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Intraocular pressure responses to a virtual reality shooting simulation in active-duty members of the Spanish Army: The influence of task complexity

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ABSTRACT

Ocular physiology is sensitive to cognitively demanding tasks. However, it is unknown whether the intraocular pressure is also affected by the cognitive demands of military operations. The main objective was to determine the impact of a virtual reality shooting simulation with two levels of complexity on intraocular pressure levels in military personnel. Eighteen active-duty members of the Spanish Army and eighteen civilians performed two 4 min simulated shooting tasks with two levels of complexity using a virtual reality. In the “easy” task participants performed a simulated shoot when the stimulus (military with a rifle) appeared, while in the “difficult” task the stimulus randomly was a military with a rifle or with his hands on the air and participants were instructed to respond only when the military with a rifle appeared. Intraocular pressure was measured with a rebound tonometer before and immediately after each task. Complementarily, perceived levels of mental load and shooting performance (reaction time) were assessed. Intraocular pressure was greater after completing the more complex task in both military personnel (p-value < 0.01, Coheńs d $= 1.19$) and civilians (p-value < 0.01, Coheńs d $= 1.16$). Also, perceived levels of task load and reaction time were higher in the difficult compared to the easy shooting tasks (both $p < 0.001$). The rise in intraocular pressure is positively associated with the cognitive demands of simulated military operations. The potential application of this finding is the development of objective tools based on intraocular pressure for the evaluation of the mental state in real-world contexts, permitting to improve soldiers ́ safety and performance.

1. Introduction

Military personnel have to make appropriate and rapid decisions, and they are often made in the presence of risk and uncertainty [34]. Military operations are particularly challenging in cognitive terms and cause an increase in mental workload, which may compromise performance and safety [11, 36, 42]. In these situations, it is crucial to determine soldiers ́ overload threshold, with the most frequently used tools to assess task load variations being based on subjective tests and questionnaires [17, 35]. Nevertheless, subjective measures present some inherent limitations due to its dependence on personal and motivational factors [31], or their inability to capture small changes in mental load [7].

In recent years, numerous researchers have explored the acute physiological responses to the cognitive demands of military operations, aiming to develop a workload soldieŕs fit-for-duty system [2, 5, 11]. Within the wide range of physiological indices (e.g., heart rate variability, stress hormones, electroencephalographic activity, skin conductance) that have demonstrated to be sensitive to mental workload (see [4]) for a recent review on this matter), different parameters related to the ocular physiology and function (i.e., pupil size, blink rate, eye movements, intraocular pressure) have also been proposed as objective indicators of mental workload in different contexts [8, 10, 38, 39, 41, 43]. Besides physiological and ocular variables, reaction time (RT) measurements have been routinely used for evaluating soldiers’ preparedness [22, 26, 44]. Previous studies showed that RT tests can be

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used as indicators of the speed of information processing and that the RT values are positively related with the complexity (i.e., cognitive demands) of the tasks [6, 27, 29].

Intraocular pressure (IOP), which is defined as the pressure exerted by the eye fluids inside the eyeball [33], has demonstrated to be sensitive to mentally demanding situations in laboratory and applied settings such as academic examinations [18], simulated surgical procedures [41], or arithmetic and mental workload tasks [37, 39]. Remarkably, this measure assessed by rebound tonometry, is rapid (3–4 s), easy to measure, does not require the instillation of anesthesia, and is very well-tolerated [30]. Based on these mentioned advantages, it would be worthy to determine whether IOP is able to capture changes in the levels of mental workload during a simulated war scenario, specifically whether IOP is sensitive to the complexity of a shooting simulated task.

In order to address the limitations found in the related literature, the main objective of the present study was to explore whether IOP is sensitive to the cognitive demands of a virtual reality shooting simulation task with two levels of complexity in active-duty army members and civilians. Based on the increased IOP reported for surgical and medical residents after performing simulated bronchoscopy procedures [41], we hypothesized that the high mental demands of virtual reality shooting simulation tasks would lead to higher IOP values, while the increase of the IOP would be more accentuated for the more cognitively demanding task.

2. Material and methods

2.1. Participants

Eighteen members (all males; age = 28.8 ± 4.8 years, height = 178 ± 7 cm, and weight = 76.5 ± 9.6 kg) of the “Guzmán el Bueno” X brigade (Spanish Army, military base of Cerro Muriano, Córdoba, Spain) and eighteen sport science students (all males; age = 24.1 ± 4.6 years, height = 178 ± 7 cm, and weight = 78.2 ± 10.0 kg) of the University of Granada (Faculty of Sports Sciences, Granada, Spain) took part in this study. Participants were screened according to the following inclusion criteria: (a) be free of any systemic or ocular disease, (b) present a monocular visual acuity $\leq$ 0.0 log MAR in both eyes with the best correction, (c) score $\leq$ 3 with Stanford Sleepiness Scale (SSS) in order to ensure an appropriate level of alertness (see the Questionnaires subsection), and (d) refrain for alcohol intake before the experimental session. None of the participants had previous experience playing video games using virtual reality equipment. This study was conducted in conformity with the Declaration of Helsinki, and permission was provided by the University of XXX Institutional Review Board (IRB approval: XXXX/YYYY/ZZZZ). Informed consent was obtained from all participants included in the study.

2.2. Design

Participants visited the simulation training center of the “Cerro Muriano” military base (military personnel group) or the Faculty of Sport Sciences at the University of Granada (civilian group). Upon arrival, they read and signed the informed consent form, and the examiner explained them the testing procedures. Then, we obtained data about demographic characteristics, and the dependent variables were assessed (IOP and subjective questionnaires [SSS, and NASA-TLX]). At this point, the virtually reality glasses were adjusted and a randomly chosen shooting simulation task was performed. Participants were always instructed to react as soon as they identified the enemies in the video and this was used to calculate the reaction time as an objective measure of the complexity of the task. Just after completing the simulation task, IOP was measured and participants reported their perceived levels of mental load (NASA-TLX). All participants performed this procedure four times as each task (easy-task and difficult-task) was performed twice. Participants were allowed 3 min of rest between consecutive trials. The study design of this study was not preregistered, but the raw data on which the study conclusions are based on are available as a supplementary file.

2.3. Measurements

2.3.1. Intraocular pressure

IOP was assessed using a portable rebound tonometer (ICare, Tiolat Oy, Inc. Helsinki, Finland), which has been clinically validated and demonstrated a high level of reproducibility [24]. Due to its inherent characteristics (i.e., handheld, portable), the use of this instrument allowed us to assess IOP immediately after completing the simulated shooting tasks. Following the manufacturer instructions, six rapidly consecutive measurements were taken from the right eye, while participants fixated on a distant target. From the six measurements, the apparatus calculates the average value and indicates the level of variability of these measurements. We always considered IOP readings with low standard deviation (ideal measure).

2.3.2. Questionnaires

At the beginning of the experimental session, participants were asked to complete the SSS in order to assess their level of alertness/sleepiness [16]. The SSS is a self-rating scale that provides a global measure of alertness and contains seven statements ranging from 1 “Feeling active, vital, alert, or wide awake” to 7 “No longer fighting sleep, sleep onset soon, having dream-like thoughts”. Also, participants were asked to complete the mental subscale of NASA-TLX (task load index), which classifies the perceived level of mental demand from 0 to 100, after the four simulated tasks [15].

2.3.3. Virtual reality glasses and shooting simulation tasks

A military-specific test was implemented through virtual reality glasses (Oculus Quest 2, Meta Platforms, USA). The glasses were wirelessly connected to the laptop using the Virtual Desktop app (version 1.20.19), allowing us to have external control of the content displayed on the virtual reality glasses. The videos were presented to the participants using a custom-made LabView program (National Instruments, version 8.2.1). The custom-made LabView program did not serve only for presenting the video with the stimuli, but also to detect every instant when participants reacted to the stimulus by pressing a gun-shaped mouse.

Volunteers were placed in a standing position, and the virtual reality glasses were individually adjusted with the corresponding straps in order to achieve clear vision. First of all, a short sample of a similar video to the one used for the simulated shooting task was displayed for familiarization purposes. The same forest scenario was used for both shooting tasks, and both tasks were performed twice. In the simple shooting simulation (easy-task), soldiers appeared from different points of the scenario with the rifle pointing towards the camera, and participants were instructed to press the gun-shaped mouse as soon as they perceived the enemies. However, in the discrimination shooting simulation (difficult-task), soldiers appeared from different points of the scenario with the rifle towards the camera (enemies) or with their arms in the air (allies), and participants were instructed to press the gun-shaped mouse only when they perceive the enemies and abstain from any action when perceiving the allies (**Fig. 1**). The duration of both tasks was 4 min. A total of 56 stimuli were randomly presented in each task. The duration of all stimuli was approximately 0.5 s, while the foreperiod between two consecutive stimuli was randomized and ranged from 1 to 5 s.

2.4. Statistical analyses

Paired sample t-tests and standardized mean differences (Cohen’s d effect size) were used to compare the IOP measurement taken before and after both shooting simulations as well as the perceived levels of

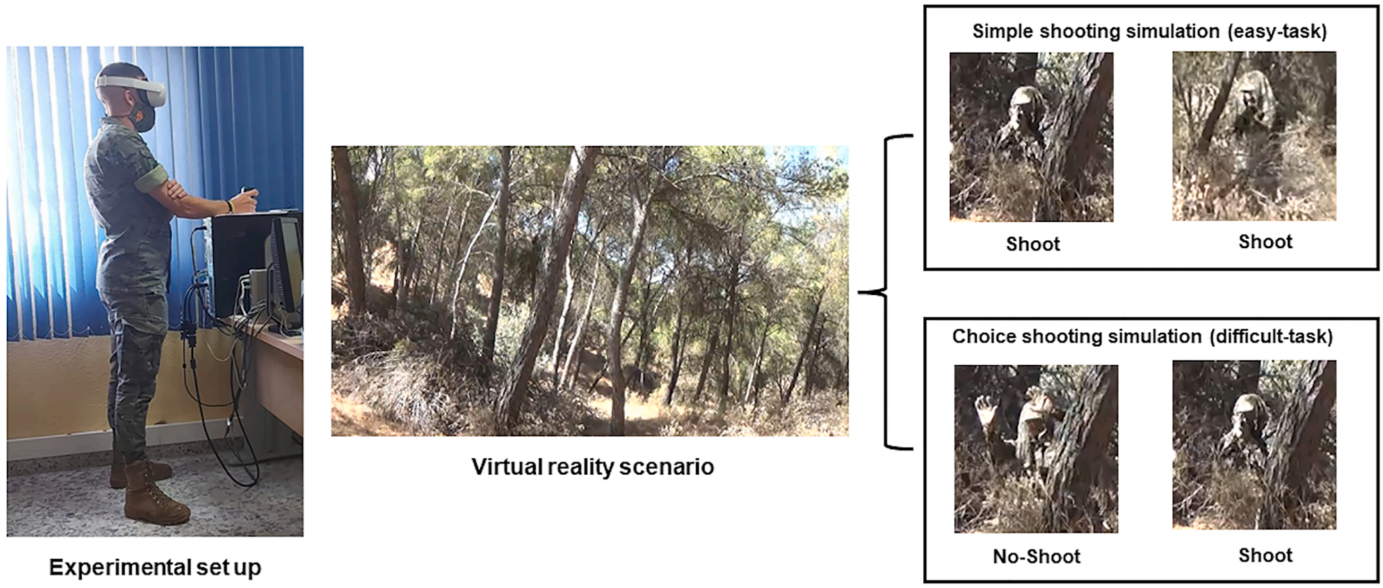

Fig. 1. A schematic illustration of the experimental set up and both shooting simulation tasks. The simple shooting simulation (easy task) is depicted in the upper panel, whereas the discrimination shooting simulation (difficult task) is shown in the lower panel.

mental demand between both sessions. Reliability was assessed by the coefficient of variation (standard error of measurement/subjects' mean score × 100) and the intraclass correlation coefficient (model 3.1). Due to the high intraclass correlation coefficients for IOP and perceived mental demand measurements (intraclass correlation coefficient ranging between 0.88 and 0.96), data from both trials were averaged to increase the internal validity.

Differences in the mental load recorded after the simulated shooting tasks were assessed by a repeated-measures analysis of variance (ANOVA) with the "task complexity" (easy vs. difficult) as the within-participants factor and the "group" (military personnel vs. civilians) as the between-participants factor. For its part, the changes in IOP caused by the shooting task in the virtual reality simulator were analyzed using a repeated measures ANOVA with the "point of measure" (before vs. after the simulated shooting task) and the "task complexity" (easy vs. difficult) as the within-participants factors, and the "group" (military personnel vs. civilians) as the only between-participants factor. We reported Cohen's d and eta-squared (η^2) as effect size indices, and post-hoc tests were corrected with Holm–Bonferroni procedure. The level of statistical significance was always set at 0.05.

Table 1
Descriptive (mean ± standard deviation) and statistical (P-value and Cohenś d) values for measurements taken in both experimental sessions, and at both shotting conditions and points of measure.

		Session 1	Session 2	P-value	Cohenś d
Simple shooting simulation (easy-task)	IOP before (mmHg)	16.47 ± 3.92	16.31 ± 3.92	0.505	0.04
	IOP after (mmHg)	16.14 ± 4.38	16.36 ± 4.16	0.537	0.05
	NASA-TLX (0-100)	28.33 ± 18.13	30.28 ± 18.90	0.147	0.11
Choice shooting simulation (difficult-task)	IOP before (mmHg)	16.28 ± 3.69	16.00 ± 3.58	0.263	0.08
	IOP after (mmHg)	18.58 ± 4.02	18.22 ± 4.20	0.205	0.09
	NASA-TLX (0-100)	51.39 ± 19.15	51.94 ± 18.80	0.790	0.03

3. Results

Table 1 shows the descriptive and statistical values of IOP (before and after the task) and perceived levels of mental demand (after the task) for the easy and difficult shooting task conditions.

3.1. Perceived levels of sleepiness/alertness and mental demand

The levels of sleepiness/alertness at the beginning of the experimental session did not differ between military personnel and civilians ($t = 1.28$, $p = 0.209$). Regarding perceived levels of mental demand, there was a statistically significant effect for the "task complexity" ($F_{1,34} = 106.11$, $p < 0.001$, $\eta_p^2 = 0.76$), with participants reporting greater levels of mental demand after performing the difficult in comparison to the easy task (mean differences of 21.94 ± 15.06 for the military personnel and 22.78 ± 10.60 for civilians). However, the main effect of "group" or the interaction "task complexity × group" did not reach statistical significance ($F_{1,34} < 0.01$, $p = 0.981$; and $F_{1,34} = 0.04$, $p = 0.849$; respectively) (**Fig. 2A**).

3.2. Shooting performance

Reaction time was sensitive to "task complexity" ($F_{1,29} = 121.97$, $p < 0.001$, $\eta_p^2 = 0.40$) and "group" ($F_{1,29} = 40.32$, $p < 0.001$, $\eta_p^2 = 0.30$), obtaining a shorter reaction time for the easy compared to the difficult task, as well as for the military personnel in comparison to civilians (**Fig. 2B**).

3.3. Intraocular pressure

The analysis of IOP showed a main effect of the "point of measure" ($F_{1,34} = 11.51$, $p = 0.002$, $\eta_p^2 = 0.25$), "task complexity" ($F_{1,34} = 27.04$, $p < 0.001$, $\eta_p^2 = 0.44$), and the interaction "point of measure × task complexity" ($F_{1,34} = 116.99$, $p < 0.001$, $\eta_p^2 = 0.78$) statistically significant. However, the main effect of "group" ($F_{1,34} = 0.01$, $p = 0.917$), as well as the interactions "point of measure × group" ($F_{1,34} = 2.34$, $p = 0.135$), "task complexity × group" ($F_{1,34} = 1.77$, $p = 0.193$), and "point of measure × task complexity × group" ($F_{1,34} = 1.41$, $p = 0.243$) did not reach statistical significance. Specifically, we found an IOP rise after the execution of the difficult-task in both experimental groups (military personnel: corrected p-value < 0.01, Cohenś d = 1.19; civilians:

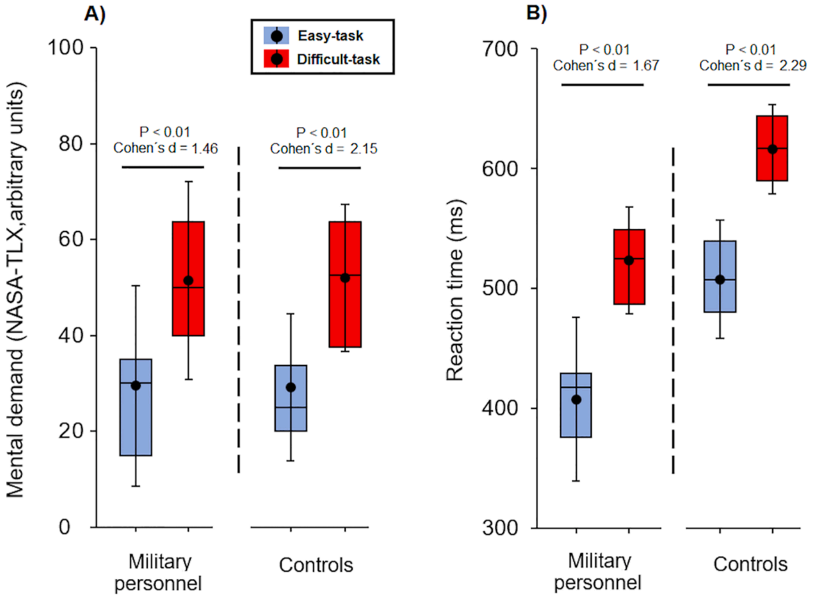

Fig. 2. Boxplot of the effect of performing a simple (easy-task, in blue) and discrimination (difficult-task, in red) shooting training session in a virtual reality system on perceived levels of mental load (Panel A) and reaction time (Panel B). Statistically significant differences for the point of measure are depicted with the corresponding p-values and effect sizes. The whiskers represent the standard deviation, horizontal lines indicate the median value, and filled circles the average value.

corrected p-value < 0.01, Cohens d $= 1.16$), whereas IOP remained stable after performing the easy-task (military personnel: p-value $= 0.409$, Cohens d $= 0.20$; civilians: p-value $= 0.146$, Cohens d $= 0.45$) (Fig. 3).

4. Discussion

The main aim of this study was to explore the impact of simulated shooting tasks with different levels of complexity on IOP values in military and non-military personnel. Our data showed that IOP was sensitive to the cognitive demands of the task, observing greater IOP values after performing the more difficult task. To the best of our knowledge, these results incorporate preliminary evidence about the IOP changes caused by cognitively demanding military simulated operations. Accordingly, participants reported greater levels of perceived mental load (NASA-TLX) after completing the difficult compared to the easy simulated shooting task. The lower cognitive demand of the easy-task seems to be supported by the shorter reaction time obtained during the easy task compared to the difficult task. This set of findings are in line with previous studies showing that changes in the cognitive state are associated with IOP variations [18, 25, 37, 39, 41] and, therefore, it could lead to the development of a fit-for duty index for estimating soldiers´ mental overload.

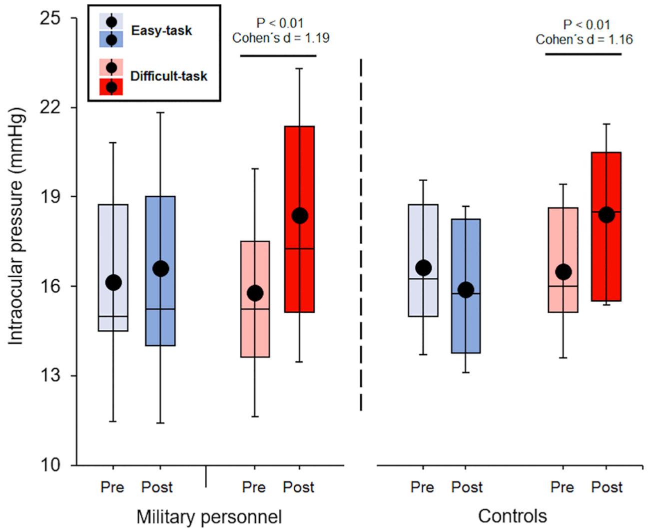

Fig. 3. Boxplot of the effect of performing a simple (easy-task, in blue) and discrimination (difficult-task, in red) shooting training session in a virtual reality system on intraocular pressure. Statistically significant differences for the point of measure are depicted with the corresponding p-values and effect sizes. The whiskers represent the standard deviation, horizontal lines indicate the median value, and filled circles the average value.

Previous studies in laboratory and applied settings (i.e., academic exams, surgical procedures, aircraft piloting, and army drivers´ workload) have used the subjective responses of the NASA-TLX questionnaire and performance in the corresponding procedures to examine differences in task complexity [10, 21, 32, 39]. In this regard, the successful experimental manipulation of task complexity was confirmed by the analysis of the perceived levels of mental load and shooting performance assessed by the reaction time. Specifically, military personnel and civilians indicated that the difficult simulated shooting task was more mentally demanding than the easy simulated shooting task, while reaction time (task performance) was longer in the difficult- than in the easy-task. Taken together, these findings corroborate an effective manipulation of the complexity of the simulated shooting tasks designed for the current investigation. The analysis of IOP values allowed us to corroborate our hypothesis, with these results being in agreement with the studies that have reported a heightened IOP response to cognitively demanding tasks [9, 18, 25, 37, 39, 41]. For example, Vera et al. [41] found an acute IOP increment after performing a simulated surgical task, suggesting a bidirectional relationship between IOP and the nervous systems activation state (i.e., arousal level). It is reasonable to hypothesize that a similar arousal-based effect is responsible for the IOP rise caused by the more complex simulated shooting tasks in the current study. Based on our findings and the accumulated scientific evidence in laboratory and ecological settings, changes in the nervous system activation state affect the IOP behavior. Additionally, military personnel had lower RT in comparison to sports science students. A possible explanation is that the specific nature of the RT content (i.e., simulated military situation) might be responsible for prompting faster responses in the military personnel, which is in line with previous studies in which experts showed better RT values than non-experts or novice athletes when using specific RT tasks [13, 14, 27, 28].

The validity and utility of numerous neurophysiological measurements have been assessed in an attempt to predict the functioning of the central and autonomous nervous systems, which may permit to minimize catastrophic consequences [2]. In practice, the implementation of these neurophysiological tests is challenging due to the laborious procedures for data acquisition and analysis, cost limitations, dependence of uncontrollable exogenous factors (i.e., light levels for pupil size), instrument bulkiness or interfering with operators ́ performance. In this regard, IOP measurement incorporates some advantages since it is easy and rapid to obtain as well as very well-tolerated. The IOP, as measured by rebound tonometry, allows to obtain discrete measurements during or immediately after the execution of different tasks. However, recent developments in contact-lens sensors (SENSIMED Triggerfish, Sensimed, Switzerland) that allows to continuously assess IOP may be considered as a promising tool for controlling task (over)load or fatigue in applied scenarios [23]. In regard to the physiological mechanisms responsible of these IOP variations, this ocular metric has been proposed as an indicator of changes in sympathetic-parasympathetic balance as consequence of cognitive effort [3, 18]. Indeed, it is well-known the role of the autonomous nervous system on IOP regulation, as well as the mediating effect of the sympathetic-adrenal system in aqueous humour inflow and outflow [12, 20]. Therefore, it is plausible to expect that IOP variations linked to cognitively demanding tasks are mediated by changes in the nervous system's activation state.

The findings of this investigation should be cautiously interpreted in light of the following potential limitations. Firstly, IOP was measured in a pre/post manner and, thus, the behavior of this variable during the course of the simulated shooting task is unknown. Future studies should try to continuously monitor IOP during cognitively demanding tasks. This is now possible due to the recently developed contact-lens sensors allowing a continuous IOP monitoring. Secondly, the physiological reactivity to the challenging situations simulated during the shooting tasks may be dependent on the level of expertise [1, 19], but due to the small sample size in this study soldiers were not classified according to their military experience. Thirdly, IOP has demonstrated to be sensitive to mental fatigue in drivers [40], and considering that the military personnel conduct long working shifts during simulated or real operations, it would be worth investigating the potential utility of IOP to detect soldiers ́ fatigue in combat situations. Lastly, we used a virtual reality simulator, but the generalizability of the current results in real-world scenarios needs further investigation.

5. Conclusions

IOP increased after performing a cognitively demanding simulated shooting task in active-duty army members and civilians. This set of results suggests a link between the nervous system ́s activation state and IOP responsiveness. The present findings may help to develop objective tools for the assessment of the mental state in applied settings, which would permit to predict future performance of operators and prevent fatal accidents. Future studies are required to ascertain the external validity of these results in real-world scenarios.

Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.physbeh.2022.113957.

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