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Detecting Lucid Dreams by Electroencephalography and Eyebrow Movements

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Abstract

Objective When metacognition arises during rapid eye movement (REM) sleep, people experience lucid dreaming (LD). Studies on this phenomenon face different obstacles. For example, its standard verification protocol requires at least three types of sensors. We hypothesized that preagreed frontalis movements (PAFMs), as a sign of lucidity, could be seen on electroencephalography (EEG) during REM sleep. In this case, only one EEG sensor would be needed to verify LD.

Method Under laboratory observation, five volunteers were instructed to induce LD, during which they needed to use the standard verification protocol with pre-agreed eye movements (PAEMs) and then immediately raise their eyebrows three times as a PAFM.

Results All participants were able to send signals from a total of eight LDs using one or both methods. Preagreed frontalis movements and PAEMs were equally distinctive on most EEGs, but PAFM quality was strongly dependent on the accuracy of the method. Preagreed frontalis movements exhibited two types of EEG patterns and led to immediate awakening when LD was not stable.

Discussion Though the outcomes show that PAFMs can be used to verify LD, this method was less consistent and apparent than PAEMs. Furthermore, accurate instructions are needed before using PAFMs. When polysomnography is unavailable, PAFMs can be applied, as it requires only one EEG sensor to detect REM sleep and consciousness simultaneously.

Keywords

- lucid dreaming
- REM sleep
- electroencephalography
- consciousness

Introduction

In 1913, Dutch writer and physician Frederik Willem van Eeden suggested using the term lucid dreaming (LD) to refer to dreams in which people know they are dreaming.[1] In the 1970s and 1980s, the phenomenon was recognized by the scientific community with the help of laboratory studies in England and the USA.[2–4] Though LD's nature remains unclear,[5] it provides many application opportunities, such as interacting with computers while asleep,[6] honing motor skills,[7,8] preventing nightmares,[9,10] solving problems,[11,12] improving waking mood,[13–15] reducing depression,[16] and eliminating chronic pain.[17] No less than 55% of people have experienced LD at least once in their lifespan, and many of them experience it regularly.[18] This frequency may be 88% or more if other phenomena related to LD are considered.[19] For example, consciousness in rapid eye movement (REM) sleep is also linked to sleep paralysis,[20,21] false awakenings,[22] and out-of-body experiences.[23–25] In 2004, we suggested that these phenomena could be united under the term *phase*

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state, as doing so may provide a more accurate picture of their nature.[26,27]

The number of LD studies has increased by 5.6% each year.[28] Lucid dreaming appears to be most often detected during REM sleep, with just a few confirmed exceptions.[29–31] Later, it was found that LD was associated with increased activity in the occipito-temporal cortex cuneus, prefrontal cortex, parietal lobules, and bilateral precuneus.[32] The connectivity between the temporoparietal junction and anterior prefrontal cortex was also associated with LD, as was the volume of gray matter in the anterior prefrontal cortex.[33,34]

As LD studies become more advanced, they require more optimized and effective methods and technologies, especially regarding LD verification methods. In 1978, Hearne was the first to confirm LD under laboratory conditions, which he did by observing preagreed eyelid movements (PAEMs).[4] Later, LaBerge used the same method, and it became the gold standard for LD studies.[2] Though the method is not ideal,[35] almost all LD laboratory studies since those mentioned above have used polysomnographic (PSG) observations, which include at least electroencephalography (EEG), electromyography (EMG), and electrooculography (EOG). As a result, LD verification has become expensive for independent researchers and requires PSG skills, which restricts the efficiency of all such studies.

In 2021, in an attempt to simplify and make LD studies cheaper, it was suggested and confirmed that REM sleep and consciousness can be detected at the same time using only one EMG sensor. This was possible by preagreed chin movements (PACMs), even though muscle atonia in the submentalis area exhibits less activity than in the distal muscles.[36] In this case, an EMG sensor detects REM sleep by its main feature in the form of muscle atonia and then detects consciousness based on the residual electric activity of three chin movements.[37] This PACMs method is effective when studies require many cords and sensors besides PSG.[38] However, the main problem with this method is that it may be hard to differentiate genuine muscle atonia from deep relaxation or the N3 stage of non-REM sleep.

It is unclear whether there is any way to verify LD that is as simple as the PACM method. As any such method should disqualify false results, EOG cannot be used because eye movements are easy to control willingly. At the same time, EEG could be used for brain-computer interface, even during LD,[6] meaning that EEG may represent conscious actions. Moreover, even during PACMs testing, there were distinctive EEG artifacts remaining from jaw movements during LD.[37] Furthermore, facial muscles present EMG activity during dreaming and LD, mostly because speech and emotions in dreams, which can be controlled by will,[38,39] are only partially paralyzed.[40–42] This fact is usually regarded as a problem for EEG sensors—especially those located close to the face—because electrical spikes from this area may create artifacts in EEG data.

This situation begs the question of why preagreed EEG artifacts are not created intentionally. In theory, this would be possible in locations where EEG sensors are close to facial muscles, such as *Fp1, Fpz, Fp2, AF7, AF3, Afz, AF4*, and *AF8* (10–20 system), and could detect raising the eyebrows. Therefore, it is possible to transfer preagreed signals via EEG. Then, the same sensor simply needs to detect REM sleep.

Hypotheses

The main hypothesis of this study is that PAFMs can be used to verify LD when only EEG is available. This idea was evaluated by having a few LD practitioners test PAEMs and PAFMs alongside one another under laboratory conditions. Confirmation of the hypothesis would indicate that there is a simple way to verify LD in studies with few sensors or for which PSG is unavailable. It would also make LD studies cheaper and more convenient for volunteers. These implications are especially important in regard to sleep paralysis, which has the same physiological attributes as LD, making studies on this phenomenon more effective in some cases than in others because people could use PAFMs to report cases of sleep paralysis.

Materials and Methods

Resources and Participants

The current experiment was performed by experienced LD practitioners under laboratory conditions. The study approach was approved by the Phase Research Center ethical committee review board (PRC-2022-03-30-01). Written informed consent about the study and its methods was received from all volunteers. They also confirmed the absence of any psychological or physiological health issues that could have been affected by the study tasks. All participants confirmed that they were at least 18 years of age. The volunteers received a financial reward for their participation, and their travel and accommodation expenses were covered. No medical supplements were used to enhance LD attempts or the study results.

Experimental Task

Participants were asked to follow these steps: A) to induce LD by any technique or method; B) in LD, make three consecutive PAEMs to the left/right/left sides; C) after making the PAEMs, make three consecutive PAFMs by raising the eyebrows; D) report these LD actions upon awakening. Participants had up to 4 nights in the laboratory to achieve the experimental task at least once. They were also allowed to use maintaining and stabilizing techniques to make LD more stable and vivid. No questionnaires were applied, as PSG sensors represent highly objective information.

Apparatus

Lucid dreaming was detected and verified using Encephalan-EEGR-19/26, with the following settings: one EEG channel (*Fpz* and *A2* positions from the 10–20 system; 50 Hz notch filter; 0.7–70 Hz band-pass filter), two EOG channels (50 Hz notch filter; 0.7–70 Hz band-pass filter), and one chin EMG channel (50 Hz notch filter; 16–70 Hz band-pass filter).

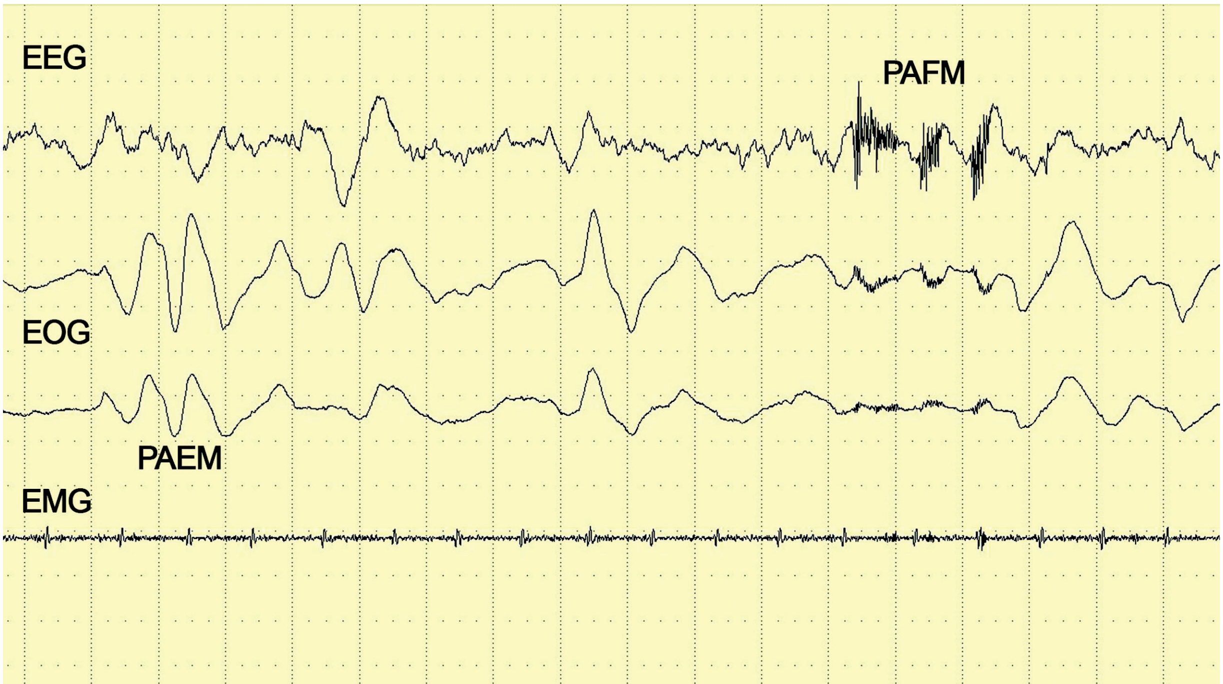

Fig. 1 PAEM/PAFM Cycle of Volunteer #1. Note: The EOG sensors were not opposite.

Results

Five volunteers participated in the present study (25–38 years old, all males). They reported eight LDs. In one dream, PAEMs were not apparent, but PAFMs were distinctive; in another dream, the opposite pattern emerged. In the other six cases, both LD verification methods were distinctive. Preagreed frontalis movements left two different patterns of artifacts on EEG, both of which could be observed in the LDs of one participant. In three LDs, the most distinctive pattern represented a bold EEG artifact of high-frequency waves with inconsistent low or average amplitudes that varied from LD to LD, but not in one PAFMs set. Another type of PAFMs consisting of slow-sinusoidal, high-amplitude EEG artifacts were detected in two LDs. In another two LDs, both patterns were mixed in a single set of signals.

Volunteer #1 reported a dream that coincided with the most distinctive PAEM and PAFM cycles. Preagreed frontalis movements were observed as high frequency, average-amplitude EEG artifacts (►**Figure 1**). Volunteer #2 reported a dream that coincided with a distinctive PAEMs and mixed PAFMs cycles. This participant's PAFM were observed as the simultaneous presence of high-frequency, average-amplitude EEG artifacts and slow-sinusoidal, high-amplitude EEG artifacts, which changed each other (►**Figure 2**). Volunteer #3 reported two LDs that coincided with distinctive and clear PAEMs and PAFMs cycles. Preagreed frontalis movements were observed as high-frequency, low- or average-amplitude EEG artifacts (►**Figures 3** and **4**). Volunteer #4 reported two LDs that contained only distinctive PAEM or PAFM cycles. In the first dream, only PAEMs were visible; in the second dream, only PAFMs were visible, which were observed as slow-sinusoidal, high-amplitude EEG artifacts (►**Figures 5** and **6**). Volunteer #5 reported two LDs that coincided with distinctive and clear PAEMs and PAFMs cycles. In the first dream, PAFMs were visible as simultaneous high-frequency, low-amplitude EEG artifacts and slow-sinusoidal, high-amplitude EEG artifacts, which changed each other. In the second dream, PAFMs were visible only as slow-sinusoidal, high-amplitude EEG artifacts (►**Figures 7** and **8**).

Discussion

Other than eye movements and sleep atonia, two of the main features of REM sleep are low alpha waves and dominant theta EEG waves.[43,44] This wave pattern is a defining feature of REM sleep but has some deviations in LD.[35] In general, EEG could represent REM sleep as well as consciousness, and it cannot be scammed. In a search for a simple and reliable method for verifying LD under laboratory conditions, it was hypothesized that straining frontalis during LD may create distinctive EEG artifacts during REM sleep, representing lucidity. This new method would make LD studies much cheaper, as it does not require PSG and is more convenient than current methods in some situations. This idea was tested by comparing the PAFMs method with the traditional PAEMs method under laboratory conditions.

Hypothesis Confirmation

Neither the PAEMs nor the PAFM method was 100% efficient, but both were distinctive in the same number of LDs. These results confirm our hypothesis by showing that PAFMs can be used as an LD verification method, as it was visible in the form of EEG artifacts in most of the reported LDs and

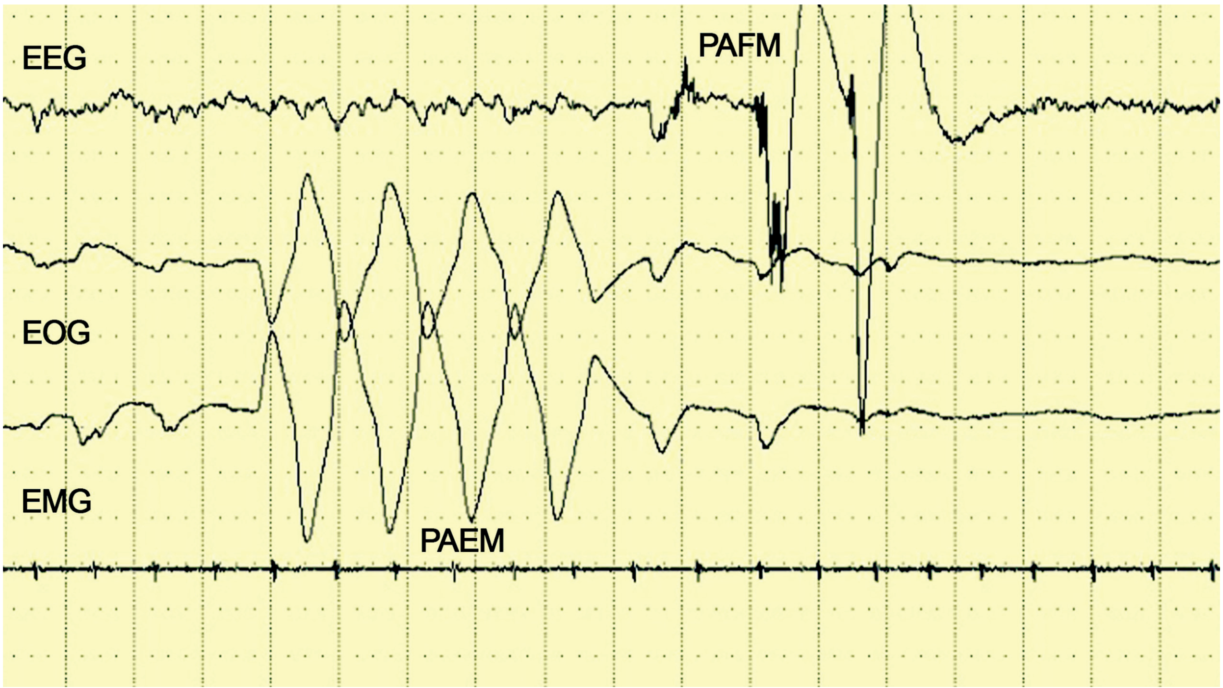

Fig. 2 PAEM/PAFM Cycle of Volunteer #2.

coincided with verbal reports. As a result, if the *Fpz* EEG sensor represents the dominance of theta waves with sawtooth waves adherent to REM sleep,[43,44] and if there are consecutive artifacts, it could mean that LD occurred. This outcome was apparent from previous studies, which show that facial muscles have residual electrical activity during sleep.[36–42,45] The main contribution of the study is that it creates a clear procedure for using this knowledge in a new practical way. As the PAFMs method requires only one EEG sensor, it is more convenient than the PAEMs method for LD practitioners and researchers to use. Furthermore, the PAFMs method is substantially cheaper than the traditional PAEMs method using PSG.

The most important aspect of this study is the development of a new and simple method for LD verification, which could promote LD studies and reduce their cost. As the PAFM

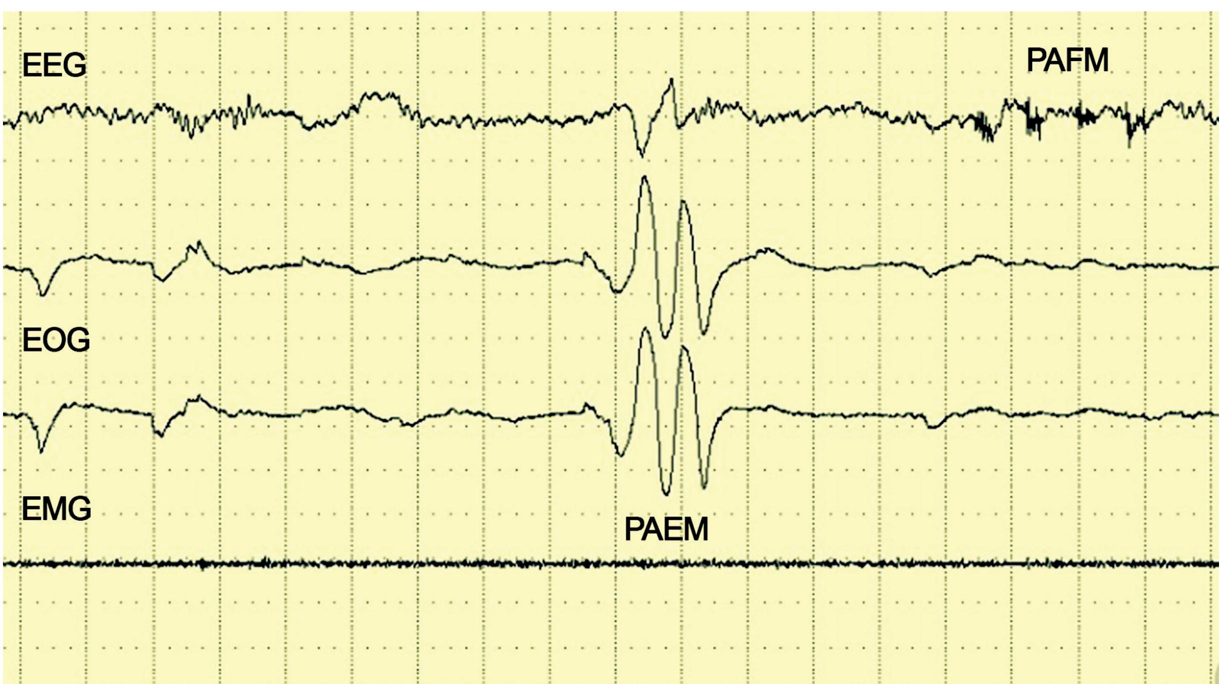

Fig. 3 PAEM/PAFM Cycle #1 of Volunteer #3. Note: The EOG sensors were not opposite.

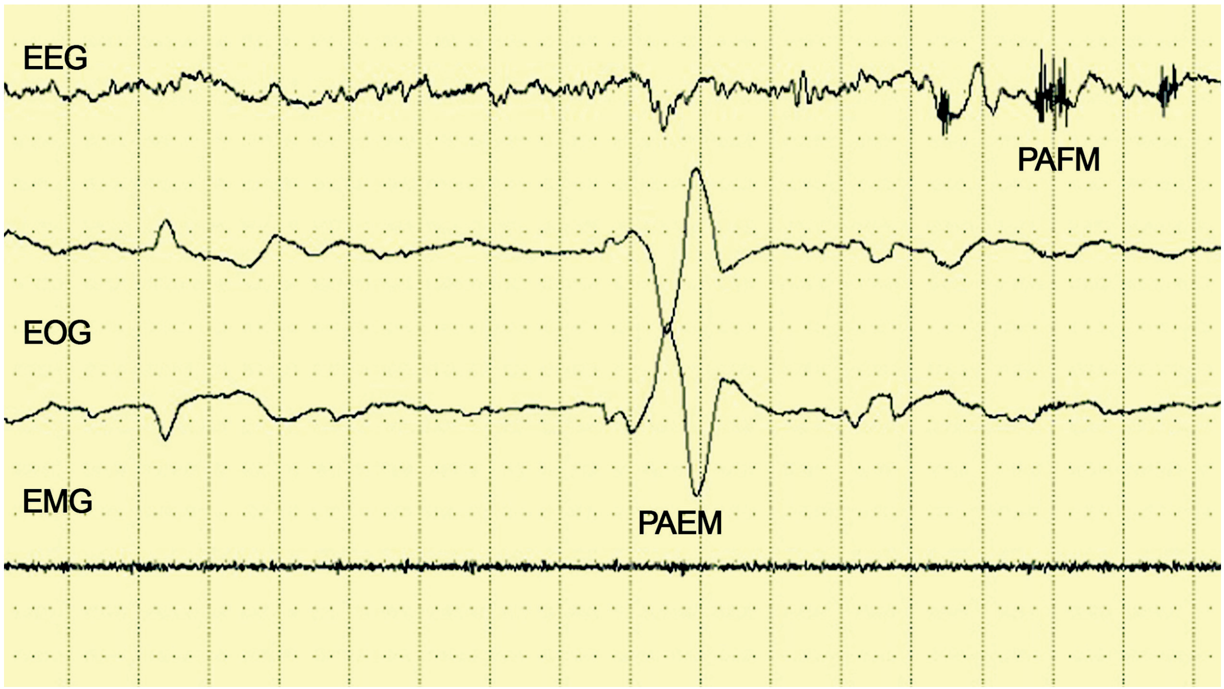

Fig. 4 PAEM/PAFM Cycle #2 of Volunteer #3.

method requires only one EMG sensor, it takes little time to assemble and could be applied by LD practitioners themselves, especially if dry-contact EEG sensors are used. As sleep paralysis, out-of-body experiences, and false awakenings share similar features with LD,[19] the PAFMs method could facilitate studies of all these phenomena.

PAFM Procedure

During the pilot tests and the study, itself, the implications of PAFMs appeared to require more attention than those of PAEMs. All that is needed to detect PAEMs on EOG is for the eyes to move in a left-right-left pattern; however, merely straining the frontalis may not lead to the detection of PAFMs, or they may become less distinctive on EEG. The results show that the following factors are important for detecting PAFMs: A) there should be at least three PAEMs; B) frontalis movements must be done with an emphasis on straining the muscle, not just on raising the eyebrows; C) frontalis straining must be prolonged, approximately from 0.3 to 1 second; D) there must be breaks (approximately 0.5–

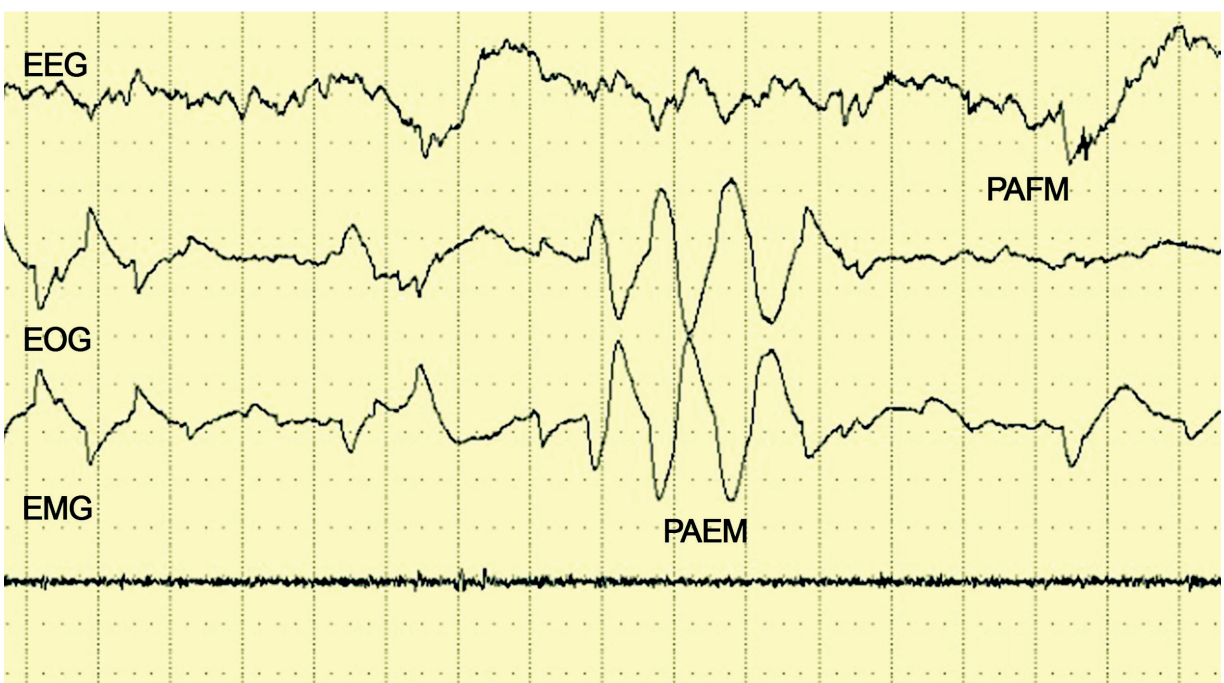

Fig. 5 PAEM/PAFM Cycle #1 of Volunteer #4.

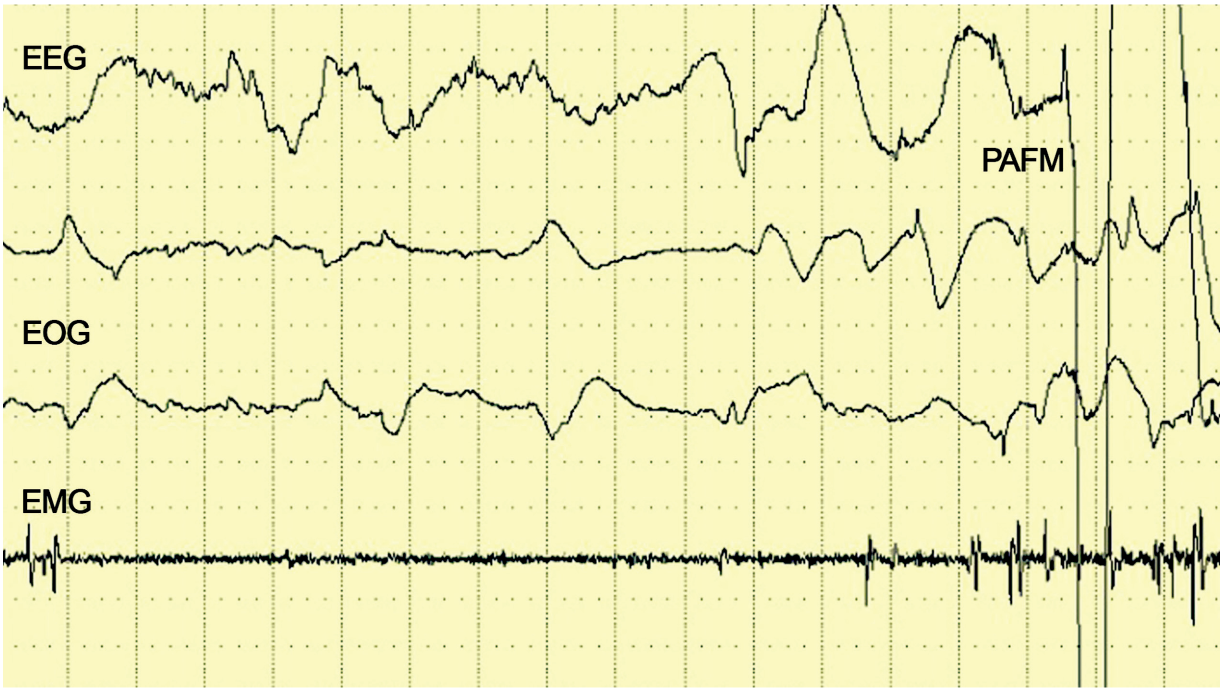

Fig. 6 PAEM/PAFM Cycle #2 of Volunteer #4.

2 seconds) between frontalis movements; E) frontalis movements should not be performed during unstable LD stages because this leads to immediate awakening; and F) PAFM artifacts on EEG should coincide with verbal reports given after LD.

Regarding EEG sensor positions, *Fpz* was used in the present study. In theory, *Fp1*, *Fp2*, *AF7*, *AF3*, *AFz*, *AF4*, and *AF8* may be apt for PAFMs, but the artifacts could be less apparent.

The most unexpected result was that two types of EEG artifacts were observed when the PAFMs method was used. Artifacts emerged as high-frequency waves with inconsistent low- or average-amplitude or slow-sinusoidal, high-amplitude EEG artifacts. Both types were recorded in similar LD cases and could mix with each other. The most obvious explanation is that the physical frontalis movements could lead to slow-sinusoidal, high-amplitude EEG artifacts.

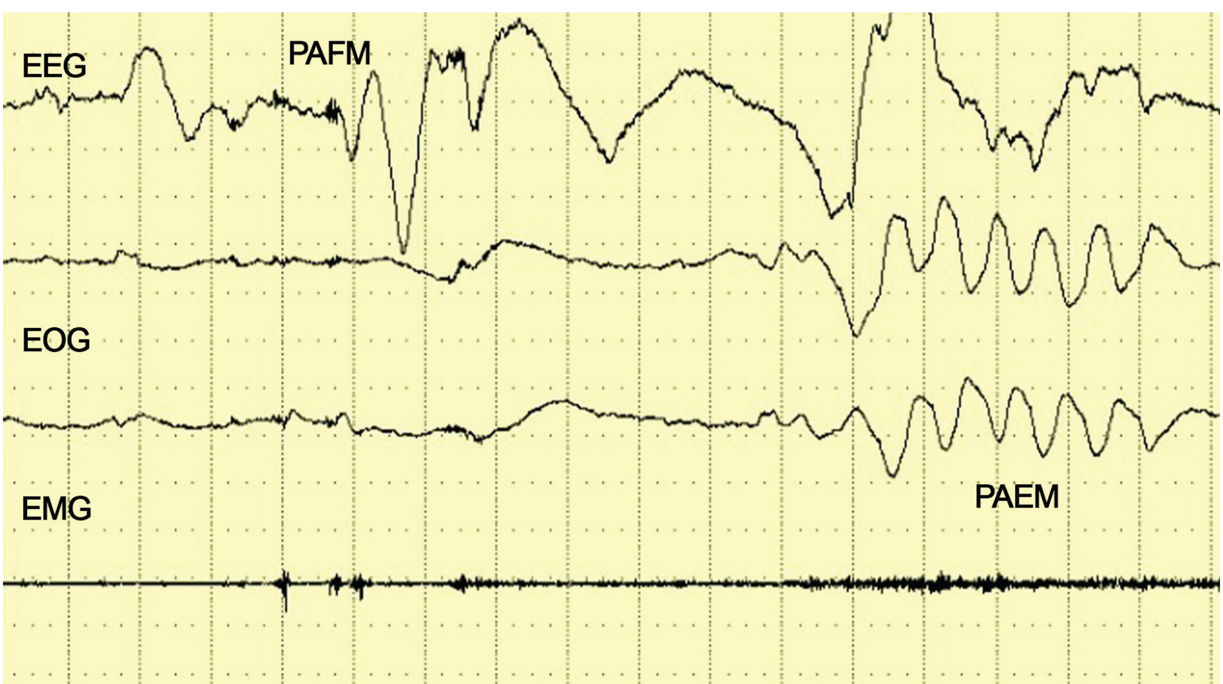

Fig. 7 PAEM/PAFM Cycle #1 of Volunteer #5.

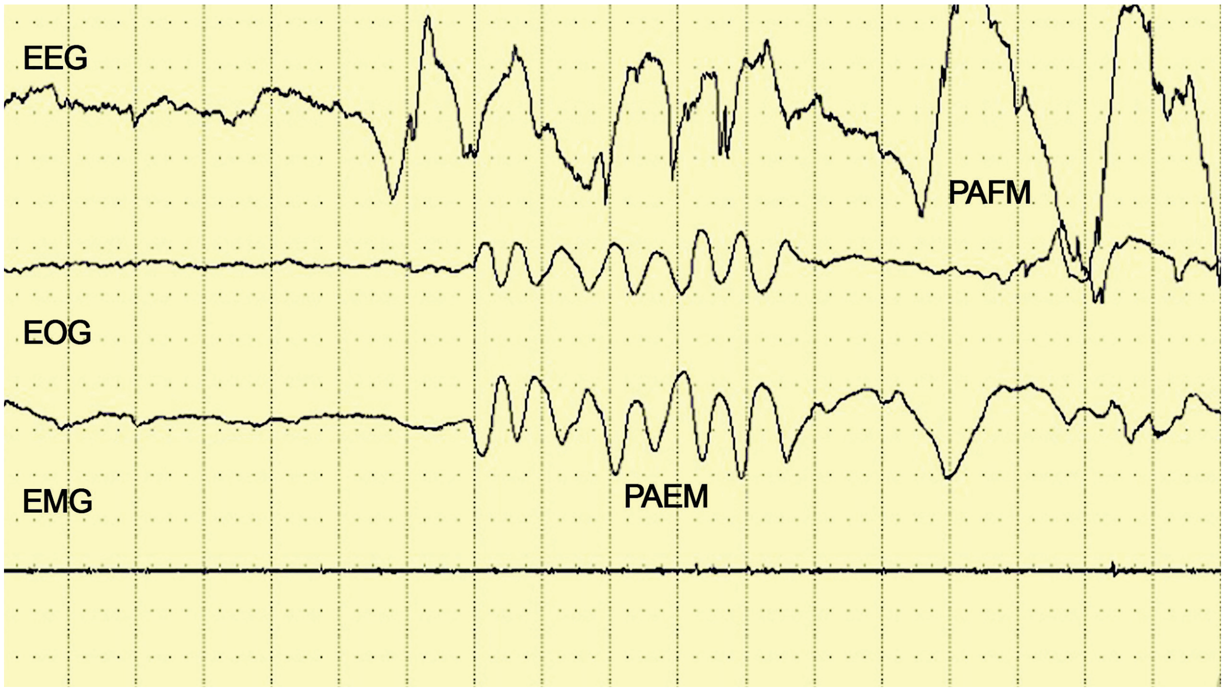

Fig. 8 PAEM/PAFM Cycle #2 of Volunteer #5.

However, no such artifacts were observed during PAFMs training, which was performed by actually raising the eyebrows. Currently, we cannot explain this issue, and it is important to expect and accept both types of artifacts while using PAFMs.

PAEMs, PACMs, or PAFMs

It is possible to compare three methods for verifying LD. The traditional PAEMs method is the most complicated, expensive, and inconvenient, but it gives the most reliable and detailed data, it can be performed in cases of unstable LD, and it is the easiest to use during LD, as it requires only simple eye movements.[35] To date, the PAEMs method is the only LD verification method recognized by the scientific community, making studies based on it more legitimate, whereas the PACMs method has been accepted in only one study.[38] The PACMs and PAFMs methods are cheaper and more convenient to use while asleep. In addition, they are less complicated, but both need concentration during LD. Both can lead to awakening if performed in an unstable LD stage. Before choosing an LD verification method, the pros and cons of each should be considered based on the specific study conditions and goals.

All three methods can support each other to verify LD more reliably. This became apparent when we analyzed the attempts of volunteer #4 (►**Figures 5** and **6**). In one LD, only PAEMs were clearly distinctive, while only PAFMs were visible in the second attempt. Without considering PAFMs, the second LD would not have been verified. So, PACMs and PAFMs could be considered to support PAEM, thus providing more reliable data than when considering PAEMs alone. As the PAEMs method can be used during any LD stability stage, PACMs and PAFMs could not only highlight LD but also verify its stable forms (they lead to awakening otherwise). The PACMs and PAFMs methods are more convenient than the PAEMs method when the goal is to confirm rigid LDs.

PAEMs and PAFMs Failures

It is important to note that one volunteer (#4) experienced PAEMs and PAFMs failures (in different LDs). It could be a coincidence, but this volunteer has participated in some of our other studies, in which similar issues were observed. These failures were related to conscious EMG or EOG signals during LD, sent by facial or body muscles. While this is a different topic to study, two hypotheses could explain this situation. First, unlike all other volunteers, this one lacked muscle development and led a lifestyle without engaging in physical activity or sports. As a result, the weak development of this participant's neuromuscular circuit could manifest while sending signals during LD. Secondly, this volunteer's sleep atonia could be more profound than others'. However, problems with the PAEMs method contradict this idea. Both hypotheses could explain why the PAEMs and PAFMs methods may not work for some individuals.

Limitations

Alpha waves can be much higher during LDs than during REM sleep.[35] At least visually, these EEG patterns could be very close or similar to patterns observed during relaxed wakefulness, meaning that the PAFM artifacts from LD could be confused with wakefulness. Conversely, fake LDs could be reported when no chin EMG is recorded to detect sleep atonia, which is the hallmark of REM sleep, even in LD. Therefore, only PAFM artifacts in EEG patterns with low alpha waves can verify LD if no other sensors are used.

Conclusions and Future Studies

The PAFMs method was tested in a search for a simple LD verification method. Two types of distinctive EEG artifacts during REM sleep represent lucidity in dreams. This new method could make LD studies cheaper and more convenient in some situations, resulting in more studies on the topic.

Future studies could focus on explaining why PAFMs have two types of EEG artifacts or how to clearly separate LD EEG patterns from the patterns observed during wakefulness. Research could also look for simple ways to verify LD other than the PAEMs, PACMs, and PAFMs methods. Such studies may generate new research and application opportunities in many areas, enhancing the understanding of dreams and consciousness in general.

Conflict of Interests
The authors have no conflict of interests to declare.

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