0.62 ± 0.05*	0.66 ± 0.04*	0.65 ± 0.04*	0.65 ± 0.06*
	Valsalva manoeuvre group	0.66 ± 0.04	0.61 ± 0.05*	0.64 ± 0.07	0.63 ± 0.03*	0.66 ± 0.03
Push-ups	Normal breathing group	0.67 ± 0.04	0.61 ± 0.07*	0.66 ± 0.05	0.68 ± 0.04	0.68 ± 0.05
	Valsalva manoeuvre group	0.68 ± 0.03	0.63 ± 0.03*	0.65 ± 0.04*	0.67 ± 0.04	0.68 ± 0.03

Note: AVR – arteriovenous ratio. * – $p < 0.05$, statistically significant difference compared with the baseline value.

During the plank exercise performed with normal breathing, the baseline mean AVR value was 0.69 ± 0.03. Immediately after exercise, AVR decreased significantly ($p < 0.05$). At 5, 10, and 15 minutes after exercise, AVR remained significantly reduced by 10.7–5.1% compared with baseline ($p < 0.05$), with large effect sizes ($d = 1.14–0.84$). During the plank exercise performed with the VM, baseline AVR was 0.66 ± 0.04. Immediately after exercise, AVR decreased significantly ($p < 0.05$, 8.6%, $d = 1.5$). At 5 minutes after exercise, AVR had no statistically significant change observed. However, at 10 minutes after exercise, AVR decreased significantly again ($p < 0.05$; 4.7%, $d = 1.35$). At 15 minutes after exercise, AVR recovered to baseline values (0.5%, $d = 0.14$).

During the push-up exercise performed with normal breathing, baseline AVR was 0.67 ± 0.04. Immediately after exercise, AVR decreased significantly ($p < 0.05$, 8.6%, $d = 1.5$). At 5, 10, and 15 minutes after exercise, AVR recovered to baseline values and slightly exceeded them (3.0–0.5%, $d = 0.3–0.1$). During the push-up exercise with the VM, baseline AVR was 0.68 ± 0.03. Immediately after exercise and at 5 minutes after exercise, AVR decreased significantly ($p < 0.05$, 8.5%, $d = 0.9$). At 10 and 15 minutes after exercise, AVR recovered towards baseline values ($p > 0.05$, 1.9%, $d = 0.4$).

There were no significant changes comparing between normal breathing with VM groups.

Subjective arm pain, muscle fatigue, and perceived exercise intensity were evaluated under different breathing strategies during the plank and push-up exercises. They are presented in Table 5.

Table 5. **Values of evaluated pain, fatigue, and intensity of arms in participants (x ± SD)**

	Characteristic	Pain	Fatigue	Intensity (tremor)
Plank	Normal breathing group	3.4 ± 2.1	4.7 ± 1.9	9.8 ± 1.5
	Valsalva manoeuvre group	3.2 ± 1.5	4.4 ± 1.6	9.6 ± 1.7
Push-ups	Normal breathing group	13.5 ± 2.8#	14.2 ± 2.2#	15.1 ± 2.5#
	Valsalva manoeuvre group	14.3 ± 2.7#	14.9 ± 2.4#	15.1 ± 1.4#

Note: # – $p < 0.05$, statistically significant difference between the plank and push-up groups.

During the plank exercise, differences between the normal breathing and VM groups were minimal across all three assessed parameters. Mean arm muscle pain scores were very similar and did not differ significantly between groups (3.4 ± 2.1 vs. 3.2 ± 1.5 points, respectively; $p > 0.05$, $d = 0.1$). A similar pattern was observed for muscle fatigue, with the normal breathing group reporting a fatigue score of 4.7 ± 1.9 and the VM group reporting 4.4 ± 1.6 ($p > 0.05$, $d = 0.1$–0.3). Perceived exercise intensity/muscle tremor scores also remained nearly identical between groups (9.8 ± 1.5 vs. 9.6 ± 1.7 points).

In contrast, during the push-up exercise, a tendency towards increased subjective muscular load was observed in the VM group. Mean arm muscle pain was slightly higher in the VM group (14.3 ± 2.7) compared with the normal breathing group (13.5 ± 2.8), although the difference was not statistically significant ($p > 0.05$, $d = –0.3$). A similar trend was found for muscle fatigue, with the VM group reporting higher fatigue scores (14.9 ± 2.4) than the normal breathing group (14.2 ± 2.2; $p > 0.05$, $d = –0.3$). Perceived movement control or muscle tremor during exercise remained comparable between breathing conditions, with scores of 15.1 point during push-ups and 9.6–9.8 points during the plank exercise.

When comparing the plank and push-up exercises, all subjective outcomes were significantly higher during push-ups ($p < 0.05$). Specifically, arm muscle pain increased by 77.6%, muscle fatigue by 70.5%, and perceived hand tremor during exercise by 36.4%.

4. DISCUSSION

The aim of this study was to evaluate the effects of different breathing techniques on IOP, ocular and systemic haemodynamics, pain, fatigue, and intensity perception during static (plank) and dynamic (push-ups) bodyweight exercises. Results demonstrate that breathing strategies (normal breathing versus the VM) modulate cardiovascular and ocular responses differently depending on exercise type. In many cases, these findings align with previously published literature.

During the plank exercise with normal breathing, MAP increased by 4.3%, supporting earlier findings that isometric exercise temporarily elevates ABP due to increased peripheral resistance and sympathetic activation (MacDougall et al., 1985). In contrast, when the plank was performed with the VM, MAP did not increase and showed a slight decreasing trend. This response is consistent with the classical haemodynamic model of the VM, in which increased intrathoracic pressure reduces venous return, leading to a temporary reduction in ABP (Ludbrook et al., 1994; Sharpey-Schafer, 1955). Dynamic exercise performed with normal breathing resulted in a 3–6% increase in MAP immediately after exercise, confirming prior evidence that dynamic upper-body strength exercises cause greater ABP responses due to higher metabolic demand (Cameron & Jones, 1990). MAP subsequently decreased by up to 5% after 10–15 minutes, consistent with after exercise hypotension described by Halliwill et al. (2001).

When push-ups were performed with the VM, MAP showed only a non-significant immediate increase, followed by a significant decrease during the 5–15 minute recovery period. This pattern aligns with reports that reduced venous return and stroke volume during the VM accelerate after the exercise pressure declines (Porth et al., 2011). Across all conditions, MAP did not differ significantly between groups, supporting the concept of effective ABP autoregulation in healthy young adults (Mitchell et al., 1981).

Baseline IOP during the plank exercise with normal breathing was 16.8 ± 3.4 mmHg, with a non-significant immediate reduction of 6.6% after exercise. IOP gradually returned to baseline within 5–15 minutes. Similar results were observed during the plank with the VM, where IOP decreased by approximately 4% and normalised without significant fluctuation. These findings are consistent with recent evidence that isometric exercises induce small IOP changes in healthy individuals (González-Devesa et al., 2024). In contrast, push-ups performed with normal breathing caused significantly greater IOP reductions. The largest decrease occurred at 5 minutes after exercise ($p < 0.001$, $d = 0.75$) and remained significant at 10 minutes ($p < 0.001$, $d = 0.84$), returning to near baseline levels by 15 minutes. These findings support previous reports that dynamic strength exercises involving large muscle mass produce more pronounced temporary IOP reductions due to blood flow redistribution and enhanced venous return (Alfaqeeh et al., 2022; Vera et al., 2020). Push-ups performed with the VM also resulted in significant IOP reductions at 5–10 minutes, followed by recovery at 15 minutes. This pattern aligns with studies showing that the VM may initially attenuate IOP reduction but later promotes venous compensation leading to decreased IOP (Hackett et al., 2024). This is also consistent with the literature indicating that intense strength exercises, particularly those involving large muscle mass, result in greater IOP fluctuations (Hackett et al., 2024). Between group comparisons revealed no significant IOP differences at most time points. However, significant differences appeared after 5 minutes with normal breathing and after 10 minutes with the VM ($d = 1.01$ and $d = 0.9$, respectively). These findings are further supported by recent studies indicating that dynamic strength exercises induce significant IOP fluctuations depending on movement phase and intensity (Vera et al., 2020), whereas isometric exercises generally cause only minimal changes (Krobot et al., 2024). Our results align with these trends and confirm that dynamic strength exercises induce greater short-term IOP reductions than static exercises, while the effects of the VM are complex and time dependent.

Analysis of retinal AVR revealed an immediate after exercise decrease, indicating sympathetic dominance and vagal withdrawal, consistent with previous findings (Tarvainen et al., 2014). During the plank exercise, AVR decreased similarly with both breathing methods, but recovery was slower with normal breathing, consistent with prolonged sympathetic activation following isometric exercise (Samora et al., 2000). With the VM during the plank, AVR recovery was oscillatory, showing temporary normalisation followed by secondary decreases before returning to baseline. This pattern reflects autonomic instability caused by intrathoracic pressure fluctuations during the VM. Therefore, VM abrupts intrathoracic pressure fluctuations and provokes rapid baroreceptor mediated reflex responses, resulting in transient oscillations in ABP, heart rate, also in vascular tone, reflecting dynamic autonomic modulation rather than stable physiological regulation (Pstras et al., 2016). These rapid alternations between sympathetic activation and parasympathetic withdrawal, followed by a recovery of parasympathetic activity once pressure is released, are characteristic of short-term autonomic instability during the VM (Jha et al., 2018; Sun et al., 2020).

During push-ups with normal breathing, parasympathetic recovery was fast, supporting evidence that moderate intensity dynamic exercise facilitates efficient autonomic reactivation (Michael et al., 2017). During push-ups, the VM delayed early recovery, although baseline values were restored by minute 10–15. This change is consistent with the previous findings (Pstras et al., 2016), which demonstrated that combining the VM with dynamic exercise increases cardiovascular stress and temporarily slows or even suppresses autonomic reactivation. However, over a longer period, vagal activity recovers relatively quickly.

Subjective assessments showed no significant differences in pain, fatigue, or tremor between breathing conditions during the plank exercise, consistent with reports that the VM does not enhance isometric performance or fatigue perception (Ikeda et al., 2009). During push-ups, the VM tended to increase perceived muscle tension, although differences were not statistically significant. This trend aligns with evidence that breath-holding enhances effort perception via increased intrathoracic pressure and central effort regulation (Chigira et al., 2024; Ikeda et al., 2009). Comparatively, push-ups caused greater subjective muscle tension than plank, consistent with the literature indicating that dynamic strength exercises cause greater metabolic stress and neuromuscular fatigue than isometric exercises (Chigira et al., 2024). This distinction between dynamic and static exercise appears repeatedly across physiological and subjective outcomes. Normal breathing was associated with lower discomfort and improved recovery, supporting the role of parasympathetic activation during exercise (Bernardi et al., 2001).

Future research should incorporate a wider range of physiological and perceptual markers to further clarify the complex interactions between breathing strategies, exercise modality, and ocular and cardiovascular regulation.

5. CONCLUSIONS

Dynamic exercises (push-ups) cause significantly higher systemic and ocular physiological changes than static exercises (plank), and their effect on the autonomic nervous system and blood pressure is more pronounced and more variable. The effect of breathing techniques is most evident during dynamic exercises: the Valsalva manoeuvre enhances haemodynamic fluctuations and the subjective perception of effort, whereas during static exercises these differences remain minimal. Changes in ocular parameters (IOP, AVR) are small and temporary. However, they clearly depend on the nature of the exercise: dynamic movements lead to more pronounced changes than static exercises.

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