Motion and Time Sequences of Roll-Overs During Sleep for Development of Self-Helped Roll-Over Movements: A Preliminary Study

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This study aimed to identify the motion sequences and time-flow of roll-overs during sleep in women to develop a self-helped roll-over maneuver for elderly patients. Shifts from deeper sleep stages to lighter stages leading to arousal occur at roll-over-onset. Quick re-falling-asleep after completion may aid peaceful sleep continuation. Motion sequences of six women aged 43-65 years were examined at a sleep laboratory using polysomnography and infrared video. Relationships among phase I (before roll-over onset), II (roll-over movements), and III (roll-over end to re-falling-asleep onset) were determined. Mean total sleep time was 6.72±0.77 h, with over 80% sleep efficiency. Among 12 patterns examined, only supine-to-left and supine-to-right lateral roll-overs were classified: type A, sliding waist with pause (n=11, sleep); B, sliding waist without pause (n=56, sleep and arousal); and C, without sliding waist or pause (n=1, arousal). Time spent in phase I and III in type A were correlated (r=0.78, p=0.005), and were the shortest among the types. Discriminant analysis for type A (n=11) and B (n=20, sleep) showed 80.6% correct classification. In conclusion, type A roll-overs, involving efficient motion with quick re-falling-asleep, may be a useful foundation to develop self-helped roll-over maneuvers.

(Key words: Infrared camera, Polysomnography, Roll-over, Self-helped, Sleep)

1 Introduction

Roll-overs, sometimes referred to as “major body movements”1, often occur during sleep, especially during lighter sleep stages2. In operational terms, it has been defined as a series of rotational trunk motions from static state to static state during sleep, as measured by a wearable sensor3. Roll-overs have attracted the interest of researchers because of their associations with sleep-stage transitions3 and potential to disrupt the sound sleep of bed partners4. Lateral motion brought about by an artificial bed partner during the sleep of a real subject on the same mattress significantly increases time spent in Stage 1 of non-rapid eye movement (NREM1) sleep and significantly decreases time spent in deeper sleep stages4. Thus, when people sleep together, these synchronous movements may act to shift the sleep of both individuals to lighter stages at the same time. Furthermore, shifts in body position that alter the nasal cycle (nasal airflow lateralization) during sleep mostly lead to rapid eye movement (REM)5,6. Thus, changes in body position during sleep, both self- and externally initiated, may significantly shift sleep to the lighter stages.

Light sleep stages, such as REM or NREM1, are at greater risk for sleep disruption from environmental stimuli4, and frequently lead to an arousal state. While the neurological, cause-effect relations between body movements and sleep stages are still inconclusive4, most previous studies indicate that roll-overs lead to an arousal state by lightening the depth of the sleep4,5. In addition, if roll-overs during sleep create stiff or useless movements, they can delay re-falling asleep even after the movement itself is over. Consequently, the prolonged arousal might interfere with the descent from NREM1 into the deeper stages needed for sound sleep. Previous studies have implied that postural immobility is mostly preserved when NREM sleep descends into the deeper sleep stages7,8; therefore, interruptions may be minimized by roll-overs with less stiff movements since they do not disturb this descent.

Roll-overs that create less sleep interruption are...
particularly necessary for patients who should move frequently during sleep to prevent pressure ulcer formation\(^8,9\) and for those who maintain specific body positions to manage physiological status (hemodynamics, metabolism, etc.) or pathological conditions such as sleep-related breathing disorder and high intraocular pressure\(^11\)\(^-\)\(^14\). In particular, for elderly patients, a roll-over performed efficiently during sleep is indispensable not only for sleep continuation, but also to ensure sufficient trunk rotation despite limited pelvic flexibility\(^15\). When assisting these patients, the roll-over sequence is usually performed consciously while awake\(^16\)\(^-\)\(^18\) as a positioning technique. Such techniques have been well documented, with past studies looking at effective positions for individual needs\(^11,19\), roll-over timing and frequency, and preferences based on age or gender\(^19\)\(^-\)\(^22\). However, the research on roll-overs performed during sleep is quite limited, and insufficient for the development of a positioning scheme.

The ability of humans to roll-over generally starts during early development\(^23\)\(^-\)\(^25\), possibly implying an innate function that precedes muscle strengthening or higher levels of motor control\(^26\). As an innate function, roll-overs may depend on a lower level of motor control\(^26\), to involuntarily or unconsciously roll the body over without wasted effort. Specific roll-over sequences or patterns during sleep in early development tend to persist throughout subsequent developmental stages\(^17\), perhaps implying roll-over is a habitual trait characterized by ontogenetic movement in adults. Such habitual roll-overs in adults may also create smooth motion to enable prompt re-falling asleep. Efficient roll-overs with smooth motion and quick re-falling asleep could be useful as a ‘self-helped’ movement, resulting in independent body positioning. Pre-sleep instructions about how to change posture during the night may be able to promote the actual movements during sleep\(^27\). Therefore, instructions for self-helped roll-over movements in daily practice are expected to appear unconsciously during sleep in the night.

It is expected that habitual roll-over sequences performed during sleep will be clearly exhibited in adults with unrestricted body movements compared to in those with sedentary lifestyles or chronic diseases. The aim of this study is to examine the sequence and time flow of roll-over movements performed unconsciously during sleep in healthy adults, and to determine which roll-over types least interrupt sleep.

2. Methods

2-1. Ethical considerations

The study was approved by the Ethics Committee Institutional Review Boards of the University of Shizuoka (Number: H27-44), the primary investigator’s institution, and the Shizuoka Institute of Epilepsy and Neurological Disorders (Number: 2015-34), where measurements were taken. Written informed consent was obtained from each participant.

2-2. Design and setting

This was an explanatory, observational study conducted during the night at a hospital’s sleep laboratory. Measurements commenced in the evening of the first day of the study and ended on the morning of the fourth day. While sleep study measurements are usually made on consecutive days in a sleep laboratory setting\(^1,28,29\), our study did not utilize this design because participants continued their jobs during the study period, requiring a measurement schedule that minimized interruptions to their working life. Notably, workplace performance and mood can be impaired by spending time in laboratory environments or procedural factors\(^30\). To ensure potentially poor sleep in a laboratory setting would not impact workplace safety, participants spent one night at home during the study protocol. An additional reason for this design was to minimize risk of postural instability during morning work triggered by consecutive days of laboratory measurements, since postural balance control is affected less by morning somatosensory input than in the evening\(^31\). Therefore, we designed a measurement schedule consisting of two sets: each set consisted of one night sleep at home followed by one night sleep at the laboratory. Thus, the day prior to laboratory measurements was controlled under similar conditions.

2-3. Participants

Participants were recruited from a community using the snowball method after initially advertising on workplace bulletin boards. The inclusion criteria were adults who were actively involved in their work, part of the community, regularly slept at night, had no uncontrolled health problems
such as musculoskeletal pain, and were able to understand the study protocol. The exclusion criteria were outpatient treatment for mental health issues or cancer. Six healthy women working either full- or part-time aged between 43 and 65 years were enrolled in the current study during the six-month recruiting period. Although we initially sought men as well, few were interested in participating. We decided a women-only design was acceptable, because the muscle content of elderly individuals generally tends to be more similar to that of women than that of men. In other words, measurements related to roll-over sequences in women would better contribute to the development of a later study design involving the elderly patients. Participants were asked to choose their own days for measurements to avoid inconveniencing their occupational activities.

2-4. Measurement tools

The main outcomes of this observational study were the motion and time sequences of roll-overs during sleep, and were measured by polysomnography (PSG) (PSG-1100; Nihon Kohden, Tokyo, Japan) with a Neurofax digital electroencephalogram (EEG) system (EEG-1200; Nihon Kohden). Sleep was monitored with surface electrodes to provide EEG (C3–A2, C4–A1, O2–A1), electrooculogram (EOG; EOG-L, EOG-R), and submental electromyogram (EMG) signals, as well as an electrocardiogram (ECG) and infrared video camera recordings (Supervision camera for security; Daiwa, Tokyo, Japan).

Roll-over sequences were monitored using the infrared video camera in conjunction with infrared lighting. PSG was performed simultaneously with a posture sensor attached to a band on the chest to detect body position during sleep as a supplement to the video recording. Electrode sensors to capture muscle activity were placed on target muscle groups representing the deltoids, biceps brachia, triceps brachia, and sternocleidomastoid muscles (indicating movements of the upper body), and the hamstrings, quadriceps, and femoral muscles (indicating movements of the lower body). For validation of this measurement, a few initial roll-overs were randomly selected and assessed by three researchers. To determine the angles of left and right lateral positions on the bed, a spot on the rear trunk (i.e., lower back) was chosen as a benchmark. Previous research has defined as “laterally stable” those positions where the supine is angled 60–105 degrees with respect to the bed surface, therefore, we defined a lateral position as lying on the right or left side at approximately a 90-degree angle with respect to the bed surface. This lower-back-bed angle was directly measured and confirmed by an infrared video camera, with the monitor screen placed at the middle of the foot of the bed. Head and trunk motions were easily viewed from this location. The roll-over sequences were first described visually by a researcher and then validated by two researchers. The timing of a roll-over from beginning to the end was confirmed by PSG recordings synchronized with the infrared video camera. The camera was located about 200 cm from the head of the bed and elevated approximately 135 cm above the floor to capture an overall view of roll-over sequences with just one device. Thus, the optical axis was at a 45-degree angle to the horizontal plane and a 0-degree angle to an imaginary line bisecting the bed from head to foot.

2-5. Procedure

The shielded sleep laboratory had the following criteria: room size, 3 × 4 m; electromagnetic wave damping, 40 dB with 0.5–15 MHz; dark to dim lighting, Slidac voltage regulator; soundproofing, < 30 dB; and room temperature, 24–27°C, with the environmental conditions controlled based on individual preferences. Typical or specialized mattresses were randomly assigned for alternating nights (i.e., a typical mattress for the first night followed by a specialized one for the second night versus a specialized mattress for the first night followed by a typical one) to reduce the risk of sleep disturbance, as the condition of a mattress influences mobility and comfort during sleep. A thin cotton blanket was placed over the participants so that roll-over sequences could still be observed clearly using the infrared video camera.

On her first day, a participant woke up at home in the morning, and arrived at the sleep laboratory by 6 pm after finishing work and dinner. Self-reported health status and vital signs were measured by a researcher. Wearing a cotton-polyester nightgown, the participant was then admitted to familiarize herself with the new environment. Afterwards, two certified clinical technologists attached PSG sensors to the participant with thin cords while sitting on the bed. Attaching these sensor electrodes took approximately 40–50 minutes.

After the participant had been prepared as above, she
engaged in her usual evening activities, such as reading books, doing paperwork, or communicating by mobile phone with family or friends to facilitate adaptation to the environment, until going to bed to sleep. The recording started when she indicated verbally that she was ready to go to sleep after choosing a fitting pillow. Additionally, each participant chose her own wake-up time and means (i.e., alarm clock, radio) for the following morning.

The next morning (the second day of the study), a researcher removed all sensor electrodes from the participant and helped her with usual morning activities after taking vital signs and asking about health conditions. A cup of tea or coffee with a light snack was provided, and the participant left the hospital for work between 6 am and 7 am. After completing work for the day, she returned home that evening and slept there as usual.

On the morning of the third day, the participant went to work from her home as usual. After finishing work, she returned to the sleep laboratory around 6 pm for the second round of measurements. The same clinical technologists followed the same procedures precisely as performed on the first measurement, and the same procedure and snacks were followed the next morning. Again, the participant left the laboratory for work between 6 am and 7 am.

2-6. Analyses

Sleep studies conducted in a laboratory-setting usually control for so-called “first night effects” by completely removing the measurement data from the first night\(^1\)\(^2\)\(^8\)\(^39\)\). However, because of the limited number of nights these actively employed participants could spend in the laboratory, we used the two-set schedule described in 2-2 to minimize first-night effects attributable to environmental differences. The next night, the same clinical technologists followed the same procedures precisely as performed on the first measurement, and the same procedure and snacks were followed the next morning. Again, the participant left the laboratory for work between 6 am and 7 am.

2-6-1. Roll-over sequences

Roll-overs were positively identified if they met our definition: trunk rotation including head and limbs from a static supine position to a lateral or prone position, as well as such rotations back to a static supine position. For qualitative analyses, all roll-overs were categorized into patterns (e.g., supine to left- [S-to-L] or right-lateral [S-to-R], supine to prone, and left- or right-lateral to supine). S-to-L and S-to-R patterns were then classified based on differences and commonalities in the cascade of steps comprising the roll-over sequence. Only S-to-L and S-to-R patterns were examined because the study’s scope specifically regards self-helped roll-overs that require little physical effort. Video recordings with PSG waveforms were repeatedly examined using Polysmith Version 9.0 (Gainesville, FL, USA).

2-6-2. Time required for each roll-over

Sleep-related data were first analyzed by a PSG specialist and then checked by the researchers, including a neurologist. Sleep stages are usually monitored using a 30-second epoch according to the standard criteria of the American Academy of Sleep Medicine (AASM)\(^35\). We adhered to this protocol, evaluating each epoch based on the majority of stage-specific EEG waves observed.

There are no established standards for evaluating how specific EEG activity relates to the motion and time sequence of roll-overs, so we developed our own analytical framework in-house (Fig. 1). This time flow was divided into three phases: phase I, the time spent arousal before roll-over onset (sleep usually continues until roll-over onset); phase II, the time required for the roll-over sequence (from start to finish); and phase III, the length of time from the end of the roll-over to the onset of re-falling asleep. After analyzing 30-s epochs by EEG activity, we manually examined EEG waves for every 1-s interval during the epoch to search for the exact timing of roll-over onset. The granularity of the 1-s window gave us clearer insight into the real-time changes in sleep stages due to roll-over onset. Specifically, this method allowed us to effectively detect characteristic signs of ‘upward’ shifts to lighter sleep stages, such as the posterior background rhythm (PBR), which is altered by roll-over onset. In this approach, a
10-min duration (i.e. 5 min before and after roll-over onset) was applied to determine the timing of EEG changes.

Sleep shifts to lighter stages during a roll-over, which often manifests as a PBR. While the presence of a PBR with eyes closed tends to indicate unconscious sleep, this association diminishes once the person becomes aroused. That being noted, the unconscious state itself in the light, PBR-associated stage can continue for a while until complete wakefulness is achieved. Therefore, a cutoff point is necessary to clearly distinguish roll-overs initiated in sleep from those initiated while aroused. The cutoff was tentatively set at the middle of the 30-s epoch. Thus, a roll-over initiated in sleep was positively identified if a PBR appeared < 15 s before the onset of the roll-over.

In other words, by determining whether phase I continues until before or after the EEG cutoff at 15 s before roll-over onset, it is possible to confirm whether a roll-over was initiated during sleep versus an aroused state. We checked for relationships between time spent in the three time phases. Roll-overs classified into sequence types with the EEG cutoff applied were also analyzed using χ² tests to identify if they were associated with significantly higher incidence of roll-over types.

Lastly, the mean time spent in phases I, II and III for the different roll-over types was examined.

2.6.3. Discriminant analysis

Ideally, our roll-over classification scheme could be adopted in other studies to make generalizable hypothesis. To test its validity with our observational data, discriminant analysis was applied to cross-validate the roll-over type scheme (in terms of time spent in phase I, II, and III) and determine the percentage of correct classifications and discriminant values. We additionally checked whether any roll-over type was significantly association with less sleep interruption.

3. Results

The demographic characteristics of the participants are shown in Tab. 1. They were six women with a mean age of 53.67±8.48 years. Demographic characteristics that could potentially influence roll-overs were homogeneous, except for BMI. Our decision to combine the first- and second-measurement data was justified by the resulting ICCs for roll-over frequency (0.724: substantial), AI (0.776: substantial), percent time in N1 (0.813: almost perfect) and N2 (0.643: substantial). The exception was SE (0.465: moderate). Tab. 2 shows sleep-related quantitative data: mean sleep period time (SPT) was 6.72±0.77 hours; mean percentage of time in NREM2 was 60.30±8.22%; and in REM was 21.66±3.87%.

| Tab. 1 Demographic characteristics. | n = 6 |
|-----------------------------------|------|
| **Descriptor** | **Total** |
| Age (y) Mean±SD (range) | 53.67±8.48 (43–65) |
| Work status Full-time (n) | 4 |
| Part-time (n) | 2 |
| BMI (kg/m²) mean ± SD (range) | 24.72 ± 5.49 (19.24–35.06) |
| Health status Good (n) | 1 |
| the past month Fair (n) | 5 |
| Workload Moderate | 5 |
| Slightly active | 1 |
| Menopause Post | 3 |
| Pre | 3 |
| (post-menstrual) (3) | |
| Menopausal disorder None | 6 |
| Usual SPT (h) mean±SD (range) | 6.17±0.26 (6–6.5) |
| Sleeping Bed (n) | 4 |
| environment Futon mattress (n) | 2 |
| Sleeping pills None (n) | 6 |
| Smoking Never (n) | 6 |
| Drinking None (n) | 3 |
| 1–2 times /week (n) | 2 |
| 3–4 times /week (n) | 1 |
| Living With family (n) | 4 |
| situation Alone (n) | 2 |

SD, standard deviation; BMI, body mass index; SPT, sleep period time.
Roll-over sequences

The 143 roll-overs recorded were categorized into 12 patterns (Tab. 3). Only S-to-L and S-to-R patterns (constituting 68 roll-overs) were further investigated and classified into three types (A, B, and C) based on an eight-step cascade of specific body movements (Fig. 2). Type A was characterized by a significant step that involved sliding the waist then pausing before turning to the other side while in the supine position with legs either extended or bent at the knees, followed by the contra-lateral foot pressing onto the bed’s surface (total: 11 onsets, only asleep). Fig. 3-1 and 3-2 show representative EEG and EMG waveform changes observed in association with characteristics movements. With type B, the body moved continuously from the onset of the roll-over to the end, without a pause after sliding the waist (36 awake; 20 asleep), whereas with type C, the trunk continuously rolled without any sliding of the waist or pausing (1 awake). In the first night’s measurement, five type A roll-overs, 31 type B, and one type C were identified, and six type A, 25 type B, and 0 type C in the second one ($\chi^2$ test = 1.214, df = 2, $p = 0.545$), indicating no significant difference in the types of roll-over sequences between the first and second measurements. Thus, the total frequency of type A, B, and C sequences was 11, 56, and 1 events, respectively.

Time required by roll-overs

The earliest time that EEG changes were observed was 313 s before a roll-over, but 66 out of 68 (97%) roll-overs fell within 300 s (5 min) of roll-over onset. Therefore, the analysis window was configured to 10 min, to cover the 5 min before and after roll-over onset.

First, we tested for relationships among the respective lengths of time spent in phase I, II, and III in 68 roll-overs. The relationship between phase I and III was significant (Spearman, $r = 0.40$, $p = 0.001$, Fig. 4-1): the shorter phase I was, the quicker re-falling asleep occurred. Second, the type A sequence often accompanied a PBR appeared within 15 s of roll-over onset, interpreted as the roll-over originating in sleep: it was present in 11 type A, 20 type B and 0 type C roll-overs, whereas the PBR was present 15 s or more before onset in 0 type A, 36 type B, and 1 type C sequences ($\chi^2$ test = 16.2, df = 2, $p = 0.001$). Third, focusing on relationships among phase I, II, and III in type A sequences only, a strong relationship between phase I and III was significant (Spearman, $r = 0.78$, $p = 0.005$, Fig. 4-2) was noted, indicating that the shorter phase I in type A sequences was, the quicker re-falling asleep occurred.

Tab. 2 Sleep characteristics.

|                | Max       | Min       | Mean±SD     |
|----------------|-----------|-----------|-------------|
| SPT (h)        | 8.23      | 5.32      | 6.72±0.77   |
| TST (h)        | 6.95      | 4.56      | 5.82±2.36   |
| TRT (h)        | 9.15      | 5.55      | 7.18±1.06   |
| Sleep efficiency (TST/TRT) (%) | 94.80 | 70.00 | 82.78±9.66 |
| Time to fall asleep (min) | 52.00 | 3.50 | 17.96±13.96 |
| Arousal index | 35.70     | 9.10      | 22.63±7.90  |
| REM (%)        | 26.00     | 12.30     | 21.66±3.87  |
| NREM1 (%)      | 37.50     | 8.80      | 18.05±8.23  |
| NREM2 (%)      | 73.70     | 43.20     | 60.30±8.22  |
| NREM3 (%)      | 3.00      | 0.00      | 0.63±0.92   |
| Subjectively reported arousal time (freq) | 5.00 | 1.00 | 2.67±1.07   |
| Duration between two positions (min) | 220* | 68** | 114.75±48.95 |

Tab. 3 Roll-over positions, patterns, and frequencies.

| Body position* | Mean±SD (%) |
|----------------|-------------|
| Supine         | 51.50±5.20  |
| Left           | 23.50±10.63 |
| Right          | 24.08±9.36  |
| Roll-over pattern (n = 143) | Number (%) of roll-overs per pattern |
| 1) Supine to left lateral | 35 (25) |
| 2) Supine to right lateral | 33 (23) |
| 3) Left lateral to supine | 34 (24) |
| 4) Right lateral to supine | 29 (20) |
| 5) - 12) Other patterns | 12 (8) |
| Frequencies    | Mean±SD     |
| Roll-overs per person (range) | 12.08±5.23 (4−21) |
| Roll-overs per hour (in SPT) | 1.76±0.63    |
| Roll-overs per hour (in TST) | 2.04±0.83    |
| Roll-overs per hour (in TRT) | 1.64±0.54    |

SD, standard deviation; SPT, sleep period time; TST, total sleep time; TRT, total recording time. *, counted in frequency (i.e., number of instances in position), and presented in %.

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Tab. 4 shows the mean time spent in phase I, II, and III for type A sequences ($n = 11$) and in type B and C combined.
In addition, when focusing on type A (n = 11) and B (n = 20) sequences with PBR appearance < 15 seconds before roll-over onset, the phase II means of type A and B were 13.18±4.05 and 13.25±3.99 s, respectively, indicating the time required to complete type A and B sequences were similar. However, when the pause-time (1.5-4 seconds) in phase II of type A sequences was subtracted, the mean duration of type A was shorter than that in type B (10.18±3.76 s vs 13.25±3.99 s, respectively).

Because of high variability in BMI in six participants, correlations between it and time spent in phase I, phase II, and phase III were examined: they were calculated as −0.66, 0.20, and 0.66 (Spearman, p = 0.156, 0.704, and 0.156), respectively.

3-3. Discriminant analysis

According to discriminant analysis for types A (n = 11) and B (n = 20) sequences with PBR appearance < 15 s before roll-over onset, the Wilks criterion (0 ≤ λ ≤ 1) was significant (λ = 0.721, p = 0.03). Type A and B sequences
were therefore further examined to determine correct classifications based on time spent in phases I, II, and III. The percentage of correct classifications was 80.6%, with 74.2% cross validation.

4. Discussion

We examined roll-overs performed during sleep in terms of their movement and time-flow sequences. Sleep was
dominated by time in N2, consistent with the prevalence of lighter sleep stages seen in previous studies conducted in laboratory settings\(^1,2\). The proportions of time spent in different body positions, such as supine or lateral, were also similar to those reported previously\(^3\). In previous studies, roll-overs appeared more frequently during REM and light sleep stages than during deep sleep stages\(^1~3\). However, in the current study, the onset of roll-overs always coincided with the appearance of a PBRs or switch to arousal: in other words, and no roll-overs occurred during deep sleep stages.

### 4-1. Roll-over sequences

One of the three types of S-to-L and S-to-R roll-overs that originated in sleep was the type A sequence, characterized by sliding the waist and taking a pause before rolling the trunk. These motions differed from roll-overs performed while awake or aroused\(^14,15\). This pause was seen only in type A sequences, which originated while participants were asleep, although the EEG signal indicated the appearance of a PBR or arousal state until re-falling asleep. Body movements that include a pause, such as intermittent rest during continuous body motions, may synchronize with breathing and contribute to its smooth rhythmic transition, because airflow changes in the nasal chamber occur at the same time as shifting the body position\(^40\).

The body motion of type A sequences may be basically influenced by the thoracolumbar flexion (TCF) angle\(^18\). Lateral body rotation requires that the TCF angle support an adequate range of motion to provide pelvic flexibility\(^3\). A good TCA angle allows the body to efficiently rotate, meaning that type A roll-overs performed during sleep might require less physical effort. Visual inspection revealed that the posture and head and arm motions taken immediately after the sliding motion of the waist were similar to postures resulting from the asymmetric neck reflex (ATNR)\(^41\). In addition, the posture during the sliding motion of the waist was similar to that created by the tonic lumber reflex (LR)\(^42,43\). Thus, these reflexes in cooperation with the TCA angle may operate involuntarily in type A sequences originating in sleep, leading to efficient body movements without wasted efforts that thereby disturb sleep less.

These reflexes are an innate function as they are controlled by the spinal reflex rather than the cerebral cortex\(^26\). Surprisingly, postural reflexes can be induced by manual manipulation in adults\(^41~46\), and their occurrence during arousal have been qualitatively identified\(^47\). Although the LR or ATNR is usually latent in healthy adults, movement with postural reflexes may be involuntary incorporated into normal body movements during sleep, as these reflexes work unconsciously to reinforce body movement in athletes, or to enhance equilibrium in morphologically unstable postures in daily activities\(^42\).

A previous report has shown that roll-overs are assisted by a righting reflex action that relocates the body back to the

### Tab. 4 Phase I-II-III durations for three roll-over types.

| Type  | Phase I (s) | Phase II (s) | Phase III (s) |
|-------|-------------|--------------|---------------|
| Type A (n = 11) | 8.64 ± 4.70 s | 52.97 ± 73.78 s | 13.18 ± 4.05 s |
| Type B (n = 56) | 13.18 ± 4.05 s | 13.56 ± 8.73 s | 43.09 ± 33.52 s |
| Type C (n = 1) | 43.09 ± 33.52 s | 104.26 ± 102.78 s | 104.26 ± 102.78 s |

SD, standard deviation. I, time spent arousal before roll-over onset; II, time required for roll-over sequence; III, length of time from the end of the roll-over to the onset of re-falling asleep.
original place on the bed during sleep; thus, healthy adults seldom fall down from the bed during a roll-over while asleep. Such reflexes may play an involuntary role during roll-over sequences performed unconsciously as a habitual behavior. In addition, while trunk stability, which is assisted by abdominal and back muscles, may significantly decrease during long bed-rest, postural reflexes working with those muscles might be maintained due to the innate function controlled by the spinal reflex. Thus, type A sequences may be helpful for elderly patients with less muscle volume due to bed rest or immobilization.

4-2. Time required by a roll-over

A positive relationship between phases I and III was identified, indicating that re-falling asleep occurred promptly if the duration of PBRs before onset of roll-over was short. The relationship between the phase I and III of type A sequences was particularly strong. Because the PBR does not last very long, leading to quick re-falling asleep in type A roll-overs, sleep interruption may be minimized by shortening the time a person is exposed to environmental stimulation, which can facilitate the descent from NREM sleep into deeper sleep stages. Type A sequences were considered to have originated in sleep, a consideration reflected by our setting the PBR cutoff at 15 s before roll-over onset. Surprisingly, type A sequences analyzed using a 1-s window showed a pause that lasted for a few seconds after sliding the waist to the contra-lateral side prior to the body turning laterally from the supine position. The major difference between type A and B sequences with PBR appearance less than 15 seconds before roll-over onset was the pause. Such an intermittent rest, a so-called “move-rest-move” sequence, created by a type A roll-over may differ from the continuous motion created by type B and C roll-overs. This pause may also instantly reduce the physical effort required and provide explosive power to the foot that presses against the bed surface to turn the trunk. For further discussion on such mechanisms, the influence of the leg’s motion on the sliding of the waist should be further studied because the lower limbs exert great effort in pushing against the floor, influencing the speed of the roll-over motion. The significance of the pause in type A roll-overs should be examined further with regard to its mechanisms.

Participants had similar workloads, or routine levels of activity, so it was unlikely to have been associated with individual differences in roll-over movements and timing. BMI was highly variable, and correlated negatively with time spent in phase I and positively with time spent in phase III. In other words, compared to women with low BMI, women with high BMI tend to spend more time asleep before roll-over onset, and to take more time until falling asleep again. However, the interpretation of these correlations warrants caution, as they were not statistically significant: they should be checked in a larger sample to confirm.

4-3. Discriminant analysis

To determine whether type A roll-overs originating in sleep can be reasonably discriminated from others based on the time spent in phases I, II, and III, we performed discriminant analysis for type A (n = 11) and B (n = 20) sequences where a PSG appeared < 15 s before onset of roll-over. Our classification scheme’s performance—80.6% correct classification with 74.2% cross validation—may be a reasonable classifier, comparable to the 80.4% rate reported by Okamoto and Harasawa. Thus, to increase sleep quality by minimizing sleep interruption, type A roll-overs with sliding of the waist and a pause may effectively allow people to continue to sleep undisturbed. In addition, type A roll-overs can be identified by visual inspection, thus provided a visual cue about the most appropriate time to perform an intervention.

4-4. Study limitations

Because this study was conducted in a laboratory setting, the dominance of the lighter sleep stages may not be representative of normal sleep in a home setting. Measurements recorded during the first night were included in the analysis after confirming acceptably high ICCs. Although we did not control for first-night effects, we proactively attempted to minimize potential bias by 1) randomly assigning comfort mattresses across the two nights of measurements, and 2) creating similar conditions between the first and second laboratory measurements, with participants sleeping at home prior to the night measurement at the sleep laboratory. The findings of our qualitative and quantitative analyses suggest a new insight concerning roll-overs during sleep, but the generalizability of our findings is limited because of the small sample size and homogeneity in participants.
5. Conclusions

Type A roll-over movements may involve efficient motions and quick re-falling asleep that minimize sleep discontinuation. These motions could be used in the form of a self-helped roll-over maneuver by elderly patients: with daily practice, they may be able to execute this roll-over sequence involuntarily during sleep.

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