Two-way control of a virtual avatar from lucid dreams

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Summary. Objective. In lucid dreams (LDs), it is possible to maintain consciousness and achieve predetermined goals while in REM sleep. Since the 1980s, scientists have been searching for LD application areas. The current study is the first to demonstrate a method for controlling a car avatar with feedback from LDs. Support for this possibility could be used for personal applications and LD studies. Method. Five experienced LD practitioners participated in the present study. Electromyographical (EMG) sensors were used to detect leg and arm muscle movements, and red diodes were put in front of participants' eyes to indicate obstacles. Software converted EMG impulses into movements of a virtual car, which was chosen as the avatar. The study was conducted under laboratory conditions with polysomnographic LD verification (pre-agreed eye signals were recorded during REM sleep). Results. The participants spent one to four nights in the laboratory and induced 18 confirmed LDs. In 12 LDs, they drove a virtual car, successfully avoided obstacles, or both. All results were observed in real-time and recorded by the research team. Discussion. The results show an achievable way to control the functions of a computer program with feedback from LDs. In theory, many more options for controlling and feedback besides EMG sensors and diodes could be used. With development, all these technologies could help control more sophisticated objects in virtual and physical realms. The two-way communication from LDs with computers observed in this study could facilitate new studies because people could correct the settings and functions of devices by themselves from LDs. This would also foster communication between people while asleep.

Keywords: Communication, lucid dreams, avatar, REM sleep, electromyography

1. Introduction

When people become conscious while dreaming, these dreams are called lucid dreams (LDs). Frederik Willem van Eeden, a Dutch writer and physician, was the first to use this term in 1913 (Van Eeden, 1913). In 1975, Keith Hearne verified the existence of LDs in laboratory conditions (Hearne, 1978), and scientific interest in the subject subsequently started to increase (LaBerge, 1985; LaBerge et al., 1981). From 1966 to 2019, the number of published scholarly papers on LDs rose by 5.6% each year (Pepe, 2020). These studies have improved the general understanding of various disciplines such as physiology, psychology, psychophysiology, and psychiatry.

One of the reasons for this growth in knowledge is the fact that LDs are prevalent among the human population. A meta-analysis of 34 studies conducted over 50 years (1966–2016) revealed that, on average, 55% of people have experienced at least one LD (Saunders et al., 2016). Several phenomena are closely related to LD, including sleep paralysis (Hishikawa & Shimizu, 1995; Terzaghi et al., 2012), out-of-body experiences (Levitan et al., 1999; Raduga, 2014; Schenck & Mahowald, 2005), and false awakenings (Barrett, 1991). Such phenomena have the same main feature as LD—namely, that consciousness is aroused during REM sleep. These and other similar phenomena can be united under the term *dissociated REM state or phase state* (Mahowald & Schenck, 2005; Raduga, 2004).

Scientists still have to conduct many studies to better understand LDs (Baird et al., 2019). Currently, only a few cases of LDs in non-REM sleep stages have been recorded, meaning that LDs happen almost exclusively in REM sleep (Dane & Castle, 1984; Mota Rolim et al., 2015; Stumbrys & Erlacher, 2012). LDs could be associated with increased activity in the cuneus, bilateral precuneus, parietal lobules, occipito-temporal cortex, and prefrontal cortex, but more data is needed to confirm this idea (Dresler et al., 2012). Researchers have shown that the connectivity between the anterior prefrontal and temporoparietal junction cortex is probably responsible for LDs (Baird et al., 2018). The volume of gray matter in the anterior prefrontal cortex could also play a significant role in LDs (Filevich et al., 2015).

LDs do not only happen spontaneously. People can learn how to intentionally enter LDs and achieve predetermined goals in the dream universe (La Berge, 1980). Many online reports, especially those on enthusiasts' forum boards, which contain millions of posts, describe various LD application areas (Dream Views, 1998; Форум осознанных сновидений [Lucid Dreaming Forum], 2004). Researchers have also demonstrated that LDs may help people improve their waking mood (Schredl et al., 2020; Stocks et al., 2020; Stumbrys & Erlacher, 2016) and motor skills (Bonamino et al., 2022; Schädlich & Erlacher, 2018; Stumbrys et al., 2016), prevent nightmares (de Macêdo et al., 2019; Zadra & Pihl, 1997), solve everyday life problems (Schmidt et al., 2014; Stumbrys et al., 2011), overcome phobias and anxiety (Schatzman, 1983; Wittmann et al., 2007; Zhunusova et al., 2022), and reduce depression (Sackwild & Stumbrys, 2021) or chronic pain (Zappaterra et al., 2014). The number

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of studies on LD applications is likely to rise and reveal new and unexpected directions.

One of the most fascinating LD applications is the possibility of controlling real-life objects from the dream state. Oldis (2016) presented the concept of creating a virtual human avatar by detecting residual electromyography (EMG) activity in the muscles during REM sleep. A pilot study was conducted with two participants whose dream movements were decoded into avatar movements (Oldis, 2017). Though the study was meant to animate dreams, the same protocol could also work for LDs. Indeed, Mallett (2020) demonstrated the possibility of controlling virtual objects from LDs. Instead of EMG sensors, a brain-computer interface based on electroencephalography (EEG) was used. In this pilot study, a volunteer was trained to move an object on a screen using his brain during wakefulness. The participant was later able to recreate this skill in LDs (Mallett, 2020).

Since 1978, it has been known that people can send signals from LDs. All that remains is to utilize these signals in scenarios to control virtual avatars, gadgets, programs, or real objects. For example, it is known that physical eye movements can be controlled in LDs, and this ability is still used as a gold standard method to verify LDs by electrooculography (EOG) (Hearne, 1978; LaBerge et al., 1981; Mota-Rolim, 2020). While in LDs, people can use their breath or muscles to send signals through EMG sensors and transfer whole words in Morse code (LaBerge et al., 1981). EMG sensors can also help decode speech in LDs because it has the same patterns as vocalizations in wakefulness (Raduga, 2022). EEG can also be intentionally affected in LDs (Erlacher et al., 2003), as can the facial muscles responsible for emotions (Konkoly et al., 2021).

Sending signals from LDs is not sufficient for full-fledged object control from LDs because two-way communication is required for this task. Few advancements have been made in this direction, but, with some limitations, it is possible to send sound, light, and voice signals into LDs (Appel, 2013; Konkoly et al., 2021; Mironov et al., 2018; Oldis & Oliver, 2012; Strelen, 2006). These technologies are complicated and, to date, can be used only in laboratory conditions. Though researchers were able to communicate with people in LDs and have attempted to control virtual objects from LDs, no studies have shown two-way object control in LDs. Other than possible technical and software difficulties, no apparent obstacles prevent this possibility; all preliminary studies have shown prospective directions for accomplishing two-way object control.

Hypotheses

The main hypothesis of the present study is that the two-way control of virtual objects from LDs is possible. Dreamers should be able to not only control object movements by muscle contractions in LDs but also receive feedback in the form of light to avoid obstacles. Confirmation of the hypothesis could provide new perspectives for LD applications because this two-way control could be applied for useful goals, including controlling different software, devices, machines, and smart homes. Also, two-way communication with computers and gadgets from LDs would facilitate new studies because it would allow people to directly correct settings, change modes, and control different functions of PSG or other devices by themselves from LDs. The same principle could help people communicate from LDs.

2. Method

2.1. Resources and participants

This study was approved by the Phase Research Center ethical committee review board (PRC-2022-05-24-01). Five LD practitioners, including two of the authors, participated. All participants were at least 18 years old and had no health issues that could have been aggravated by the research. All participants signed a written informed consent before the study commenced. The participants were recruited from previous similar studies and were financially rewarded regardless of their results; their travel and accommodation expenses were covered. The study was conducted under laboratory conditions, and no medical supplements were used to enhance LD attempts.

2.2. Experimental task

Participants spent one to four nights in the laboratory. First, before falling asleep, they were trained to control a virtual car with EMG sensors by tensing their muscles: they tensed their biceps or forearm muscles to make turns and tensed their quadriceps to drive. If an obstacle appeared in front of the avatar of the car, two diodes indicated the need to turn through the participant's closed eyes (the brightness was tuned for each participant individually). Once a turn was made, the diodes were switched off automatically. Tensing the right arm made the avatar turn right (45°), and tensing the left arm made the avatar turn left (45°). Tensing both legs moved the avatar. The duration for which the muscles were tensed affected the distance of the forward movement and the degrees of a turn.

Second, after training, participants fell asleep with all the electrodes and diodes attached, intending to repeat the task in an LD. Third, during REM sleep, after inducing an LD (either by themselves or after vibrational, visual, or audial signals sent by the research team), participants were to confirm that they were in an LD by making at least three consecutive eye movements to the left and right.

Fourth, after confirming that they were in an LD, participants were to control the avatar, which was manually activated by the researchers. After the avatar was activated, participants received obstacle signals immediately if there were any obstacles in front of the object. The participants needed to run, squat, or tense their quadriceps and then make turns using their arms if an obstacle appeared (Image 1). They could control the virtual avatar either with or without its counterpart in LDs. Fifth, either immediately after the experience or in the morning, the participants needed to verbally report all the details about the experiment, including the LD-induction method used.

2.3. LD verification

Per the standard LD verification procedure (Hearne, 1978; LaBerge et al., 1981; Mota-Rolim, 2020), participants were asked to make pre-agreed left-right-left eye signals immediately after inducing an LD. A dream could be recorded as an LD only when REM sleep features were dominated by theta EEG waves and muscle atonia (Bahammam et al., 2016). Though the gold standard method was used, all participants needed to provide verbal reports of their LDs and actions to help the research team compare their reports with the obtained data

2.4. Apparatus and software

The research team observed the participants in real-time. A custom-made device with four EMG channels (20- to 70-Hz band-pass filter; 50-Hz notch filter) was used to detect EMG impulses from participants' arms and legs. The device had only EMG sensors and was made for similar studies. Specially developed software was used to automatically connect the EMG readings with the avatar movements (in a couple of cases, the researchers manually corrected the EMG threshold before or during LDs). Five obstacles may or may not have randomly appeared on the screen during an LD, making it impossible to identify the exact route that the object would follow. All polysomnographic data for LD verification were obtained by Encephalan-EEGR-19/26: one chin EMG channel (16- to 70-Hz band-pass filter; 50-Hz notch filter), one EEG channel (*Fpz* and *A2* positions from a 10–20 system; 0.7- to 70-Hz band-pass filter; 50-Hz notch filter), and two EOG channels (0.7- to 70-Hz band-pass filter; 50-Hz notch filter) (Image 2). The thresholds were manually set above each participant's relaxed EMG tonus so that avatar movements could be controlled by EMG impulses, both in wakefulness and in LDs. Once the threshold was overcome by muscle tensing, the avatar could be moved forward or turned.

3. Results

Each participant induced up to five confirmed LDs, and they induced 18 LDs in total. In 12 LDs, an attempt was made to control a virtual avatar (REMspace, 2023). Despite various problematic issues (addressed in the discussion section), residual electrical activity in the target muscles was detected in most cases. This activity was decoded in real-time into 12 moves and 28 appropriate turns of the virtual car on a screen. Inside LDs, the participants never controlled a car or any other objects. They focused on tensing their muscles and receiving signals in the form of light (if they reached an obstacle). They tensed their muscles while either assuming a static position or walking or running in LDs.

Participant #1 induced five verified LDs over three nights and made four attempts to achieve the study goal. Although one of this participant's leg EMG sensors malfunctioned during the first LD, the participant drove the avatar in a straight line for a short time. Regarding the verbal report, the participant made an occasional turn exactly when an obstacle was reached, and the participant awoke because he saw intense flashes (Image 3). During the second attempt, the participant made a controlled turn when the avatar mode was activated. He could then drive the object in a straight line for a short time before awakening (Image 4). During the third attempt, the participant made a controlled turn but then experienced numbness in his dream legs and, thus, could not move the avatar (Image 5). During the fourth attempt, the participant made a controlled turn and drove the avatar in a straight line for a short time until the leg EMG impulses ceased for an unknown reason. In response to this issue, the research team started putting obstacles in front of the avatar. In total, the participant made 17 controlled turns from LDs to avoid virtual obstacles until he awoke (Image 6).

Participant #2 induced three verified LDs over three nights and performed three attempts to achieve the study goal. During the first LD, the participant reported active attempts to complete the task, but no EMG signals were detected. During the second LD, when the avatar mode was activated and an obstacle was placed in front of the virtual car, the participant made a controlled turn to avoid it, but only subtle EMG signals were recorded from the arms. As no impulses from the legs were detected, the participant could not drive the car forward. Even though the reported LD was relatively long and stable, the attempts to control the virtual object were visible for only 10 seconds, and all attempts involved turning the avatar (Image 7). During the third attempt, the participant made a controlled turn. The participant once again could only make turns, and the legs produced no visible impulses. After recognizing this problem, the researchers manually put an obstacle in front of the car. The participant made proper turns three times in total before awakening (Image 8).

Participant #3 induced five verified LDs over three nights and performed two attempts to achieve the study goal. During the first attempt, the participant made two controlled turns and then drove the avatar in a straight line for a short time until they awoke (Image 9). During the second attempt, the participant made a few controlled but unnecessary turns and drove the object in a straight line for a short time. They then awoke because the avatar faced obstacles too often due to the unnecessary turns, and the flashes were very intense (Image 10).

Participant #4 induced two verified LDs over two nights and performed two attempts to achieve the study goal. During the first attempt, the participant made three controlled turns and drove the object in a straight line four times until awakening (Image 11). During the second attempt, the participant could not control the object because the LD was too short.

Participant #5 induced two verified LDs over three nights and performed two attempts to achieve the study goal. During the first attempt, the participant drove the avatar in a straight line. During the second attempt, the participant made one controlled turn and drove the object in a straight line twice (Image 12).

4. Discussion

The LD application area was extended by the proposal that it is possible to control virtual dream objects in a bidirectional fashion. This idea was tested by training LD practitioners to control a virtual car with their leg and arm muscles and detect obstacles indicated by light flashes during wakefulness. The same routine was then successfully applied in LDs but was limited primarily by LD duration and electrode placement.

Hypotheses confirmation

Though the concept of controlling a virtual avatar from dreams and LD was previously shown to be applicable (Mallett, 2020; Oldis, 2017), the results of the current study have expanded the knowledge on this topic. First, the present results confirm that such an avatar can be controlled in two ways: not only can people in LDs move virtual objects, but they can also receive feedback and react to it appropriately. Many previous studies indirectly led to this conclusion, but it was not tested. Second, this hypothesis was confirmed with varying levels of success in all five participants. This outcome suggests that most people could probably achieve the same result; in other words, controlling an avatar from an LD does not require any specific predispositions or skills besides the ability to induce LDs.

The current findings could be applied in many ways, but their application depends on future technological advances. Most optimistic expectations could extend the usage of the technology to entertainment applications and beyond. Two-way communication with computers from LDs could aid unique studies in which people could directly correct or control the settings of different devices from LDs, depending on their goals and (e.g., the brightness of diodes, volume, and the activation of different modes). Similar principles could also foster communication between people in LDs. We suggest that even current advances allow this LD feature to be transferred from virtual objects to real ones. For example, instead of a car on a screen, a real car could be controlled. The same principles apply to robots, drones, and other remotely controlled devices. The current technology could also allow smart homes to be controlled from LDs by setting and switching lights, coffee machines, and other appliances on and off.

Challenges and solutions

EMG signals were sometimes absent or too weak when participants tried to control a virtual avatar from LDs. This problem could be partially resolved by using more sensitive sensors, but other issues may play a more prominent role. For example, it is crucial to train the skill of transferring EMG impulses through sleep atonia. This could be easily performed during wakefulness to memorize the basic principles of tensing a muscle severely and quickly. In wakefulness, people never pay attention to how much a muscle is tensed because the outcome is always visible, which helps to tune muscle contractions. However, in LDs, people do not see the EMG results of their actions and experience sleep atonia. These factors require a different type of attention during muscle tensing. Therefore, to send EMG signals from sleep, one must tense their muscles severely and quickly. Doing so helps to achieve the highest EMG spikes both in wakefulness and LDs, even if the sensors are not highly sensitive.

Another important factor for sending EMG impulses from LDs is the locations of electrodes. During this study and its preparation, it was found that some places and muscles were better suited than others for accomplishing the goal. For example, the turning EMG impulses from the forearm muscles appeared much stronger than those from the biceps; thus, focusing on the forearm muscles increased the study's effectiveness and made it easier for participants to perform the task. We hypothesize that the presence of subcutaneous fat and the natural ability of some muscles to be tensed quicker play a role in this difference. It was also found that it is better to place the electrodes across the muscles than along them, perhaps because this helps to harness electrical activity from more muscle bundles in case they are tensed separately in LDs. However, these suppositions need to be studied further in the future.

Participant #2 could not send leg signals from LDs despite excessive practice and the use of different electrode locations. Though arm impulses were clear, EMG spikes from the quadriceps were not detected during all three of his verified attempts to move the avatar. This outcome remains confusing because no other participants consistently encountered this problem. Moreover, the same participant has taken part in previous studies and never consistently failed to send EMG, EOG, or even EEG impulses from LDs. There were only sporadic issues in previous studies, but they involved other apparatuses. As reported, after the third night in the current study, Participant #2 tried to tense his legs in an LD as hard as possible because he was made aware of the issue, but it did not help. We hypothesize that the sensors were not sensitive enough to detect the inborn EMG activity in his legs during REM sleep, which may have been close to absent. Other muscles could be used for the same goal to solve the problem. For Participant #5, all the electrodes used to control the avatar were set only on the forearms to avoid the same issue experienced by four of the five participants.

A substantial problem related to the feedback signals was encountered. Lights or other feedback signals should be intense enough to overcome sleep atonia but not so intense that they wake a person from an LD. This issue depends on three factors: diode location, light intensity, and LD stability. For example, Participant #1 was immediately awoken during the first two attempts when his avatar encountered obstacles. Both these LDs were too shallow to withstand the light intensity. This problem was solved during his third attempt by sending less intense visual signals during a long and stable LD that lasted over four minutes. Thus, it would be better to perform similar experiments only when participants have long and stable LDs.

Limitations

The research team encountered problems because no apparatus specifically designed for the present study's goals is available. As a result, two apparatuses (one for controlling the avatar and one for verifying LDs) and two PC software packages were partially modified. However, not all of them could be sufficiently tested in advance. This limitation explains approximately 90% of the failures, which should not be falsely attributed to problems with the study itself. The avatar could be controlled from LDs with less effort than indicated in this study. In theory, with better technologies and experience, more significant outcomes could be demonstrated in the future.

Moreover, in some cases, the results could have been negatively affected by the incorrect placement of EMG sensors because the ideal position varies from person to person and could not be correlated with the tension of muscles in LDs. Because few volunteers were able to induce LDs under stressful conditions, two of the authors took part in the experiments. As the study used objective measurements that were impossible to affect willingly, the negative impact of the authors' participation was reduced.

5. Conclusions and Recommendations for Future Studies

The present study demonstrated that the two-way control of a virtual car, including driving it and avoiding obstacles, from LDs is possible. With future technological developments and more related studies, this achievement could extend the LD application area, uniting dreams and the physical realm. The next step is to demonstrate the two-way control of physical objects (e.g., robots, cars, or drones). Functions of smart homes could also be conveniently controlled from LDs. Other than the previously discussed study problems, no substantial issues could prevent these achievements.

There is also a need to identify and test all possible ways of safely sending control signals and obtaining feedback related to LD stability.

Future studies may exploit the possibility of two-way communication from LDs with computer programs to have participants control software depending on what they experience during LDs. It would also be interesting to make a parallel to biofeedback, allowing participants to see the real-time results of their physiological measurements in LDs. Perhaps a future variant of this study could give people feedback about the intensity of their muscle contractions to be used for training. For example, the intensity of the light could be set to depend on the intensity of the participant's muscle contractions, and their goal could be to make the light as bright as possible.

The current study and similar future studies may not only improve the general understanding of LDs but also provide a new worldview of physical reality because it is obvious that it could be entangled with the dream world. In the distant future, this new reality may change or at least influence the daily routines of many people, allowing them to accomplish everyday tasks before getting out of bed.

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Appendix

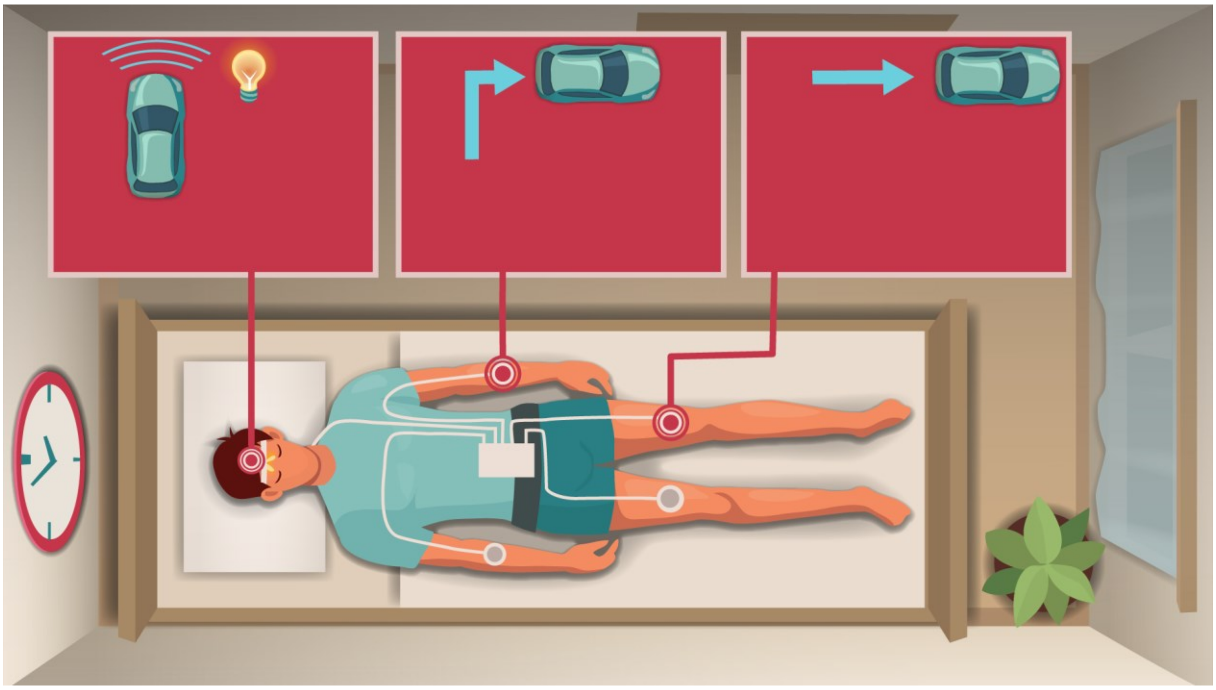

Image 1. Graphical representation of controlling an avatar from an LD. The first box represents the diodes that flash when an avatar encounters obstacles. The second box represents turning the avatar by tensing the forearm muscles. The third box represents moving the avatar by tensing the leg muscles.

Image 2. Positions of Encephalan-EEGR-19/26 (white), custom-made EMG device (black), EEG/EOG/EMG sensors, diodes, and vibration motors.

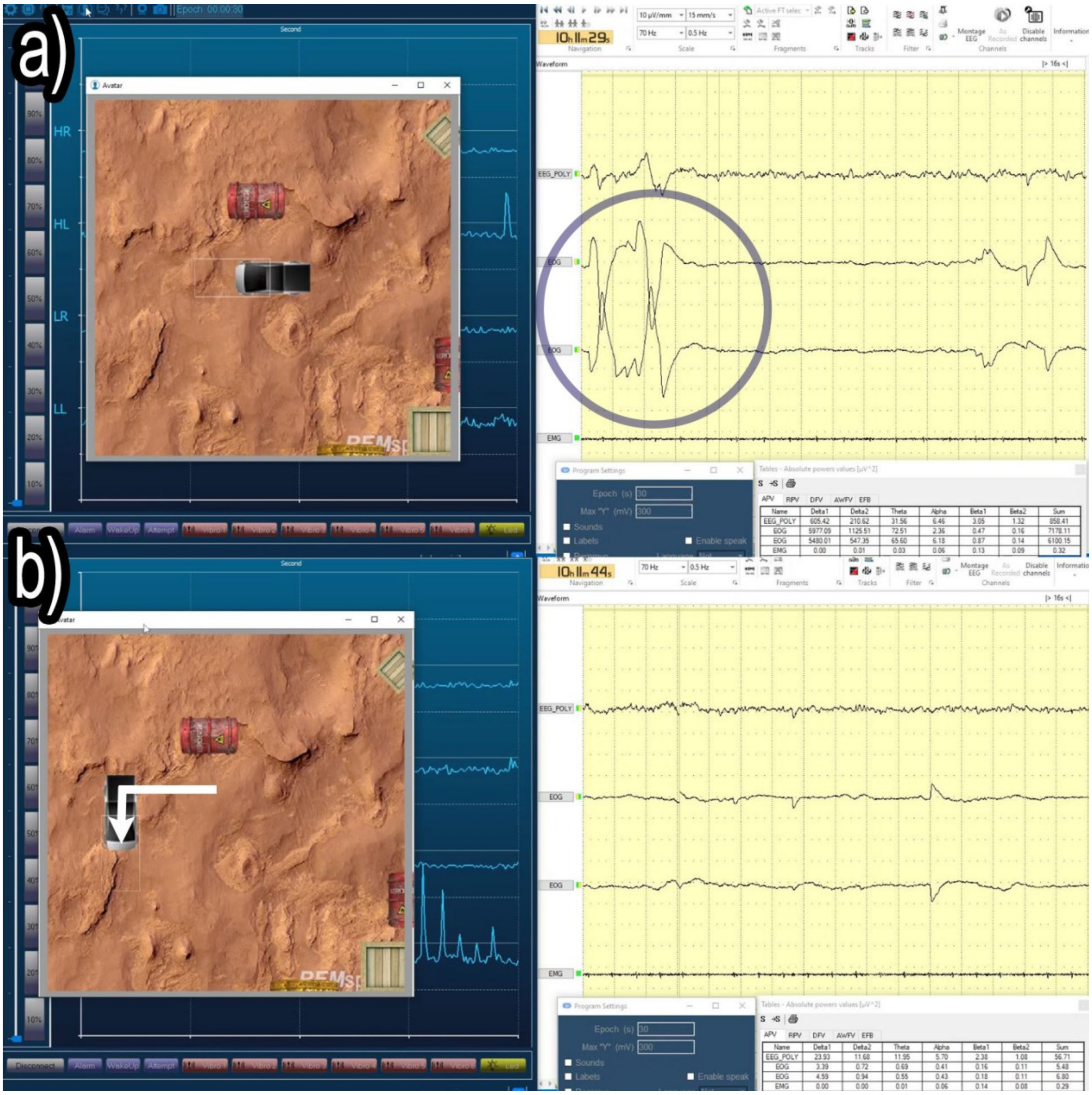

Image 3. Screenshots of real-time monitors while Volunteer #1 successfully controlled a virtual car during the first attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is indicated on the right side. EMG impulses and their decoded outcomes are presented on the left side.

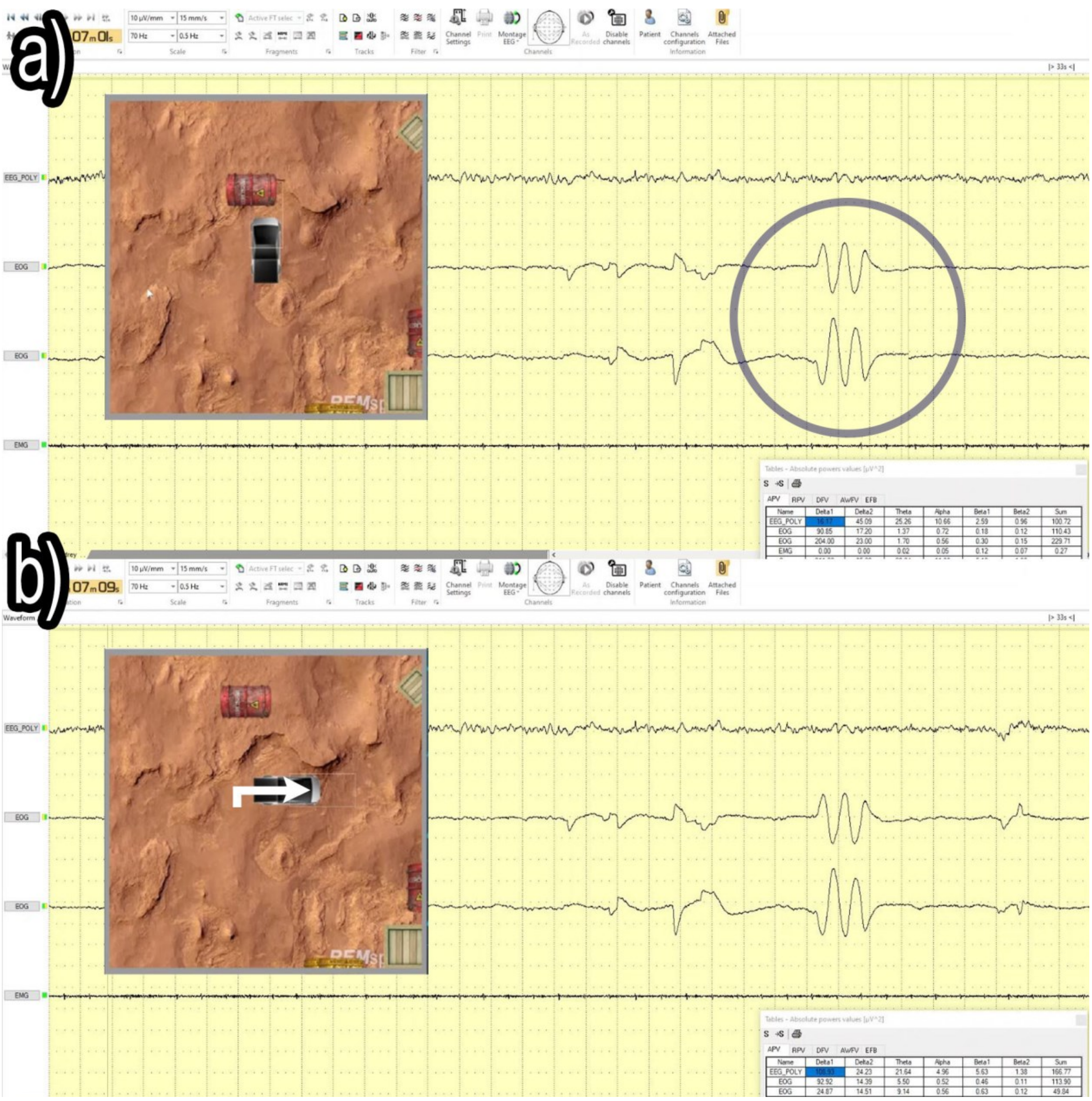

Image 4. Screenshots of real-time monitors while Volunteer #1 successfully controlled a virtual car during the second attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels is displayed on the right side. The red obstacle was moved by the research team.

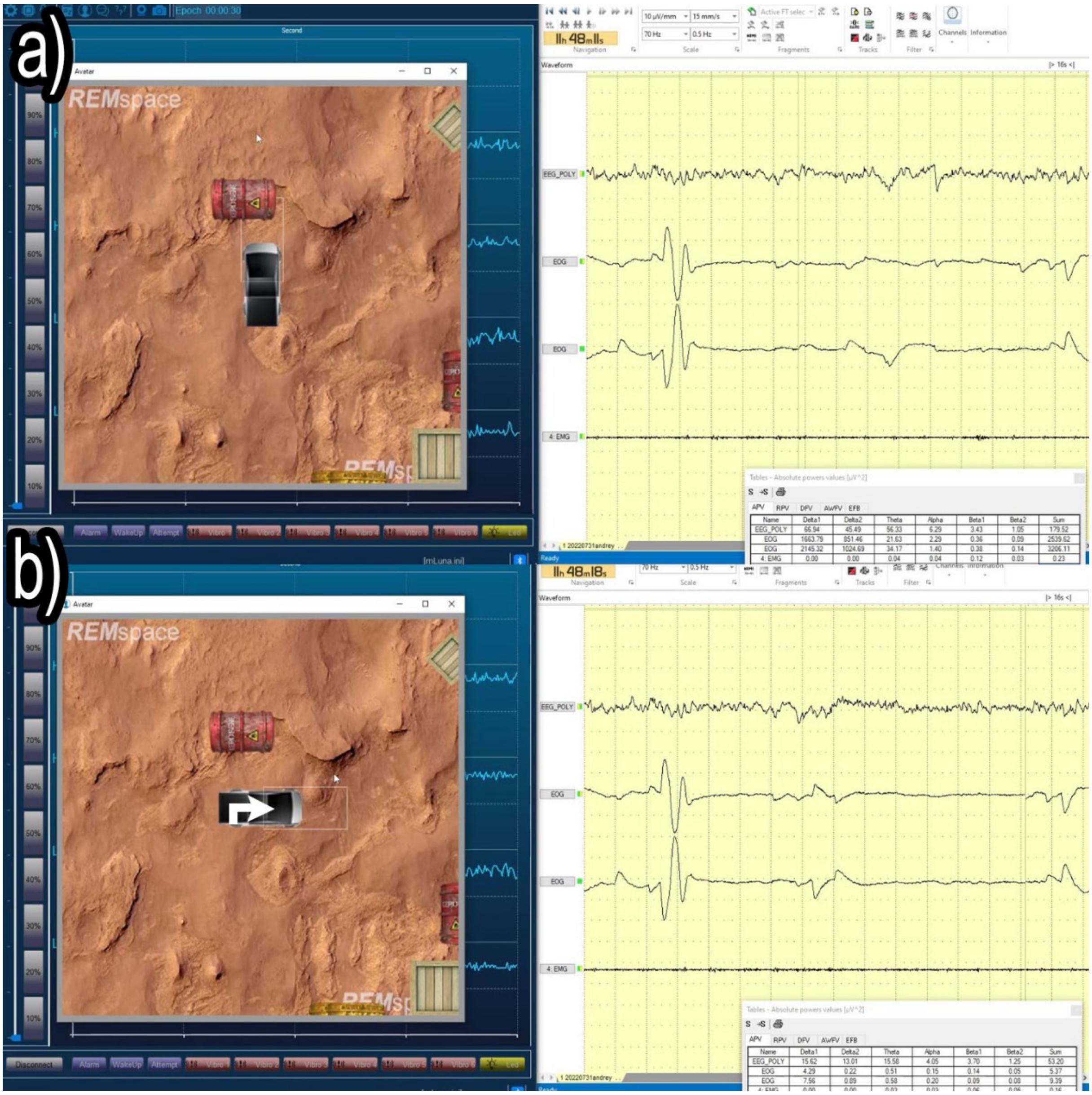

Image 5. Screenshots of real-time monitors while Volunteer #1 successfully controlled a virtual car during the third attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side.

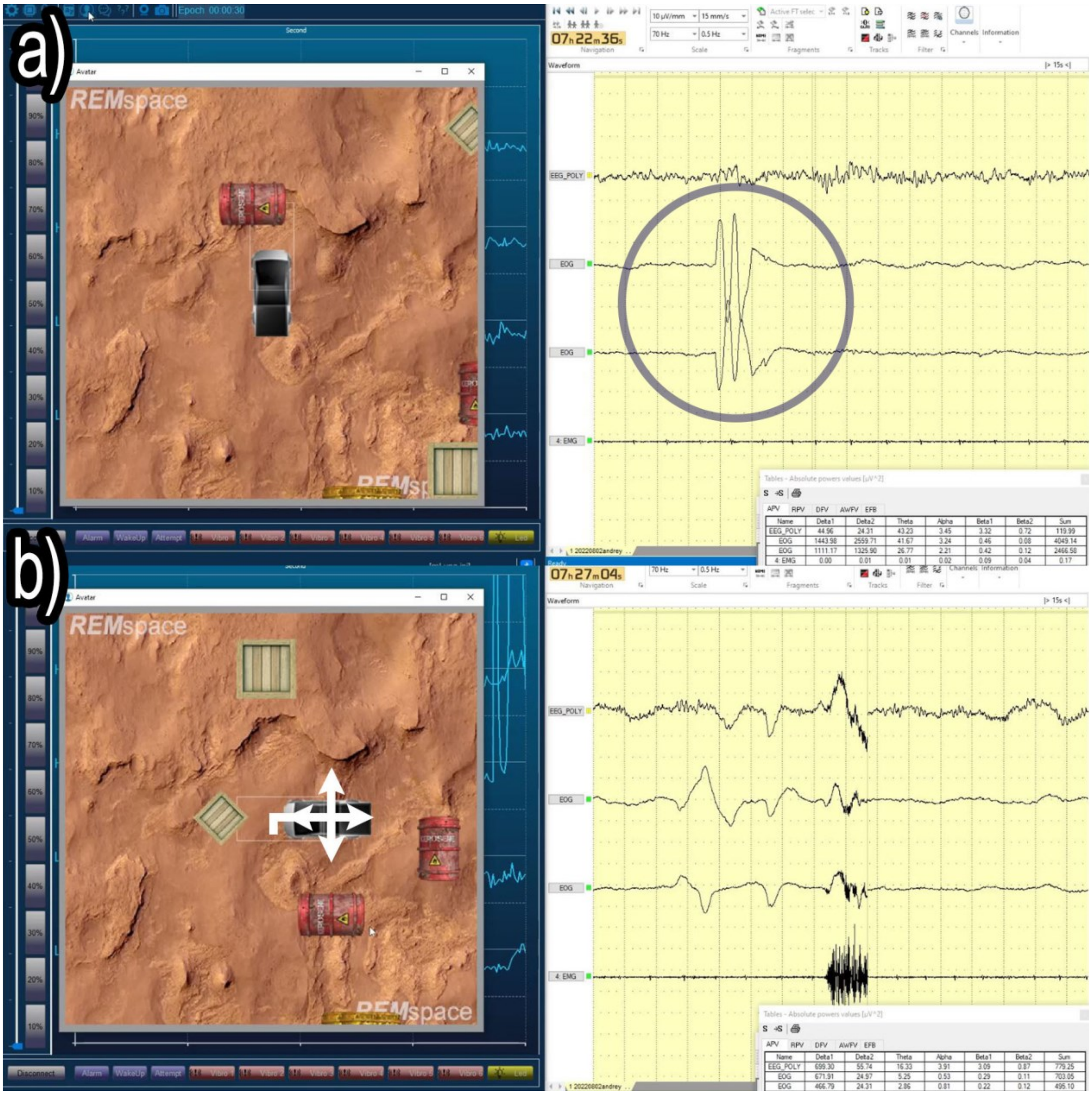

Image 6. Screenshots of real-time monitors while Volunteer #1 successfully controlled a virtual car during the fourth attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side. The obstacles were moved by the research team. Two-sided arrows indicate movement in both directions.

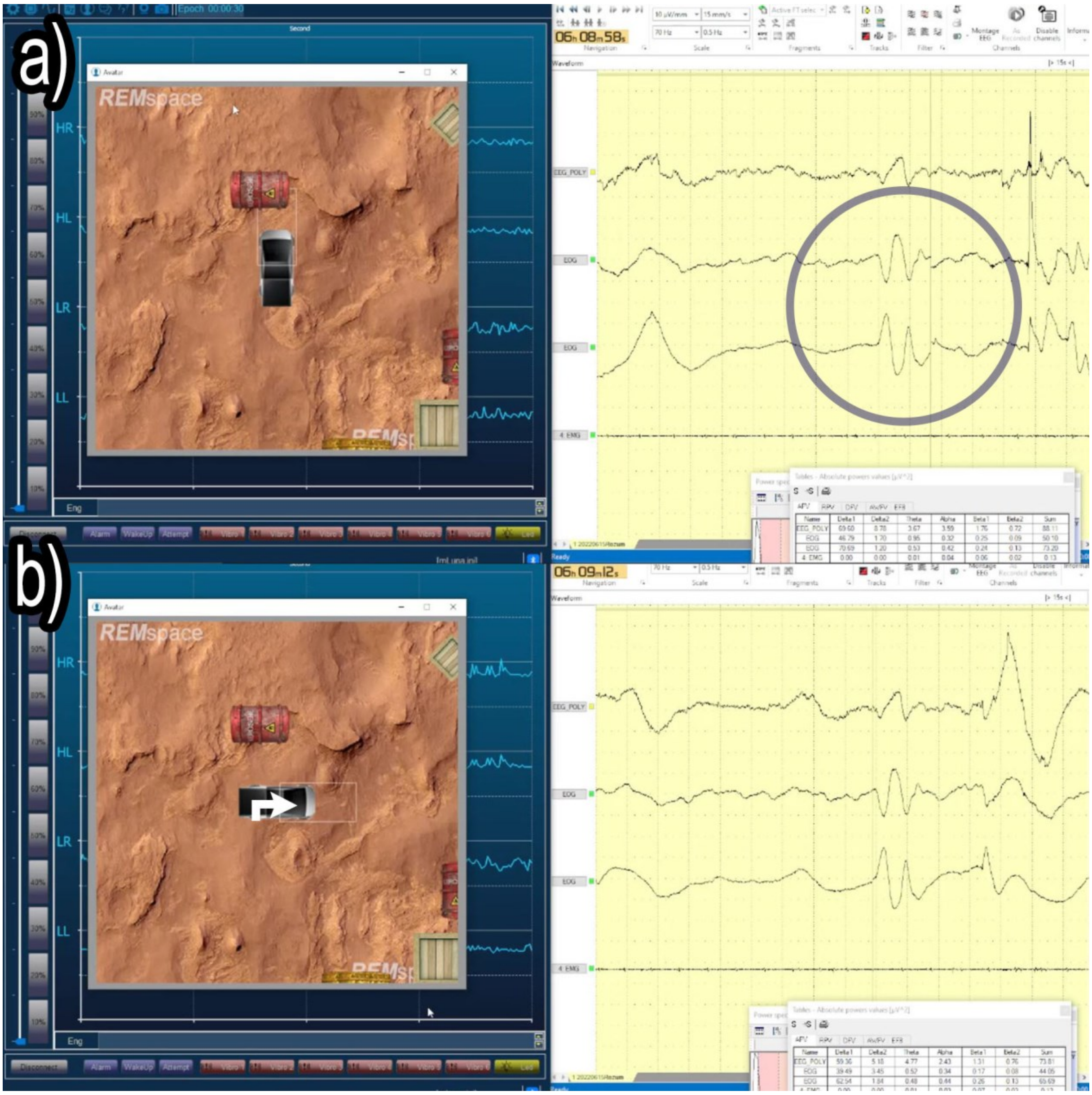

Image 7. Screenshots of real-time monitors while Volunteer #2 successfully controlled a virtual car during the second attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side.

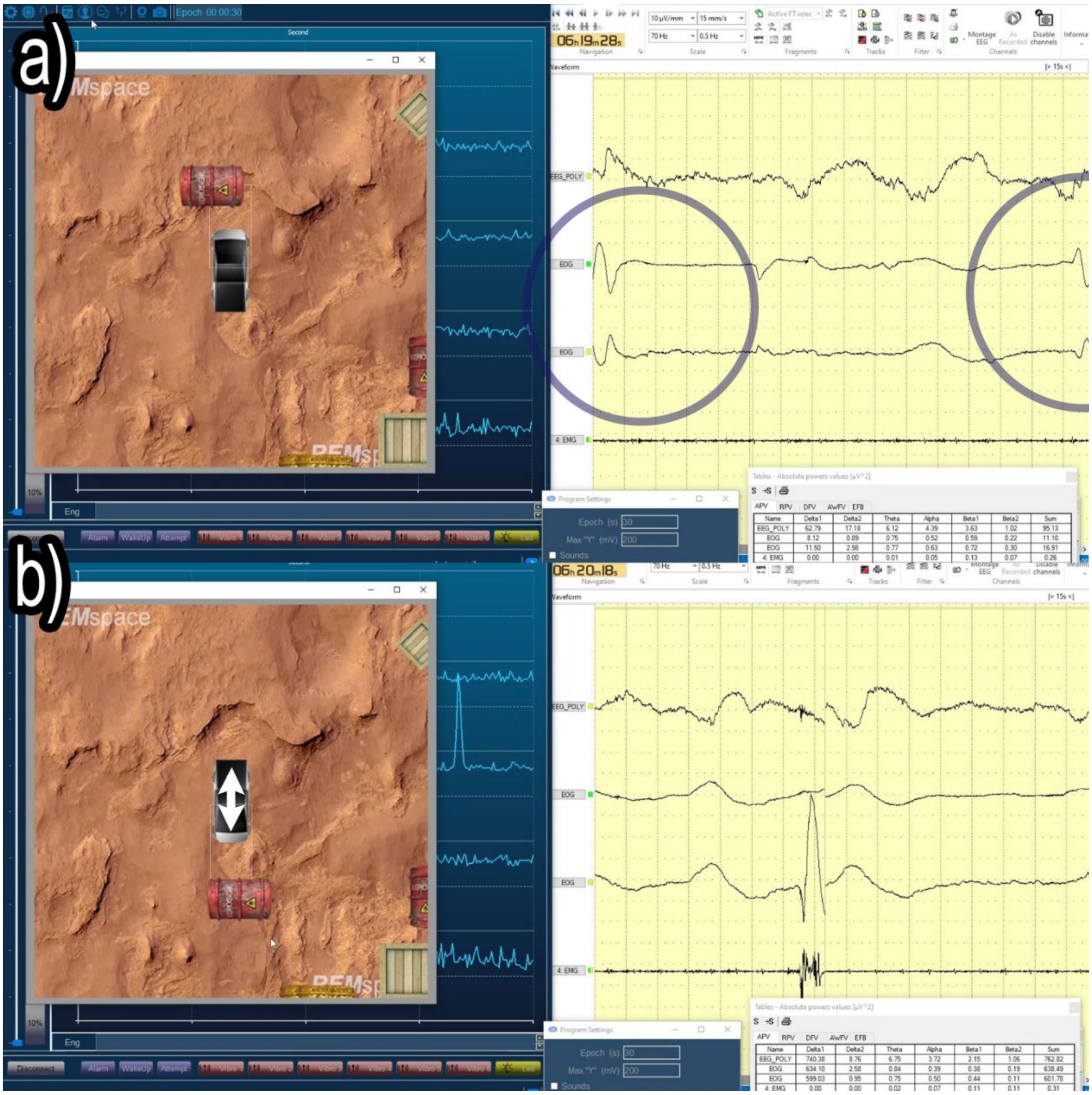

Image 8. Screenshot of real-time monitors while Volunteer #2 successfully controlled a virtual car during the third attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side. The obstacle was moved by the research team. The two-sided arrow indicates movement in both directions.

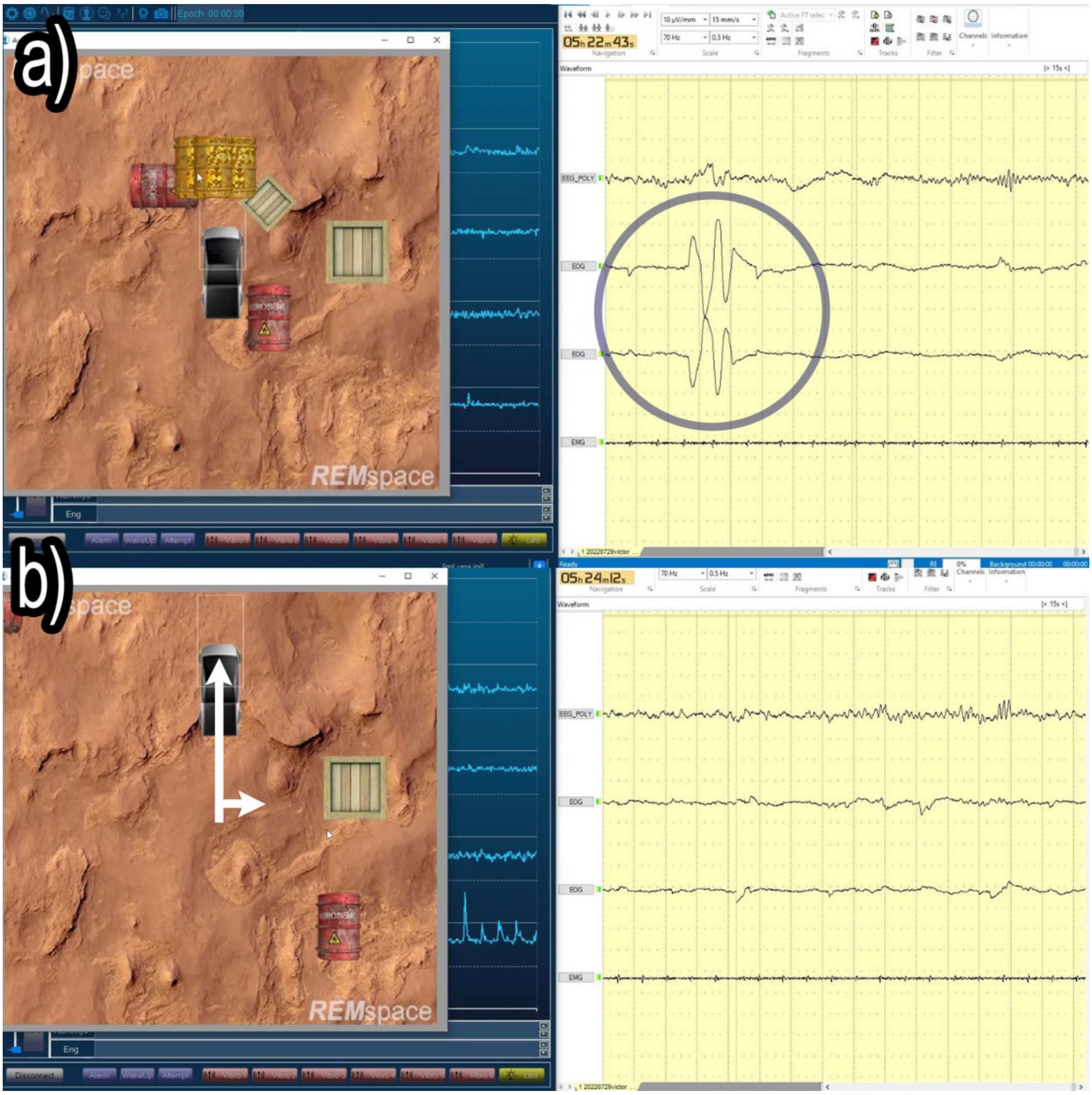

Image 9. Screenshots of real-time monitors while Volunteer #3 successfully controlled a virtual car during the first attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side. The obstacles were moved by the research team.

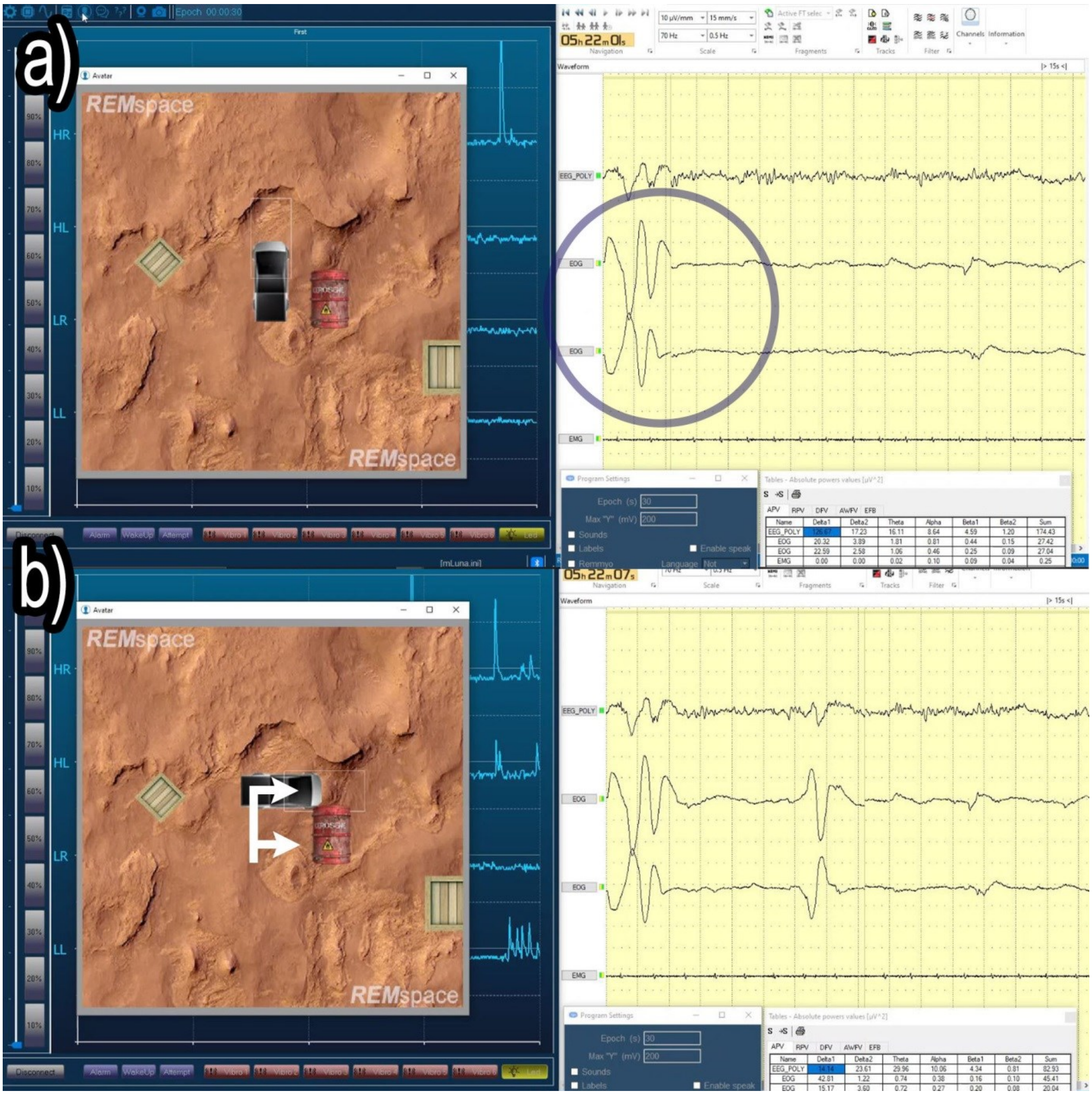

Image 10. Screenshots of real-time monitors while Volunteer #3 successfully controlled a virtual car during the second attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side.

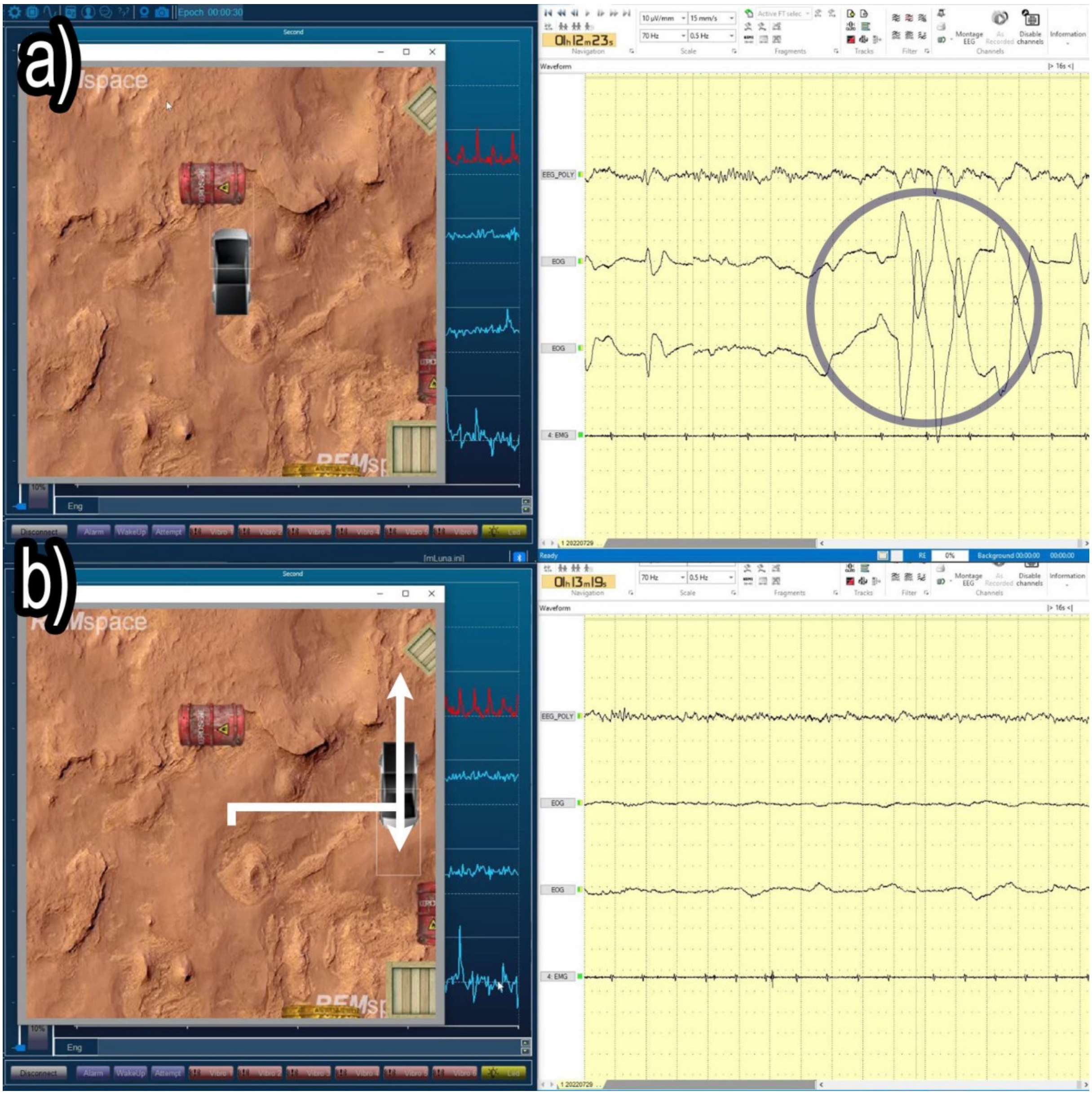

Image 11. Screenshots of real-time monitors while Volunteer #4 successfully controlled a virtual car during the first attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side. Two-sided arrows indicate movement in both directions.

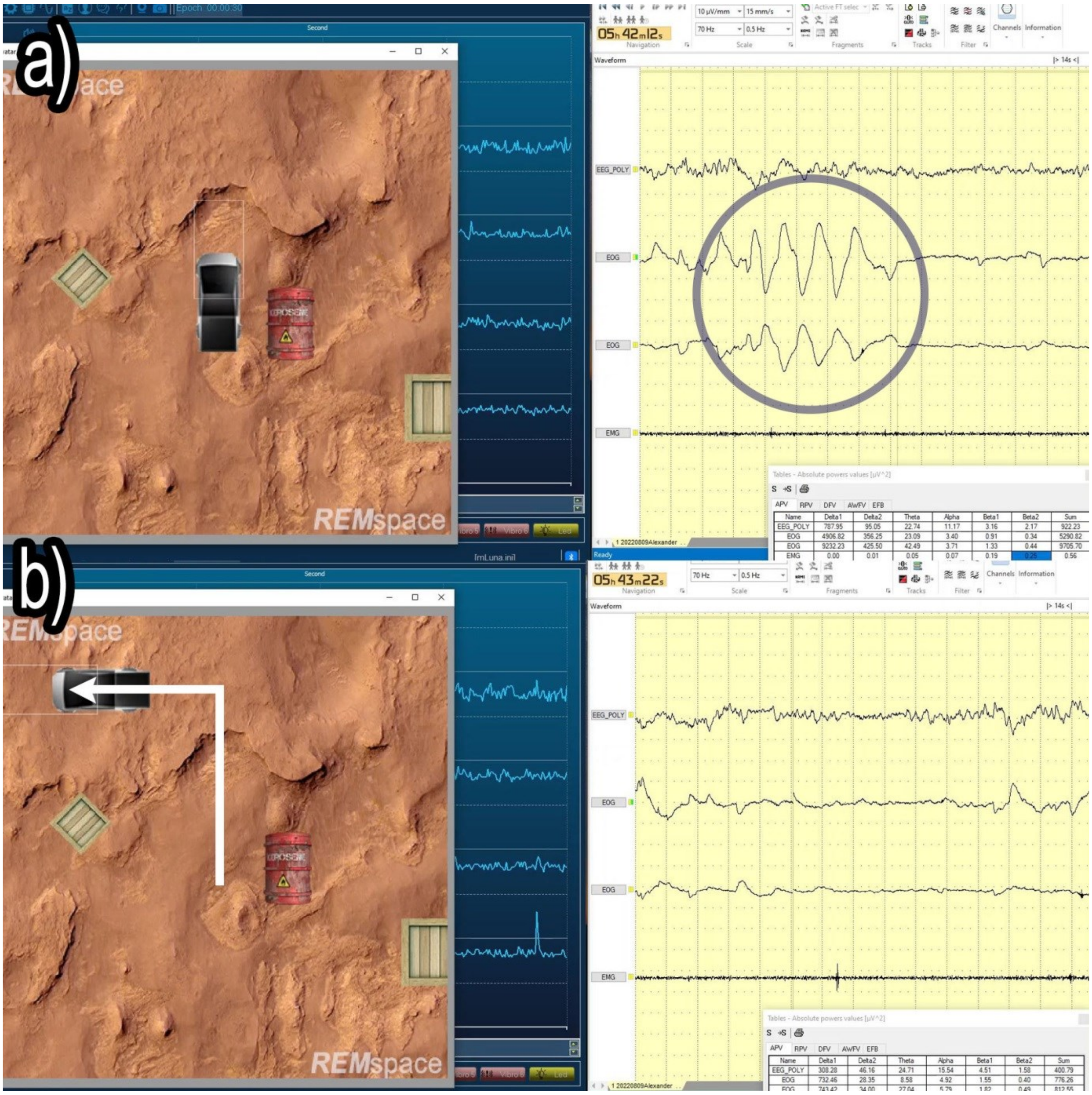

Image 12. Screenshots of real-time monitors while Volunteer #5 successfully controlled a virtual car during the third attempt. Sections a and b represent progress. The PSG observation with distinctive pre-agreed eye signals (encircled) on EOG channels (a) is displayed on the right side. EMG impulses and their decoded outcomes are presented on the left side.