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The effects of a 12-week yoga program on the CoP of military pilots before and after a flight emergency simulation using Biosignals Plux force platform

Sara Santos[1,2], José Alberto Parraca[1,2], Joana Alegrete[1,2], Carolina Alexandra Cabo[1,2], Filipe Melo[1,2,3] and Orlando Fernandes[1,2]

Abstract

This study examined the effects of Ashtanga Vinyasa Yoga Supta on Center of Pressure (CoP) displacement in healthy student pilots, using the Biosignals Plux force platform, under the premise that yoga would lead to improvements in postural control responses. CoP response was analyzed by the Plux (Portugal) one-dimensional force platform. A total of 18 military pilots participated in this study. The pilots were in their Portuguese Air Force Academy course "Masters in Military Aeronautics: Aviator Pilot Specialist," also called Tirocinium. Participants were randomly assigned to yoga classes (intervention group) or a waiting list (control group) and completed a flight emergency protocol in a flight simulator. CoP displacement was collected before and after all these maneuvers had been completed and both measures occurred before (baseline values) and after a 12-week yoga program. Although the differences observed between groups are not significant, after calculating the effect size, we can theorize that the intervention group maintains CoP displacement before and after flight and the control group has a higher CoP displacement after flight simulation. CoP information collected through noninvasive portable devices such as the Biosignals Plux force platform can relay important information quickly and easily. Knowing under what circumstances pilots are affected can then lead to development or enhancement of training strategies to improve those psychophysiological responses. In this study the effects, while not significant, are present, so it may be necessary to add more weeks of training to make the yoga program effective.

Keywords

Biomechanics, postural control, military pilots, Center of Pressure, flight emergency simulation, yoga, tirocinium, Portuguese Airforce, Ashtanga Yoga Supta

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Introduction

Spatial Disorientation (SD) is a problem faced by many military pilots during flight. SD threatens and impairs flight safety and is defined as a misperception of posture, height, and motion relative to the ground. It is accompanied by the pilot's misperception of the gravity vertical line, and misjudgment of the flight attitude relative to other aircraft.[1]

Fighter pilots have a greater sense of SD – these differences are related to the requirements of the different aircrafts used by each pilot, as well as the specific functions and adaptative responses required to fly on different aircrafts.[2] It is well known that visual factors and vestibular factors cause SD events. Vision plays a crucial role in the spatial orientation and perception of the surrounding environment. Visual stimuli can easily lead to the wrong estimation of the environment, such as self-rotation illusion (also known as vection). Vection is caused by a flowing visual scene, which causes the pilot

[1]Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Évora, Portugal
[2]Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal
[3]Universidade de Lisboa Faculdade de Motricidade Humana: Cruz Quebrada, Lisboa, Portugal

Corresponding author:
Sara Santos, Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Largo dos Colegiais 2, 7000-645 Évora, Portugal.
Email: sara.santos@hotmail.com

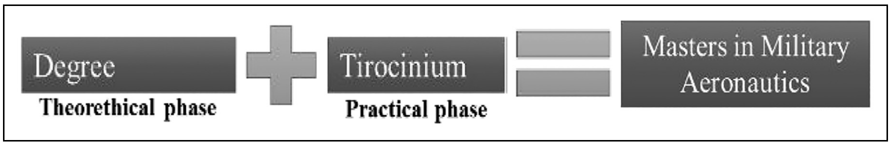

Figure 1. Training for the Masters in Military Aeronautics degree.[19]

to misjudge their aircraft's altitude. When the human body is in a small-angle-tilt state for a long time, it easily leads to the tilt illusion or somato-gravic illusion.[1]

Fifty-four percent of the aviation accidents in the past ten years were due to SD. Comparing aviation accident data in Europe from 1983 to 1992 and from 1993 to 2002, it is noticeable that while the total accident rate has decreased from 4.17 times per million flight hours to 2.70 times per million flight hours, the percentage of total accidents caused by SD has increased from 24.7% to 33.0%. These numbers indicate that aviation accidents caused by SD are increasing.[1]

Individuals maintain balance through the interaction of visual, vestibular, and somatosensory systems. Training one or more of the three sensory systems through vestibular habituation and adaptation can alter sensory weighting and postural behavior.[3] Pilots, due to their training, may have a stronger ability than other individuals to tolerate large stimuli and to suppress vestibular system illusions.[4] Pilot training in the Portuguese Airforce's Tirocinium is one of the ways to train fighter pilots' balance mechanisms to obtain an adaptative response to SD. The Portuguese Airforce has not yet purchased technological equipment to objectively measure the adaptative response to SD during the final stages of pilot training.

Flight simulators are an important part of pilot training for several reasons: to learn how to fly, gain virtual flight hours, for the transition to flying real aircrafts, and to simulate normal flight conditions. Flight simulators also make it possible to practice in adverse conditions and experience SD, malfunction of navigation instruments, power losses, loss of control of the aircraft, confusion, illusion of references, illusion of the effect of black holes, and other circumstances that would be dangerous and even catastrophic if piloting a real flight.[5,6]

Human exposure to virtual environments can have specific side effects. Some of them are a natural adaptation response related to habituation processes, others are classified as sickness signs and symptoms. The phenomena of wich we are currently aware are motion sickness without real motion or a group of specific psychophysical ailments that may be experienced as a side effect during and after exposure to simulator training – both static and dynamic.[6–8]

In addition to the feeling of general discomfort, the simulator's environment can cause nausea, oculomotor symptoms, and disorientation. It is believed that any disturbance in balance, coordination and motor control resulting from simulator training exposure may imply a safety concern for pilots who need to walk, climb stairs, drive, or fly after a simulator training session. Some of these symptoms may persist or even worsen after leaving the simulator. The problems considered of most concern are the after-exposure effects, such as illusory sensations of climbing and turning, perceived inversions of the visual field, and impaired motor control manifested by postural instability, postural unsteadiness, or postural imbalance. Following a simulated flight, pilots who experience such sickness symptoms may be grounded for up to 24 h.[6,9–11]

Previous research confirms simulator sickness assesmnets should consider the interaction of four components of the equilibrium system (visual, vestibular, proprioceptive, and foot support). Because the same four components play a key role in the process of maintaining balance in a standing position, the postural instability or ataxia can indicate the occurrence of simulator sickness symptoms. Postural instability can be measured using static, floor-based tests in which: subjects are asked to hold a given static posture with their eyes opened or closed. Surprisingly, little research has been conducted so far in military context, using a simulator or virtual reality paired with a force or stabilometric platform which allows analysis of CoP displacement.[6,12–17]

SD in a simulated environment arises mainly due to oculo-vestibular and oculo non-vestibular conflicts. In some cases, SD develops due to inter-sensory conflicts. Sensoriomotor commands are impaired, which also affects postural stability. This situation is one of the reasons why postural instability was chosen as a criterion for evaluating and predicting SD. Body sway is an efficient variable to indicate the occurrence of impairments. It is also one of the least constraining methods for a pilot training in the simulator, compared to other physiological methods.[18]

Air Force Academy (AFA) is the military institution for the higher education for military pilots. The training model in Portugal is continuous and has a duration of 5 years and 6 months[19] (Figure 1).

Pilot training is composed of four components:

- Scientific basis;
- Scientific engineering and technologies, required for each of the specializations;

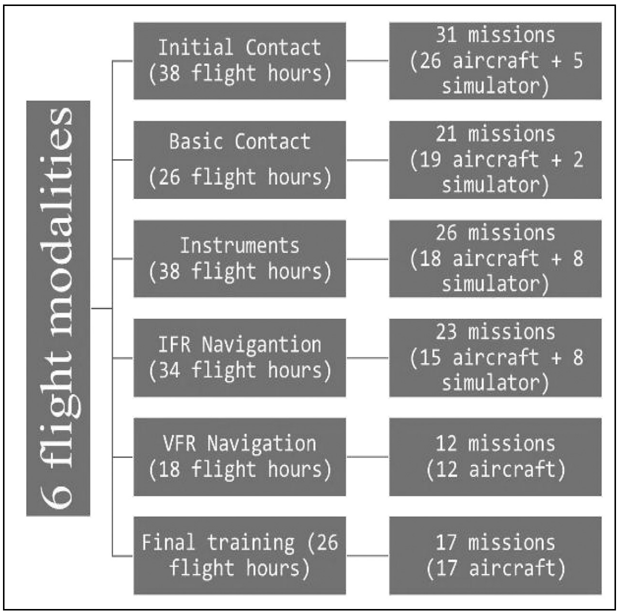

Figure 2. Flight training and flight hours distributed during the Tirocinium.[19]

- Military, ethical, and behavioral;
- Physical and miliary, to provide the physical and mental skills necessary to accomplish missions.[19]

The Tirocinium is the final stage of military aviation training and takes place in Base Aérea No. 11, in Beja, Esquadra 101. It lasts 10 months, with 18 days of theoretical instruction and 185 days of practical instruction (177 h in aircraft and 33 h in a stationary flight simulator, for a total of 180 flight hours per pilot, Figure 2).[19]

After successful completion of the practical phase, pilots receive a Masters in Military Aeronautics diploma and the attend additional complementary courses: fighter aircrafts, helicopters, and transport aircrafts.[19]

The Portuguese Airforce's Health and Physical Exercise Department is still in the process of developing a mandatory fitness training protocol for military pilots. As far as we know, pilots have so far been instructed to train as they see fit, to be approved at the mandatory annual physical examinations. We hypothesize that incorporating yoga in the physical training protocol could lead to improvements in postural control. It would be a beneficial addition to a mandatory training program to be created in the near future, as it would benefit overall fitness (and ability to get approval on mandatory fitness exams), and also improve adaptive vestibular responses associated with increased flight safety.

Therefore, we developed a personalized eight-part yoga class, focusing on closed eyes (from Sanskrit: Ashtanga Yoga Supta), to improve postural control responses through the vestibular and somatosensory systems on Portuguese Airforce pilots from the "Masters in Military Aeronautics: Aviator Pilot Specialist" course. We also hypothesize the Biosignals Plux force platform will objectively measure pilot's SD responses in a non-invasive and quick manner.

Yoga can be a useful conditioning method for improving performance in sports, but it can also be considered a sport, developing athletic qualities such as strength, endurance, reflexes, accuracy, dexterity, flexibility, endurance of various muscle groups and joints, mental conditioning, stress reduction, and will power.[20,21]

Practicing yoga continuously improves postural control and strengthens muscles and the vestibular system (increased plasticity in the sacculo-colic pathway), resulting in enhanced vestibular evoked myogenic potential (cVEMP) responses.[22] Ashtanga Yoga according to Patanjali (Hindu mythic, author, and philosopher) has techniques that address all dimensions of the human system: body, breath, mind, personality, and emotions. A yoga program with individualized tools must be specifically created and overseen by a qualified instructor, to achieve the practitioner's goals.[23,24]

Many scientists have researched the SD mechanism, SD measurements, SD countermeasures, and developed training programs for pilots to avoid SD. Although the research has achieved outstanding success, there are still some problems that need to be solved.[1]

Center of pressure (CoP) excursions have been used to assess postural stability in adults. The CoP reflects a response of the neuromuscular system to the correction of center of mass (COM) deviations, which can be measured with a single force platform, commonly used to study postural control.[25,26] There is evidence that the excursion in the CoP reflects an exploratory mechanism to acquire sensory information, suggesting that postural sway is important for balance. When the CoP values increase during quiet stance, it is usually indicative of impaired postural control.[27,28]

Pilot's CoP response was analyzed using the Biosignals Plux force platform, to evaluate the effects of the yoga training program on the systems that influence postural behavior, namely the vestibular system.[29]

To our knowledge, there is no study of yoga in this specific military context, although the existing literature with other populations suggests benefits.[30–32]

Methods

Participants

A total of 18 military pilots participated in this study. Pilots were in their Tirocinium in the Portuguese Air Force Academy course "Masters in Military Aeronautics: Aviator Pilot Specialist." Participants were randomly assigned to yoga (intervention group) or to a waiting list (control group). The procedures were approved by the Research Ethics Committee of Évora University and participants provided written informed consent according to the Declaration of

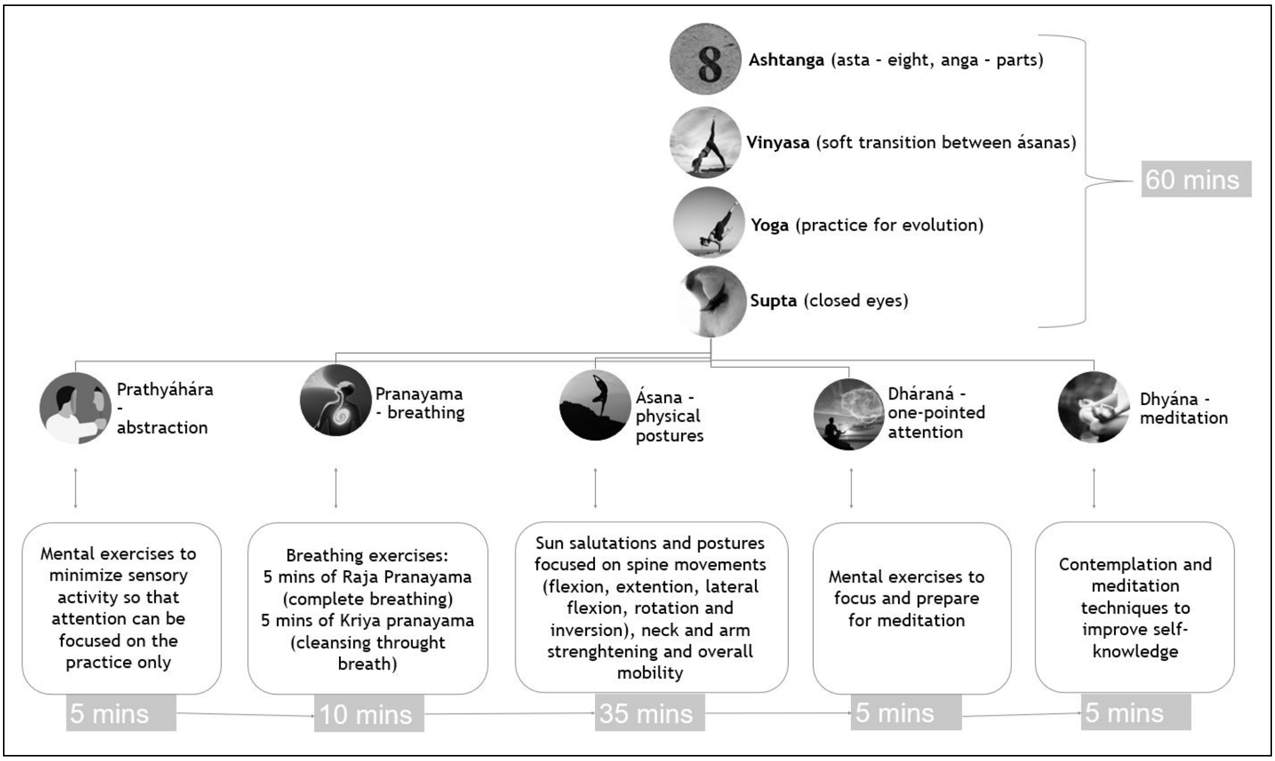

Figure 3. Flow of the Ashtanga Yoga Supta class designed for the military pilots of the Portuguese Airforce, with a focus (according with the needs perceived in this population) on supta, or having the eyes closed, to stimulate the vestibular system.

Helsinki (approval number: 21050) and the study was registered in ClinicalTrials.gov (approval number: NCT05821270).

The sample size was calculated using Open Epi, version 3, with the sample size being represented by the following equation:

$$n = [\text{EDFF} * \text{Np}(1 - \text{p})]./[(\text{d}2/\text{Z}21 - \alpha/2*(\text{N} - 1) + \text{p}*(1 - \text{p})]$$

Population size (for finite population correction factor or fpc) (N): 18

Hypothesized % frequency of outcome factor in the population (p): 50% ± 5

Confidence limits as % of 100 (absolute ± %) (d): 5%

Design effect (for cluster surveys-DEFF): 1

For a confidence level % of 95 to 99.9% the sample size is 18.

Experimental procedure

For 12 weeks the Control Group ($n = 9$) received the protocolized classes of "Masters in Military Aeronautics: Aviator Pilot Specialist" course, whereas the Intervention Group ($n = 9$) received the same course and two yoga classes per week (1 h each). Otherwise, participants were instructed to maintain their regular routines.

The pilots completed a flight emergency protocol in a flight simulator before and after the 12-week period. CoP displacement in an open-eye and closed-eye bipodal position was collected before and after all these maneuvers, and both measurements were taken before and after the 12-week period. Subjects were asked to stand comfortably on both legs on a force platform (Biosignals Plux, Portugal) for 60 s, with their arms by their sides. This was completed twice, once with the subject's eyes open and once with the eyes closed. The force platform was placed 1.5 m from a wall, which each participant faced. The force platform's readings were used to determine the center of pressure for each subject over time (Figure 3).

Data analysis

Data were sampled at 1000 Hz and electrode impedance was kept below 5 kΩ. Preprocessing was performed using the EEGLAB toolbox, which is available for use in MATLAB (The MathWorks Inc., Natick, MA). Data were downsampled to 100 Hz.

Statistical analysis

Normality was first tested with the Shapiro-Wilk test. Descriptive statistics were obtained with Jamovi (Desktop version 2.3.16) for the intervention and control groups. Data was collected directly before and after a flight simulation and before and after the 12-

Table 1. Descriptive statistics of the total CoP displacement of the pilots in bipodal stance with eyes open.

Intervention group	In.Bef.Sim.	In.Aft.Sim	Fin.Bef.Sim.	Fin.Aft.Sim
N	9	9	9	9
Mean	224	180	164	169
Median	172	179	138	174
Standard deviation	169	51.8	50.9	39.5
Minimum	118	107	106	118
Maximum	662	263	234	243
***W* Shapiro-Wilk**	0.609	0.971	0.872	0.906
***p* Shapiro-Wilk**	< 0.001	0.901	0.130	0.288
Control group				
N	9	9	9	9
Mean	315	223	197	214
Median	220	195	176	229
Standard deviation	211	102	54.7	60.6
Minimum	170	128	146	137
Maximum	808	454	325	292
***W* Shapiro-Wilk**	0.739	0.764	0.813	0.902
***p* Shapiro-Wilk**	0.004	0.008	0.028	0.266

Total CoP displacement of pilots in bipodal stand with open eyes, between the intervention group pre (Bef.Sim.) and post (Aft.Sim.) flight simulation in initial (pre-yoga – In.) and final (post-yoga – Fin.) data collection, and the control group for the same parameters.

week yoga program in bipodal stance with open and closed eyes, to investigate the immediate effect of stimuli. In addition, the effect size within and between groups was calculated using Cohen's *d* with an online calculator. Finally, the degree of accuracy and reliability between groups was calculated using Cohen's kappa and an online calculator.

While *p* values are used to assess whether an effect is present, the use of 95% CIs allows for an assessment of uncertainty in the magnitude of the effect.[33,34]

Kappa coefficients are measures of correlation between categorical variables and are often used as reliability or validity coefficients. The calculation of the kappa coefficient can be measured in intra-rater reliability: to evaluate the degree of agreement that the same person shows in a time interval.[35,36]

Merely stating the significant *p* value of an analysis is not sufficient for readers to fully understand the results or the practical implications of the results for daily life.[33,37,38] While a *p* value can provide information about whether an effect exists, the *p* value does not give information on the size of the effect. When reporting and interpreting studies, both substantive significance (effect size) and statistical significance (*p* value) are essential results to report.[33,34,38]

Results

The descriptive statistics for the pilot's open-eye bipodal stand (Table 1 and Figure 4) and for the pilot's closed-eye bipodal stand (Table 2 and Figure 5) show that the data distribution is not normal, therefore, paired *t*-tests are not possible for this data set.

At first glance, there's no statistical significance when we compare the mean differences in CoP displacement between pre and post simulation groups at the initial assessment (pre-yoga) and at the final evaluation (post-yoga) as shown on Tables 1 to 3 and in Figures 4 and 5.[39–41]

For the pilot's bipodal stand CoP displacement with eyes open as seen in Table 3.

- before the intervention, there is a small effect size (−0.477) between pre (Bef.Sim) and post flight simulator (Aft.Sim) collections for the intervention group toward a smaller displacement of the CoP and a medium effect size (−0.765) on the control group toward a smaller displacement of the CoP;
- after the intervention there is a small effect size (−0.247) between the pre (Bef.Sim) and post flight simulator (Aft.Sim) collections for the intervention group toward a smaller displacement of the CoP and no effect size for the control group.

Regarding the inter groups effect size on pilot's CoP displacement in bipodal stance with eyes open (Table 4), between the intervention and control groups after the intervention: there is a medium effect size (−0.63) before flight simulation data collection and a large effect size (−0.83) after flight simulation data collection.

For the pilot's CoP displacement with eyes open, as seen in Figure 6: although the differences between groups were not significant, after calculating the effect size, we theorized that the intervention group maintains the CoP shift before and after the flight, while the control group tends to increase this shift.

For the open eye bipodal stance, we calculated intra group kappa for the direction of the displacement of CoP (number of individuals who increased CoP displacement vs number of individuals who decreased CoP displacement, in Figure 5) for the control group before

Table 2. Descriptive statistics of total CoP displacement of pilots in bipodal stance with eyes closed.

Intervention group	In.Bef.Sim.	In.Aft.Sim	Fin.Bef.Sim.	Fin.Aft.Sim
N	9	9	9	9
Mean	186	153	187	175
Median	193	137	208	171
Standart deviation	45.3	41.6	58.7	49.2
Minimum	121	92.4	101	106
Maximum	251	218	251	235
W Shapiro-Wilk	0.957	0.919	0.894	0.900
p Shapiro-Wilk	0.771	0.386	0.218	0.252
Control group				
N	9	9	9	9
Mean	170	178	202	183
Median	166	175	198	170
Standart deviation	47.2	49.6	46.0	39.2
Minimum	119	119	128	138
Maximum	234	272	268	260
W Shapiro-Wilk	0.872	0.942	0.971	0.900
p Shapiro-Wilk	0.131	0.598	0.906	0.251

Total CoP displacement of pilots in bipodal stand with closed eyes, between the intervention group pre (Bef.Sim.) and post (Aft.Sim.) flight simulation in initial (pre-yoga – In.) and final (post-yoga – Fin.) data collection, and the control group for the same parameters.

Table 3. Inter group effect size for open eyes.

Between	Paired Cohen's *d*	*p*	Effect size
Int.I.B.S. and Int.I.A.S.	−0.477	0.226	Small
Ctrl.I.B.S. and Ctrl.I.A.S.	−0.765	0.142	Medium
Int.Fi.B.S. and Int.F.A.S.	−0.247	0.495	Small
Ctrl.F.B.S. and Ctrl.F.A.S.	−0.114	0.812	None

Inter group effect size according to paired Cohen's *d* for pilots in bipodal stance with eyes open at initial data collection (pre-yoga) before flight simulator and after flight simulator and at final data collection (post-yoga) for the same parameters in the intervention and control groups.

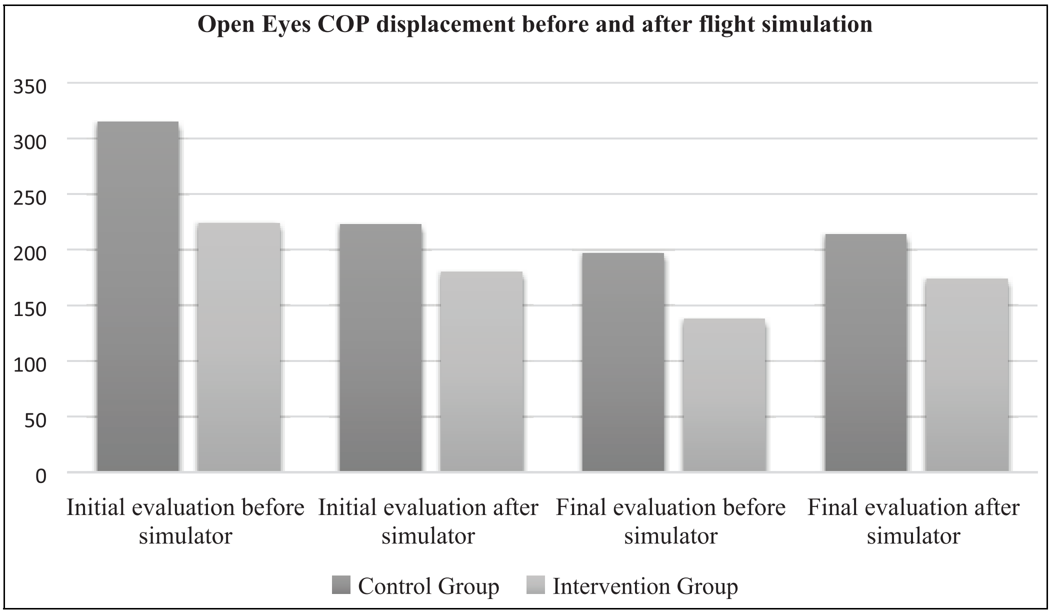

Figure 4. Comparison of open-eyed medians, between the intervention group pre and post simulation at initial (pre-yoga) and final data (post yoga) collection, and the control group for the same parameters.

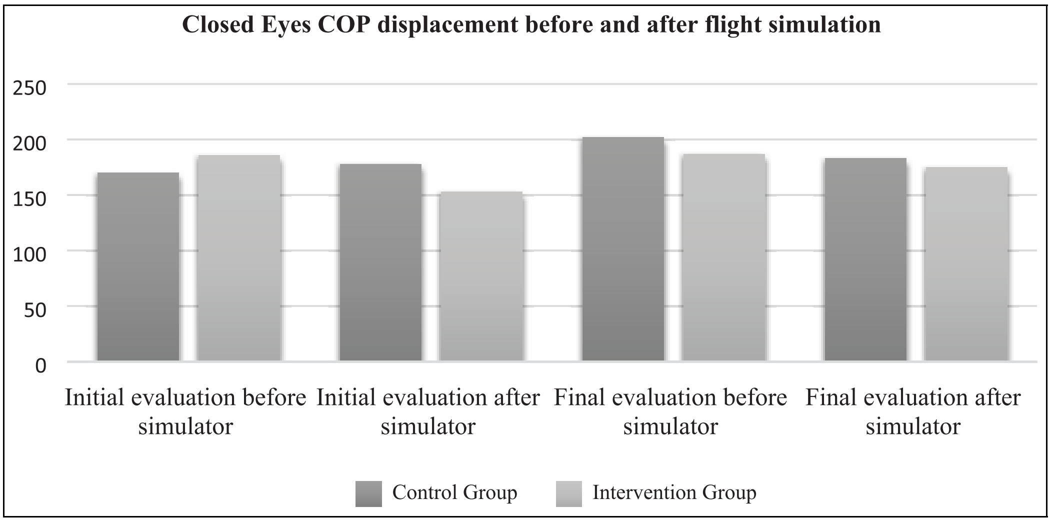

Figure 5. Comparison of closed-eyes medians, between the intervention group pre and post simulation in initial (pre-yoga) and final data (post yoga) collection, and the control group for the same parameters.

Table 4. Inter groups effect size.

	Cohen's *d*	Effect size
Fin.Bef.Sim.	−0.63	Medium
Fin.Aft.Sim.	−0.89	Large

Inter groups effect size on final data collection after yoga intervention with open eyes.

and after simulation pre- and post-intervention and the same parameters for the intervention group. On Table 5 we can see that the number of observed agreements before the 12-week yoga protocol is 9 (50% of observations) and the number of random agreements is 8 (44.44% of observations), which is classified as slight agreement; after the 12-week yoga protocol the number

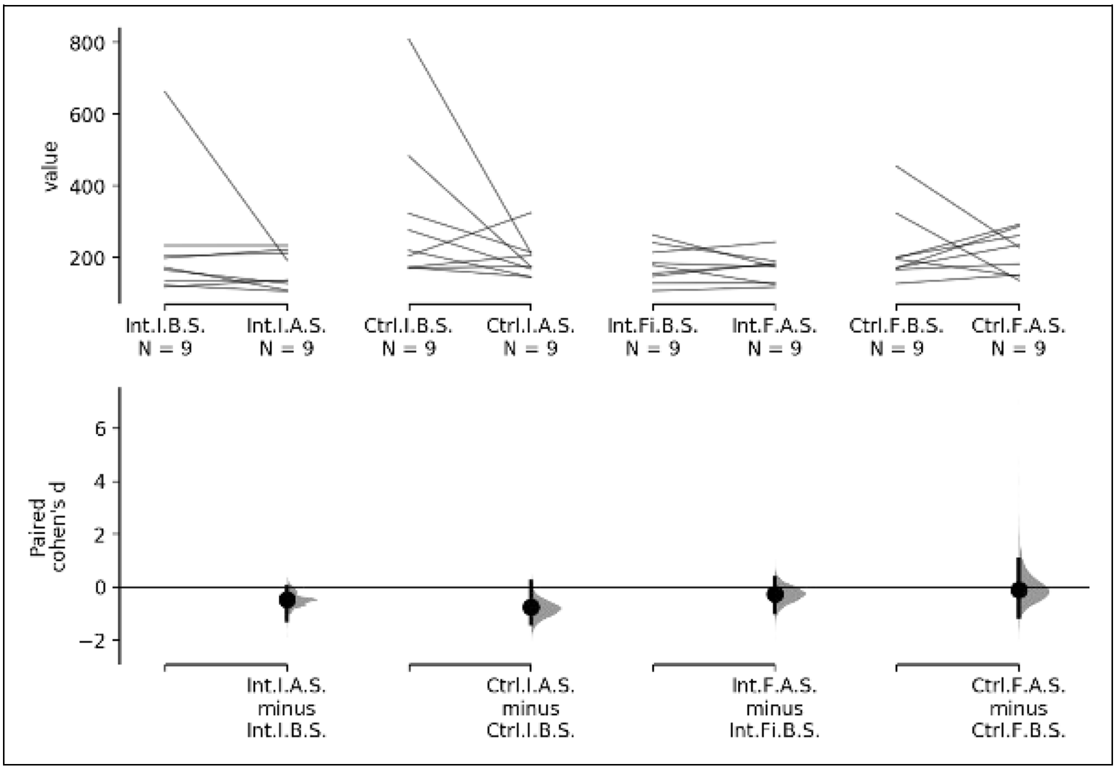

Figure 6. For the online calculator comparison with open eyes, between the intervention group (Int) before (B) and after (A) simulation in initial (I) and final (F) data collection, and the control group for the same parameters, the paired Cohen's *d* for four comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each paired set of observations is connected by a line. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars.

Table 5. Intra-rater reliability calculated online with Cohen's Kappa.

	Intervention group	Control group	Total	Kappa
Before the 12-week yoga program				
Number of pilots that increased CoP displacement after flight simulation	3	3	6	Kappa = 0.100 (slight agreement)SE of kappa = 0.19395% confidence Interval: From −0.278 to 0.478
Number of pilots that decreased CoP displacement after flight simulation	4	6	10	
Number of pilots that maintained CoP displacement after flight simulation	2	0	2	
Total	9	9	18	
After the 12-week yoga program				
Number of pilots that increased CoP displacement after flight simulation	6	5	11	Kappa = −0.111 (no agreement)SE of kappa = 0.22895% confidence Interval: From −0.559 to 0.337
Number of pilots that decreased CoP displacement after flight simulation	4	3	7	
Number of pilots that maintained CoP displacement after flight simulation	0	0	0	
Total	9	9	18	

Intra-rater reliability calculated online with Cohen's Kappa for increased or decreased CoP displacement after flight simulation before the 12-week yoga program and after for bipodal stand with open eyes.

Table 6. Inter group effect size by paired Cohen's *d* for pilots in bipodal stance with eyes closed at initial data collection (pre-yoga) before flight simulator and after flight simulator and at final data collection (post-yoga) for the same parameters in the intervention and control groups.

Between	Paired Cohen's *d*	*p*	Effect size
Int.I.B.S. and Int.I.A.S.	−0.778	0.022	Medium
Ctrl.I.B.S. and Ctrl.I.A.S.	0.163	0.763	None
Int.Fi.B.S. and Int.F.A.S.	−0.226	0.283	Small
Ctrl.F.B.S. and Ctrl.F.A.S.	−0.441	0.301	Small

Table 7. Inter groups effect for closed eyes.

	Cohen's *d*	Effect Size
Fin.Bef.Sim.	−0.28	Small
Fin.Aft.Sim.	−0.18	None

Inter groups effect size in final data collection after yoga intervention with closed eyes.

of observed agreements is 8 (44.44% of observations) and the number of random agreements is 9 (50% of observations), which classifies as no agreement.

For the CoP displacement of the pilot's bipodal stance with eyes closed, as seen in Table 6.

- before the intervention there is a medium effect size (−0.778) between the pre- and post-flight simulator collections for the intervention group toward a smaller displacement of the CoP and no effect size for the control group;
- after the intervention there is a small effect size (−0.226) between the pre- and post-flight simulator collections in the intervention group toward a smaller displacement of the CoP and also a small effect size in the control group (−0.441) toward a smaller displacement of the CoP.

Regarding the inter group size effect on pilot's CoP displacement in bipodal stance with eyes closed (Table 7), comparing intervention and control group after intervention: there is a small effect size before flight simulation data collection but no effect size after flight simulation data collection.

For the pilot's CoP displacement with eyes closed as shown in Figure 7: although the differences between groups were not significant, after calculating the effect size, we theorized that the intervention group maintains the CoP displacement before and after the flight, while the control group tends to decrease this displacement.

For the bipodal stance with eyes closed, we calculated the intra group kappa value for the direction of the CoP displacement (number of individuals who increased CoP displacement versus number of individuals who decreased CoP displacement, as shown on Figure 7) on the control group pre- and post-simulation

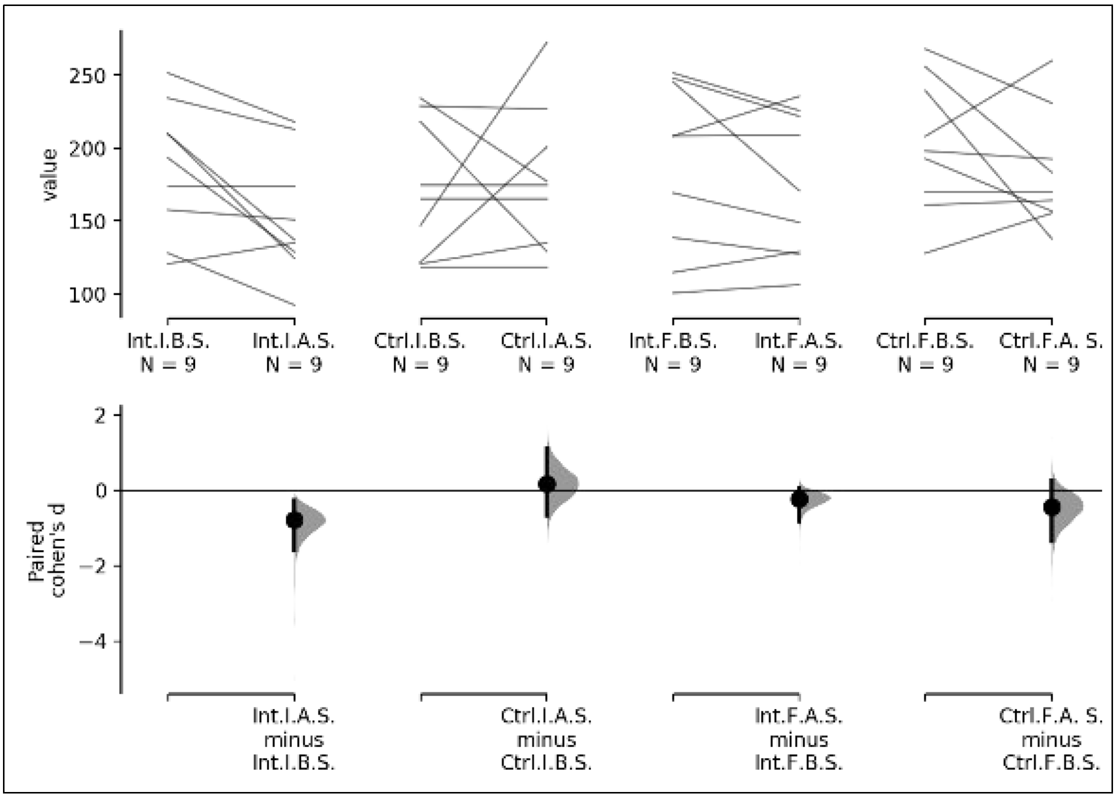

Figure 7. For the online calculator comparison with closed eyes, between the intervention group (Int) before (B) and after (A) simulation in initial (I) and final (F) data collection, and the control group for the same parameters, the paired Cohen's *d* for four comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each paired set of observations is connected by a line. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars.

and pre- and post-intervention and the same parameters for the intervention group.

As shown in Table 8: before the 12-week yoga protocol the number of observed agreements is 7 (38.89% of observations) and the number of random agreements is 9 (50% of observations), which is classified as no agreement; after the 12-week yoga protocol the number of observed agreements is 7 (38.89% of observations) and the number of random agreements is 8 (44.44% of observations), which is classified as no agreement.

Discussion

The aim of this study was to investigate the effects of Ashtanga Vinyasa Yoga Supta on CoP displacement in adult and healthy military pilot students, under the premise that yoga would lead to an improvement in postural control responses.[3,23–28]

Postural control stabilizes the human body in space. It works by integrating the sensory input (somatosensory, visual, and vestibular) regarding body position with the motor output to coordinate muscle action and maintain the body's CoP within its support base. It relies on the control of two reflexes: the vestibulo-ocular reflex, which is responsible for stabilizing images on the retina, and the vestibulo-spinal reflex, which is responsible for maintaining the body's postural stability during movement. If a conflict arises between the visual and vestibular sensory inputs, postural instability and simulator sickness can occur.[6–8,18] Improvements in postural control responses are also associated with resilience in dealing with SD both in the flight simulator and in real flight conditions.[5–18]

Because there are no studies in Portugal and very few international ones in this specific area of postural control for military pilots, we discussed our results using quantitative scales.[30–32] Cohen classified effect sizes as small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geqslant 0.8$) and statistical power depends on effect size and sample size. If the effect size of the intervention is large, it is possible to detect such an effect with a smaller sample size, whereas a smaller effect size would require a larger sample size. Methods to increase the power of a study include using longer interventions with larger effects, increasing the sample/subjects size, reducing measurement error (using highly valid outcome measures), and increasing the α level but only when a Type I error is very unlikely.[33,34,38]

When in a flight simulator, the visual system perceives moving scenery, while the vestibular and proprioceptive cues suggest that the pilot is stationary. Immersion in a flight simulator environment causes a

Table 8. Intra-rater reliability calculated online with Cohen's Kappa.

	Intervention group	Control group	Total	Kappa
Before the 12-week yoga program				
Number of pilots that increased CoP displacement after flight simulation	2	4	6	Kappa = −0.222 (no agreement) SE of kappa = 0.217 95% confidence Interval: From −0.647 to 0.202
Number of pilots that decreased CoP displacement after flight simulation	7	5	12	
Number of pilots that maintained CoP displacement after flight simulation	0	0	0	
Total	9	9	18	
After the 12-week yoga program				
Number of pilots that increased CoP displacement after flight simulation	3	4	7	Kappa = −0.100 (no agreement) SE of kappa = 0.198 95% confidence Interval: From −0.487 to 0.287
Number of pilots that decreased CoP displacement after flight simulation	5	4	9	
Number of pilots that maintained CoP displacement after flight simulation	1	1	2	
Total	9	9	18	

Intra-rater reliability calculated online with Cohen's Kappa for increased or decreased CoP displacement after flight simulation before the 12-week yoga program and afterward for bipodal stand with eyes closed.

vestibulo-visual conflict, which results in a set of sickness symptoms. The visual changes generated by the simulator create a need to adapt to the new environment that occurs in the pilots' visual and vestibular sensory systems. When pilots leave the simulator environment, they must readjust to natural conditions. After returning to the "normal" environment, balance and equilibrium may be disturbed until the pilot readjusts.[6–8,18] Regarding the inter groups size effect on CoP displacement of pilot's open-eye bipodal stance (Table 4), comparing experimental and control groups after the 12-week yoga protocol: there is a medium effect size (−0.63) before the flight simulation data collection and a large effect size (−0.83) after the flight simulation data collection. Regarding the inter groups size effect on pilot's CoP displacement in closed eyes bipodal stance, there is a small effect size (−0.28) before flight simulation data collection but no effect size (−0.18) after flight simulation data collection. These differences suggest that pilots' response to visual information after the flight emergency simulation changed, with open eyes postural control tests, after the 12 week yoga intervention, but not with closed eyes. In this study we found a smaller effect size for pilots with eyes closed and a larger effect size in open eyes postural control evaluation. These findings suggest that student pilots on their Tirocinium have a visual preference in regulating postural stability, which has also been previously found in studies with commercial pilots using stationary flight simulators.[6–8,18] This hypothesis also justifies the need for a personalized yoga intervention, with the supta component of closing the eyes for asana practice, in order to achieve an adaptive response (relying less on vision during flight missions). Thus, with a small sample but a large effect size, the Biosignals Plux portable force platform can measure the effects of the yoga intervention on military pilots CoP.

Considering that one of the study limitations is that our sample size cannot be increased because we have already studied all available student pilots in the Portuguese Airforce Tirocinium, and considering that this intervention lasted only 3 months in highly trained individuals, it might be necessary to increase the intervention duration (either by adding more time to the yoga classes, or more months to the intervention, or giving more weekly yoga classes). By this increase in intervention duration, a bigger effect size might occur on all the parameters studied. Another possibility, given the study's limitations, would be to study and compare student pilots from other countries in the same course, to increase the sample size.[28–32] Despite the limitations mentioned, this study indicates that a yoga program, tailored to the needs of military pilots, in a way that can increase the effect size (e.g. 1 year of yoga instead of 12 weeks), may be one of the tools to incorporate in a mandatory sports exercise training program, to schedule alongside the existing pilot's training course, as it could improve their postural control responses related to increased resilience to SD.

For the pilot's open eyed CoP displacement (Figure 6) we theorized that the intervention group will maintain the CoP shift before and after the flight, whereas the control group tends to increase this displacement. For the pilot's CoP displacement with eyes closed (Figure 7), we theorized that the intervention group will maintain the CoP shift before and after the flight, while the control group tends to decrease this shift.

The CoP displacement behavior of the intervention group is similar with eyes open and closed, which is consistent with previous studies showing smaller differences between the measurements with eyes open and closed.[25–28] The CoP displacement behavior of the control group appears to have change more: it increases with eyes open and decreases with eyes closed. This data means that after a flight simulator session, visual information was less important for postural control in the subjects that practiced yoga. The visual contribution to postural sway control in commercial pilots is reduced as an adaptive response to the flight simulator environment.[6] It would also be interesting to compare senior active pilots with student pilots to further these findings in the military field.

Changes in postural sway could also be related to the psychophysical state of pilots after exposure to a simulator environment,[6] so comparing heart rate variability or even subjective self-reported stress responses and CoP displacement would also be relevant in future studies.

Conclusion

The Biosignals Plux (Portugal) force platform is a non-invasive, rapid way to collect objective data to establish or improve training protocols for military pilots (in this case a program tailored to improve vestibular system responses), in relation to their balance responses by assessing CoP displacement.

We have found that data analysis using more than p-values can provide important practical information for the pilots studied, and also for future studies. The analysis and discussion of the results in this study did not show statistical significance, so the observed differences detected by effect size indicate an existing trend that requires further research. The Biosignals Plux (Portugal) force platform, a stationary flight simulator and a longer yoga protocol or a larger pilot sample (e.g. adding other countries for future studies) can be used to achieve this goal.

Practical implications

- The Plux (Portugal) force platform can be used in future studies on all systems related to balance improvement programs (vestibular, visual, and proprioceptive).
- An examination of non-linear variables (e.g. Lyapunov exponent, Sample Entropy, Detrended Fluctuation Analysis, and Correlation Dimension) would be important to deepen the information about these results.
- In future studies it may be important to apply a longer protocol to military pilots in their Tirocinium, as they are already highly trained.
- Regarding military pilots in general, it might be useful to apply a longer protocol to those less trained (e.g. once civilians pass the application process to become air force pilots; or a full year of yoga on their Tirocinium instead of 12 weeks).
- The changes in CoP displacement could be related to the pilot's personal experience with military training, the intervention with yoga for the intervention group, and perhaps even their personal experiences in dealing with stress of pilot training and the tasks they had to complete. It would also be very interesting to compare the CoP displacement with the pilot's stress levels and even compare the simulator experience with to real flights in future studies.
- An international study examining the same parameters in student pilots from other Airforce teams with the same age and training would increase the sample size of future studies.

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Trial registration

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ORCID iDs

Sara Santos https://orcid.org/0000-0002-7995-0804
Joana Alegrete https://orcid.org/0000-0002-1848-9487
Carolina Alexandra Cabo https://orcid.org/0000-0002-1880-2218

References

1. Hao C, Cheng L, Guo L, et al. Detection of unrecognized spatial disorientation: a theoretical perspective. *Technol Health Care* 2022; 30(S1): 469–480.
2. Gil-Cabrera J, Aguilera J, Sanchez-Tena M, et al. Aviation-associated spatial disorientation and incidence of

visual illusions survey in military pilots. *Int J Aerosp Psychol* 2020; 31(1): 17–24.

3. Appiah-Kubi KO and Wright WG. Vestibular training promotes adaptation of multisensory integration in postural control. *Gait Posture* 2019; 73: 215–220.
4. Yang Y, Pu F, Lv X, et al. Comparison of postural responses to galvanic vestibular stimulation between pilots and the general populace. *Biomed Res Int* 2015; 2015: 567690.
5. Villacís C, Fuertes W, Escobar L, et al. *A new real-time flight simulator for military training using mechatronics and cyber-physical system methods*. London: IntechOpen, 2019, pp.73–90.
6. Polak E, Ślugaj R and Gardzińska A. Postural control and psychophysical state following of flight simulator session in novice pilots. *Front Public Health* 2022; 10: 788612.
7. Stanney KM, Kennedy RS, Drexler JM, et al. Motion sickness and proprioceptive aftereffects following virtual environment exposure. *Appl Ergon* 1999; 30(1): 27–38.
8. Min BC, Chung SC, Min YK, et al. Psychophysiological evaluation of simulator sickness evoked by a graphic simulator. *Appl Ergon* 2004; 35(6): 549–556.
9. Baltzley DR, Kennedy RS, Berbaum KS, et al. The time course of postflight simulator sickness symptoms. *Aviat Space Environ Med* 1989; 60(11): 1043–1048.
10. Ungs TJ. Simulator induced syndrome: evidence for long-term aftereffects. *Aviat Space Environ Med* 1989; 60(3): 252–255.
11. Geyer DJ and Biggs AT. The persistent issue of simulator sickness in naval aviation training. *Aerosp Med Hum Perform* 2018; 89(4): 396–405.
12. Kennedy RS, Fowlkes JE and Lilienthal MG. Postural and performance changes following exposures to flight simulators. *Aviat Space Environ Med* 1993; 64(10): 912–920.
13. Kennedy RS and Stanney KM. Postural instability induced by virtual reality exposure: development of a certification protocol. *Int J Hum Comput Interact* 1996; 8(1): 25–47.
14. Smart LJ Jr, Stoffregen TA and Bardy BG. Visually induced motion sickness predicted by postural instability. *Hum Factors* 2002; 44(3): 451–465.
15. Li R, Peterson N, Walter HJ, et al. Real-time visual feedback about postural activity increases postural instability and visually induced motion sickness. *Gait Posture* 2018; 65: 251–255.
16. Stoffregen TA, Hettinger LJ, Haas MW, et al. Postural instability and motion sickness in a fixed-based flight simulator. *Hum Factors* 2000; 42(3): 458–469.
17. Bonnet CT, Faugloire E, Riley MA, et al. Motion sickness preceded by unstable displacements of the center of pressure. *Hum Mov Sci* 2006; 25(6): 800–820.
18. Chardonnet J, Mirzaei M and Mérienne F. Features of the postural sway signal as indicators to estimate and predict visually induced motion sickness in virtual reality. *Int J Hum-Comput Int* 2017; 33(10): 771–785.
19. Pereira N. A Realização Do Tirocínio Pela Academia Da Força Aérea Portuguesa. Trabalho de Investigação Individual – Curso De Promoção A Oficial Superior Da Força Aérea – Instituto De Estudos Superiores Militares. Lisbon: IUM Instituto Universitário Militar; c2019 [about 1 screen]. https://comum.rcaap.pt/bitstream/10400.26/12480/1/Cap%20Rodrigues%20Pereira.pdf (2009, 24 January 2023).
20. Sharma L. Benefits of yoga in sports: a study. *Int J Phys Educ Sports Health* 2015; 1: 30–32.
21. Government of India. Explaining Yoga as a Sport. Ministry of Ayush. YOGA BLOG. Ministry of Ayush, Government of India. c2020 – [about 1 screen]. https://yoga.ayush.gov.in/blog?q = 56 (2020, accessed 24 January 2023).
22. Shambhu T, Kumar SD and Prabhu P. Effect of practicing yoga on cervical vestibular evoked myogenic potential. *Eur Arch Otorhinolaryngol* 2017; 274(10): 3811–3815.
23. Balaguru P, S S and R D. Effect of pranayama training on vital capacity, respiratory pressures, and respiratory endurance of young healthy volunteers. *Natl J Physiol Pharm Pharmacol* 2022; 12(2): 173–183.
24. Desikachar K, Bragdon L and Bossart C. The yoga of healing: exploring yoga's holistic model for health and well-being. *Int J Yoga Therap* 2005; 15(1): 17–39.
25. Le Clair K and Riach C. Postural stability measures: what to measure and for how long. *Clin Biomech* 1996; 11(3): 176–178.
26. Lin D, Seol H, Nussbaum MA, et al. Reliability of COP-based postural sway measures and age-related differences. *Gait Posture* 2008; 28(2): 337–342.
27. Doyle RJ, Hsiao-Wecksler ET, Ragan BG, et al. Generalizability of center of pressure measures of quiet standing. *Gait Posture* 2007; 25(2): 166–171.
28. Gray VL, Ivanova TD and Garland SJ. Reliability of center of pressure measures within and between sessions in individuals post-stroke and healthy controls. *Gait Posture* 2014; 40(1): 198–203.
29. Gaul A, O'Keeffe C, Dominguez MC, et al. Quantification of neural activity in FMR1 premutation carriers during a dynamic sway task using source localization. *Annu Int Conf IEEE Eng Med Biol Soc* 2020; 2020: 2909–2912.
30. Chen XP, Wang LJ, Chang XQ, et al. Tai Chi and yoga for improving balance on one leg: a neuroimaging and biomechanics study. *Front Neurol* 2021; 12: 746599.
31. Ni M, Mooney K, Richards L, et al. Comparative impacts of Tai Chi, balance training, and a specially-designed yoga program on balance in older fallers. *Arch Phys Med Rehabil* 2014; 95(9): 1620–1628.e30.
32. Pinto DP, Moreira PVS and Menegaldo LL. Postural control adaptations in yoga single-leg support postures: comparison between practitioners and nonpractitioners. *Motor Control* 2022; 26(3): 412–429.
33. Ho J, Tumkaya T, Aryal S, et al. Moving beyond P values: data analysis with estimation graphics. *Nat Methods* 2019; 16(7): 565–566.
34. McGough JJ and Faraone SV. Estimating the size of treatment effects: moving beyond p values. *Psychiatry* 2009; 6(10): 21–29.
35. Chmura Kraemer H, Periyakoil VS and Noda A. Kappa coefficients in medical research. *Stat Med* 2002; 21(14): 2109–2129.
36. Landis JR and Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; 33(1): 159–174.

37. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol* 2013; 4: 863.
38. Sullivan GM and Feinn R. Using effect size-or why the P value is not enough. *J Grad Med Educ* 2012; 4(3): 279–282.
39. Pohlert T. PMCMR: calculate pairwise multiple comparisons of mean rank sums. [R package]. http://CRAN.R-project.org/package=PMCMR (2015, accessed 27 January 2023).
40. R Core Team. R: a language and environment for statistical computing. (Version 4.1) [Computer software]. https://cran.r-project.org (2021, accessed 27 January 2023).
41. Singmann H. afex: analysis of factorial experiments. [R package]. https://cran.r-project.org/package=afex (2018, accessed 27 January 2023).