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The Influence of Autonomous Movement on Adverse Events in Relaxing Virtual Environments Using a Head-Mounted Display: An Exploratory Study

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Abstract

Background Virtual reality has been increasingly used to support established psychological interventions, including relaxation techniques. Only limited knowledge about the occurrence and severity of adverse events (AEs) (e.g. cybersickness) in relaxing virtual environments is available. The aim of the study was to assess the frequency of AEs in virtual environments and factors associated with these.

Methods A sample of 30 healthy participants was included in the study. The participants completed questionnaires on susceptibility of motion sickness, and use of and attitudes towards modern technology prior to the exposition to the virtual environment. They then took part in three short virtual scenarios (no movement of the avatar, steady non-autonomous movement, and autonomous movement) using head-mounted displays and rated the occurrence and severity of AEs after each scenario.

Results The participants reported high incidence rates of different AEs (40–70%), but only in the scenario with autonomous movement. In the scenarios with no or only limited control over movement approximately 30% reported slight symptoms of dizziness, and 3–7% reported slight nausea. Nevertheless, the occurrence of AEs resulted in reduced relaxation and mood. Gender, age, and usage of computers and gaming consoles had no influence on the incidence or severity of AEs.

Discussion Our results show that virtual reality is a safe technology to be used in clinical psychology, if certain parameters are being minded. Future studies should routinely assess and report AEs in a structured way, to enable more in–depth insights regarding influential factors and potential prevention strategies.

Keywords: Virtual Reality; adverse events; Cybersickness; Head-Mounted Display; HMD

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1 Introduction

In the last decade modern technology has moved into the center of interest to support psychological interventions [AC09, VLKRC16]. Recently, especially Virtual Reality (VR) based applications [ASN15] are receiving increasing attention. So far, research in clinical psychology has mainly focused on the possibilities to use VR to treat different forms of phobias / anxiety disorders e.g. [MRK13, PPdlF$^+$15] or post-traumatic stress disorder (PTSD) e.g. [DCW$^+$14, RPJ$^+$14]. Yet,

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recent studies also showed the feasibility and possible benefits of VR-based relaxation techniques to induce relaxation and positive emotions in clinical populations [BEG+13, BGPV+13, GPA+10, STK+15, VR12]. In this context, VR can be understood as a technological assisted guided imagination [Riv05] and is therefore closely linked to the concept of 'Guided Imagery' relaxation techniques. Since the interaction in environments enriched with positive visual and auditory stimulations leads to increased self-efficacy and mood [PAS+03, PCCS06], Gorini and Riva [GR08] argued that VR-based Guided Imagery represents a promising approach to increase the effect of applied relaxation techniques.

Nevertheless, there are several potential challenges which have to be considered when using VR. It has been repeatedly reported that AEs can occur not only during, but also after exposition to virtual environments. Adverse events can be roughly grouped in three main dimensions: nausea (vomiting, dizziness), disorientation / postural instability (vertigo, imbalance), and visual symptoms (eyestrains, blurred vision, headaches) [Bar04, KLBL93].

One of the most frequently mentioned adverse events in VR is motion sickness, which is also referred to as cybersickness in this specific context [RO16]. However, incidence rates of participants reporting symptoms of cybersickness differ strongly between 10-95% [BB90, MFFS07, SK09, TBC+15]. Cybersickness is characterized through several different symptoms (polysymptomatic), which also differ from person to person (polygenic), making it complex to understand and describe [RO16]. Nevertheless, there are some reappearing factors found to influence both the onset and severity of AEs in VR: (a) technical characteristics (hardware and software), (b) task characteristics, and (c) individual characteristics. Regarding the technical aspects one important factor is the latency between the individual's movement and the system's reaction, sometimes referred to as 'lag' [DNN15]. A delay in the representation of movement strongly contributes to the occurrence of cybersickness [LaV00]. Good tracking of movement as well as real time graphical displays (>50-60Hz) are therefore essential to prevent cybersickness. Further technical aspects are the weight of the head-mounted display (HMD), resolution and contrast of the virtual environment (VE), and field of view [DNN15, FF16, MM11]. A comprehensive review on the role of rendering modes, visual display systems and application design is offered by Rebenitsch and Owen [RO16].

AEs may also be influenced by the type of task, which includes not only the content of the quest in the VE, but also the level of control over the environment (i.e. autonomous movement), or the duration of the task [DNN15]. Participants with reduced control lack predictability about the environment and thus be prone to AEs [Bar04]. On the other hand it has been reported that navigation in VEs may lead to more sensory mismatch, because participants cannot identify distances correctly [Ehr97].

Individual characteristics include general sensitivity to motion sickness [GB08], previous experience with virtual reality [ULK86], and the current level of psychological stress [MPC15]. While newer studies found no correlation of cybersickness and age e.g. [BGC+10], there might be a gender effect as women are often found to be more susceptible to cybersickness than men [Bio92, PAF+06, RO16] [Kol92]. This might be explained by the wider field of view of women, which increases the likelihood of flicker perception and therefore also the susceptibility to cybersickness [LaV00]. The evidence-base on the relationship between presence, i.e. the sense or really being in a virtual scenario, and cybersickness is still ambiguous: while some studies found lower rates of cybersickness correlated with higher presence [JDOP05, MPC15], others reported no significant relationship between presence and cybersickness [LNB+13]. Attitudes towards modern technology such as curiosity and interest, but also anxiousness and scepticism may also influence the attention and stress-level during the exposure to VEs and therefore the occurrence of AEs.

Most previous studies have been conducted in more stressful environments while information on AEs in relaxing VEs is still scarce. Baños et al. [BEG+13] conducted a study on the feasibility and possible benefits of a psychological intervention using VR (flat screen) to induce positive emotions in adult hospitalized patients with metastatic cancer. In their study only one out of 19 participants reported a slight increase of preexisting dizziness, while the majority of the patients rated the experience as pleasant. In most other studies, e.g. Gorini et al. [GPA+10], Villani and Riva [VR12], Botella et al. [BGPV+13], Shah et al. [STK+15] AEs were not mentioned.

In the light of recent research, VR is a promising approach to support established psychological interventions such as relaxation or induction of positive emotions. Yet, more knowledge on potential AEs is needed to guarantee patients' satisfaction and safety. The aim of the study was to assess the frequency of AEs in relaxing VEs and factors associated with these.

2 Materials and Method

The study was conducted according to the Declaration of Helsinki. All participants were informed about nature and aims of the study and gave their written informed consent prior to participation.

2.1 Participants

Healthy male and female participants between 18-80 years were recruited by email advertisements at the Medical University of Innsbruck and the Leopold-Franzens University of Innsbruck. Inclusion criteria were (a) age over 18 years, (b) no severe cognitive impairment at the investigators discretion, and (c) fluent German.

2.2 Procedure

A within-subjects design with three experimental conditions and repeated measurements was used. All sessions were administered in a room at the University Clinic of Medical Psychology (Medical University of Innsbruck) under supervision of a clinical psychologist.

Participants completed the consent form and general questionnaire on their sociodemographic background, use of and attitudes towards modern technology, and susceptibility of motion sickness. They then took part in three short virtual scenarios: (a) no movement of the avatar, (b) steady non-autonomous movement, and (c) autonomous movement. After each scenario participants rated the occurrence and severity of AEs. Short breaks after each exposure were included to minimize the influence of current AEs on the next scenario. From our pre-study experiments we knew that the autonomous movement was considered as the most difficult part. Since almost none of our participants had prior experience with VEs we decided not to randomize the order of the scenarios to allow a stepwise immersion.

2.3 Virtual environments

All scenarios used in the study was freeware that could be downloaded within the Oculus program (see Figure 1). Scenario A ('Introduction to Virtual Reality') consisted of 8 short sequences with different content – including e.g. being close to peaceful elephants or being in the middle of a basketball training. The avatar of the participant was standing still in in the middle of each sequence and participants were able to look around in a 360° VE by moving the head. In scenario B ('The Grand Canyon VR Experience') participants were slowly canoeing down the Grand Canyon. They were able to control the speed of the canoe with a remote control and look around, but could not steer the canoe which was following a predefined path. Finally, in scenario C ('Woofbert') participants were placed in a virtual museum with an art exhibition. They could move around freely using a remote Xbox control (left stick initiated movement, right stick turned the avatar). Since it is well documented that increasing duration increases the intensity and duration of cybersickness [RO16] we limited the exposure to relatively short time slots. While scenario A was pre-set with a duration of 3 minutes 30 seconds, participants were asked to stay at least four but not longer than eight minutes in scenario B and C.

2.4 Hardware used in the study

VEs were displayed on an immersive head-mounted display (HMD), the Oculus Rift. The Rift has an OLED display with a 960x1080 resolution per eye, a 75 Hz refresh rate, and 100° field of view. Movements in the VE were controlled using a standard wireless Xbox 360 controller. To run the software we used the MSI GT72S with a NVIDIA GeForce GTX980M and a CPU with IntelCore i7 (32 GB RAM, DDR4-2133), which is sufficient to fluently run Oculus [Ocu15].

2.5 Measures

Participants were asked to complete a questionnaire on their sociodemographic background and their use of modern technologies as well as pre-existing experience with VR. Susceptibility to motion sickness in everyday life was assessed with 9 items on a 4-point Likert scale from 'not at all' to 'often' (e.g. 'Do you sometimes feel sick on ships?' or 'Do you sometimes feel sick if you read on the train?'), which are summed up to a total score.

To assess adverse events we used applicable items from the **Simulator Sickness Questionnaire (SSQ)** [KLBL93] and extended the list for further symptoms reported in previous studies. The final

Figure 1: Scenarios used in the study

checklist included 11 items to rate the intensity of symptoms on a 4-point Likert scale ('not at all' to 'very') and an additional item for participants with glasses. Symptom severity ratings were summed up for each scenario (adv 1–3) separately as well as across all scenarios (adverse event total score).

The **Technology Usage Inventory** (TUI) was used to assess attitudes towards and acceptance of modern technology. The TUI has been specifically developed for user-oriented evaluation of modern technologies, such as Virtual Reality. It consists of 30 Items which can be aggregated into eight subscales. As suggested by the authors the scales curiosity, anxiety and interest were presented prior to the intervention, while the items on usability, immersion, usefulness, scepticism, and accessibility were filled out after the intervention. Good internal consistencies ($\alpha = 0.70 - 0.89$) and stanine norm values have been reported for the subscales of the TUI [KFH+12].

The **igroup Presence Questionnaire** (IPQ) was administered after the third scenario to assess the level of immersion and presence in the VEs. It consists of 14 items measured with a 7-point Likert Scale ('strongly agree' to 'strongly disagree'), representing three subscales: 'spatial presence' assessing the sense of being physically present in the VE, 'involvement' to measure the attention participants devote to the VE, and 'experienced realism' asking how realistic the VE was experienced by each participant. The additional single item scale 'sense of being there' assessed the participants feeling of really being in the VE. Previous studies reported acceptable to good internal consistencies for all subscales $\alpha = 0.76 - 0.82$) [FKH+14, vBI04].

2.6 Statistical analysis

For statistical analysis IBM SPSS v21 was used. Data is presented as percentile ranks, mean and standard deviation. Group comparisons were carried out using independent sample t-tests and repeated measures analysis of variance (ANOVA). The size of the mean differences was estimated using Hedges' adjusted g' [HO85], which is preferable to Cohens' d in this instance as it includes adjustment for small sample bias [Ell10]. Values of $g' = 0.2, 0.5, 0.8$ represent small, moderate, and large effects. To investigate correlations Pearson's correlation coefficient was used. Probability values $p < 0.05$ were considered statistically significant.

3 Results

A total of 30 participants was included in the study. Age ranged from 21 to 63 years (mean 39.5, SD 11.7), 60% of the participants were women. The vast majority (83.3%) had no pre-experience with VEs, and only one participant reported to have used VR more than once. All participants reported to use a computer at least several times a week, but only 40% had used gaming consoles (Xbox, Playstation, etc.) before.

3.1 Occurrence and severity of adverse events

The vast majority of participants reported no or only slight AEs in scenario A and B. In scenario C however significantly more AEs were reported ($F(1, 29) = 8.54, p < 0.001, \hat{I} \cdot 2 = 0.37$). Across all scenarios dizziness (77.7%), nausea (46.7%), and discomfort (43.3%) were the most frequent symptoms reported by the participants (for details see Table 1). Neither age

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($r = -0.7, p = 0.73$), nor frequency of computer usage ($r = 0.03, p = 0.89$) or gaming-console usage ($r = 0.08, p = 0.67$) had an influence on the severity of reported AEs.

Also, neither curiosity ($r = -0.19, p = 0.29$) / interests ($r = 0.07, p = 0.73$) nor anxiety ($r = 0.02, p = 0.91$) towards modern technology had a significant impact on the occurrence or severity of adverse events. Yet, the more sceptical participants were of technologies such as VR, the higher the adverse events total score was ($r = 0.36, p = 0.048$). We found a high correlation between general 'real world' susceptibility to motion sickness and cybersickness ($r = 0.61, p < 0.001$). Although women reported higher susceptibility to motion sickness ($t = 2.96, p = 0.002$), we found no gender differences regarding AEs ($t = -0.89, p = 0.39$). The severity of AEs was positively correlated between all scenarios ($r = 0.38 - 0.53, p < 0.05$).

3.2 Attitudes towards modern technology and VR in particular

The participants showed a higher interest in the VR-technology used in the study than in the use of modern technology in general. Basically, no participant reported anxiety above average towards the use of modern technology [KFH+12].

After using the VR equipment 70% of the participants reported to have felt like really being in the VE, with 26.7% rating the highest possible score. No correlation between perceived presence and the incidence of AEs was found ($r = 0.001, p = 0.99$). Participants rated the usability of the VR equipment quite low, with 70% below the average. The usefulness of the technology on the other hand was rated comparably high, and participants reported low scepticism towards VR.

Overall, men were more interested in the use of modern technology ($g' = 0.7 - 1.8$), while women reported higher immersion rates ($g' = 0.6$), higher values regarding spatial presence ($g' = 0.8$), and regarding the sense of really being in the VE ($g' = 0.7$) (find details in Table 2). Although, apart from the subscale interest, these differences were not statistically significant at a level of $p < 0.05$, the effect sizes indicate that there might be underestimated effects due to the small sample size.

3.3 Relaxation and mood levels

Repeated measures ANOVA showed that for both the level of current relaxation ($F(1, 28) = 0.24, p = 0.63, \hat{I} \cdot 2 = 0.008$) and current mood ($F(1, 28) = 1.01, p = 0.31, \hat{I} \cdot 2 = 0.04$) across the four time points (before VR, after first, second, and third session) no linear change was found. Yet, when investigating quadratic relationship we found a significant effect for both relaxation ($F(1, 28) = 20.59, p < 0.001, \hat{I} \cdot 2 = 0.42$) and mood ($F(1, 28) = 11.61, p < 0.001, \hat{I} \cdot 2 = 0.36$) , with lower levels before the first session, an increase after scenario 1 and 2, and a significant decrease after scenario 3. Furthermore, the occurrence of AEs in scenario 3 was negatively correlated to current relaxation ($r = -0.58, p < 0.001$) and mood ($r = -0.51, p < 0.001$).

4 Discussion

The aim of this study was to investigate the occurrence and severity of AEs when exposed to three different relaxing virtual environments (VE) with increasing possibilities for autonomous movement. The results of our study showed comparably high overall incidence rates of different AEs across all scenarios, with dizziness (77.7%), nausea (46.7%), and discomfort (43.3%) being the most frequent symptoms, which may be alarming at first sight. Yet, a separate analysis of the three scenarios showed that the high incidences were mainly reported in the third scenario in which participants were able to freely move in the VE using an Xbox 360 wireless controller. In the two scenarios with no or only limited control over movement only about a third of the participants reported symptoms of dizziness, and only 3-7% reported slight nausea. Nevertheless, the occurrence of AEs resulted in directly reduced level of relaxation and mood. This clearly shows how important the control of AEs in VEs is, especially when applying VR to foster relaxation processes.

4.1 Influential factors

It has been previously reported that navigation in virtual environments may cause problems as participants tend to identify distances incorrectly, which causes further sensory mismatch while moving [Ehr97]. When asked about their virtual experience, participants in our study repeatedly answered that move-

	Scenario A*			Scenario B*			Scenario C			
Symptoms	none	slight	mod	none	slight	mod	none	slight	mod	severe
nausea	**96.7%**	3.3%	–	93.3%	6.7%	–	56.7%	20.0%	20.0%	3.3%
dizziness	73.3%	23.3%	3.3%	76.7%	20.0%	3.3%	43.3%	26.7%	26.7%	3.3%
headache	96.7%	3.3%	–	96.7%	3.3%	–	86.7%	13.3%	–	–
eye strain	96.7%	3.3%	–	93.3%	6.7%	–	90.0%	6.7%	3.3%	–
anxiety	90.0%	10.0%	–	100.0%	–	–	86.7%	10.0%	3.3%	–
fear	93.3%	6.7%	–	100.0%	–	–	96.7%	3.3%	–	–
discomfort	86.7%	10.0%	3.3%	90.0%	10.0%	–	65.5%	24.1%	6.9%	3.4%
claustrophobia	100.0%	–	–	100.0%	–	–	90.0%	10.0%	–	–
tiredness	100.0%	–	–	96.7%	3.3%	–	90.0%	10.0%	–	–
orientation problem	96.7%	3.3%	–	96.7%	3.3%	–	86.7%	10.0%	3.3%	–
drowsiness	96.7%	3.3%	–	96.7%	3.3%	–	83.3%	13.3%	3.3%	–

no participant reported severe symptoms; mod=moderate

Table 1: Gender comparison of TUI and IPQ mean values with independent sample t-tests and effect sizes-Severity of adverse events for scenario A, B & C

	total sample (n=30)	men (n=12)	women (n=18)	ES	t-value	p-value
TUI						
interest	10.6 (6.3)	15.8 (5.2)	7.1 (4.4)	**1.8**	4.9	< 0.001
curiosity	14.3 (6.7)	17.2 (7.9)	12.3 (5.6)	0.7	1.9	0.61
anxiety	5.2 (4.3)	4.7 (4.5)	5.6 (4.3)	0.2	0.5	0.57
usability	12.9 (2.8)	12.9 (2.4)	13.0 (3.1)	0.0	0.1	0.93
immersion	15.8 (5.9)	13.8 (4.6)	17.2 (6.4)	0.6	1.5	0.13
usefulness	10.6 (5.0)	11.2 (4.9)	10.3 (5.2)	0.2	0.5	0.64
scepticism	7.8 (4.9)	6.9 (3.1)	8.4 (5.9)	0.3	0.9	0.38
accessibility	7.3 (3.8)	6.6 (4.2)	7.8 (3.6)	0,3	0.8	0.39
IPQ						
spatial presence	4.1 (1.1)	3.6 (1.2)	4.4 (0.9)	0,8	2.0	0.06
involvement	3.4 (1.6)	3.2 (1.1)	3.6 (1.9)	0,2	0.6	0.56
experienced realism	2.8 (1.2)	2.7 (0.7)	2.8 (1.5)	0,1	0.2	0.83
sense of being there	4.1 (1.7)	3.5 (1.2)	4.5 (1.8)	0,7	1.7	0.09

ES= Hedges g adjusted effect size; moderate & large effects are marked bold

Table 2: Severity of adverse events for scenario A, B & C

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ment in the VE was rather distracting for them, especially if they had low previous experience with gaming consoles. In their recent review Rebenitsch and Owen [RO16] indicated that restricting degrees of freedom in navigation controls may decrease susceptibility to symptoms.

The incidence of AEs in the VE was highly correlated to general motion sickness sensitivity, as it has been previously reported [GB08]. Also, the degree of scepticism was correlated to the reported severity of AEs. It is quite well known, that the expectation of negative events can results in the appearance of AEs, which is often referred to as 'nocebo effect' [Bin14]: the attention is focused more strongly on the body, which leads to a more alert reaction to previously unnoticed events and a misattribution as newly occurring adverse event [BSR02]. The assessment of the participants' attitudes towards the technology or potential negative previous experiences, and tailored information provision may therefore prevent such misattributions and potentially decrease the level of AEs occurring when exposed to VEs.

In our study women reported a significantly higher susceptibility of motion sickness then men. Yet, we found no gender differences in regard to the incidence or the gravity of AEs. Our findings are in accordance with previous studies, indicating that gender differences may only play a minor role in visually induced motion sickness and instead susceptibility may be a key variable [GS02]. This is particularly important, since gender is still often named as a potential influence on cybersickness (e.g. [DNN15]).

In our study both men and women perceived the VEs as being quite realistic, but - although not statistically significant - women reported higher values in regard to immersion, spatial presence, and the sense of really being in the VE. Felnhofer, Hetterle, et al. [FHS$^+$14] found comparable results in a relaxing VE, while other studies reported male advantage in physical presence [FKB$^+$12]. This discrepancy may be explained by the level of stressfulness of the VE: while in more stressful environments male advantage in regard to presence was reported, no significant gender difference was reported for relaxing environments. A possible explanation offered by Felnhofer, Hetterle, et al. [FHS$^+$14] points out that because men and women differ in their reactions to situational stressors [Mat04], the level of presence in stressful VEs may be influenced by gender-specific attribution of attentional resources. Further research may therefore compare the role of gender and presence in regard to the incidence of adverse events between stressful and relaxing VEs.

In accordance with previous studies [BGC$^+$10], we found no correlation between the participants' age and the incidence of AEs. Since only one participant had previously used a VR HMD device, we were not able to evaluate if participants who were familiar with the device showed less AEs. Other potential sources of pre-experience, such as usage of gaming-consoles or computer, had no influence on AEs in our study.

4.2 Limitations

Our study has some limitations. First of all, the order of the presented scenarios was not randomized. The strongly increased incidence of AEs in scenario C might have been influenced by repeated exposure. We tried to control this influence through the use of only very short exposure units and included short breaks between each scenario to give the participants a possibility to recover from possible AEs. When asked about it, participants clearly named the autonomous movement as primary source for the AEs. Furthermore, the differences were quite large, which is why we still consider our findings to be valid. Also, by using the same HMD for all three scenarios we controlled several key factors in current VR research: the 360° presentation, the frames per second, the field of view and the rendering mode (which in our case was stereoscopic). Scarce literature in this area did not show substantial effect of themes and complexity of the scenarios on motion sickness [RO16], yet further research is warranted to improve our understanding of their potential influence.

Presence was only assessed once at the end of our study to reduce the participants' burden. Since the correlation of presence and AEs was not the main focus of our study, we wanted to get an overall impression of the participants' ability to immerse in the VE. Yet, it remains unclear which scenario the participants had in mind when answering the questionnaire. Future studies should further investigate the relationship between presence and the occurrence and intensity of AEs.

We only used one type of navigation system in our study (Xbox 360 wireless controller), and therefore cannot generalize our findings for other navigation systems. Nevertheless, since the Xbox Controller is typically used as standard controller for computer applications we think our results are useful to a broad audience. Furthermore, since only one participant re-

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ported experience with VR, we do not know whether there are habituation effects with repeated exposure to VR, especially with regard to autonomous movement. It remains to be shown if navigation in VEs can be 'learned' or if greater input and design changes will have to be made to alleviate the effects of AEs.

While there are more advanced types of user movement in VR in driving or flight simulators and walkable room scale VR setups, we believe that the scenarios and systems we chose merit further research because of their ease of use, widespread adoption and comparatively low cost.

4.3 Conclusion

Our results show that the level of autonomous movement in relaxing virtual scenarios can influence the incidence rate of AEs and should therefore be considered when planning the use of VR as a tool to foster relaxation. Age and gender may play less of a role for AEs than previously suspected. This finding and the comparably low incidence rates in the scenarios with less autonomous movement indicate that VR is a safe technology to be used in clinical psychology, if certain parameters are being minded.

We suggest that future studies using VR should routinely assess and report the occurrence and severity of AEs in a structured way, to enable more in-depth insights regarding influential factors and potential prevention strategies. Furthermore, future research should investigate input (Xbox 360 Controller; Mouse and Keyboard; Motion Tracking; etc.) and design differences in movement and gaze control types in virtual reality scenarios. In this context it may also be fruitful to consider the possible connection between embodiment, autonomous movement and adverse effects. To evaluate if participants can adapt to autonomous movement, longitudinal studies are needed.

5 Conflict of interests

The authors declare no conflict of interest.

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