Classification of windswept posture in daily life using tri-axial accelerometers

Haruhiko Sato[1] and Takenobu Inoue[2]

[1] Kansai Medical University, Faculty of Rehabilitation, Hirakata, Japan

[2] National Rehabilitation Center for Persons with Disabilities, Tokorozawa, Japan

Correspondence: Haruhiko Sato, PT, PhD
Kansai Medical University, Faculty of Rehabilitation,
18-89, Uyamahigashimachi, Hirakata, 573-1136, Japan
E-mail: satohar@makino.kmu.ac.jp
ORCID: 0000-0002-1744-2388
Phone: +81-72-856-2251
Fax: +81-72-856-2150

E-mail address of co-authors

Takenobu Inoue: inoue-takenobu@rehab.go.jp

Declarations

Competing interests: The authors report no declarations of interest.

Ethics approval: All procedures in this study that involved human participants were performed following the ethical standards stated in the 1964 Declaration of Helsinki and its later amendments. This study was approved by the institutional ethics committee of Kitasato University (B17-014).

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Abstract

An asymmetric windswept posture is often seen in children with severe cerebral palsy (CP). However, it is still unclear how long children with CP remain in the windswept posture in daily life. Thus, we developed a triple-accelerometer system for detecting windswept posture. The aim of this study was to assess the validity of a system for classifying various body postures and movements. We assessed the accuracy of our system in 9 healthy young adults (age range, 21-23 years). The participants wore acceleration monitors on the sternum and both thighs, then spent 3 minutes each in 8 different positions and 3 physical activities. Once accuracy was confirmed, we assessed the posture and movements for 24 hours in 6 healthy young adults (age range, 21-23 years) in their home environments. The body postures and activities were correctly detected: the agreement across the subjects were 100% compatible with the subjects' activity logs at least 68% of the time, and at least 96% of the time for recumbent positions. We concluded that the proposed monitoring system is a reliable and valid approach for assessing windswept hip posture in a free-living setting.

Keywords: Windswept posture, accelerometer, 24-hour monitoring.

Introduction

Cerebral palsy is defined as a disability of posture and movement originating from damage that occurred to the immature, developing brain.[1] Generally, no structural abnormality is apparent in the trunk or extremities at the time of birth.[2, 3] Problems can arise during postnatal development, and in more severe cases, deformities such as windswept hips can occur. This condition is characterized by both knees being flexed, one hip being abducted and externally rotated, and the other hip being adducted and internally rotated.[4] These deformities gradually become more pronounced over time.[5, 6]

Although windswept hips are facilely attributed to bilateral asymmetry of centrally induced muscle tone, loss of selective motor control, and muscle imbalance,[7] the environmental factor of remaining in asymmetrical recumbent postures for prolonged periods, due to poor ability of the child to move about spontaneously, should be given earnest consideration.[8, 9] Certainly we realize that a child with severe cerebral palsy remains in the same body configuration for extended periods when sleeping,[10, 11] but we lack definitive information on the nature of such periods. A serious approach to preventing or dealing with windswept hips would substantively benefit from detailed objective information on when such a posture is assumed during a 24-hour period and how long it is maintained each time. Among other things, such information might suggest which positioning procedures are effective and the timing of such procedures.

We have previously used triaxial accelerometry to examine body positions, including in children with cerebral palsy.[11-13] We are now developing a system of three accelerometers, one on the thorax and one on each thigh, designed to distinguish the windswept-hips position amongst other body configurations, by determining the angular orientation with respect to gravity of the body part to which each accelerometer is attached. This report details a preliminary investigation on accuracy and validity of this simple noninvasive system when applied to healthy young adults.

Methods

This study was approved by the Institutional Review Board of the School of Allied Health Sciences at Kitasato University (approval number 2016-028), and written, informed consent was obtained from all participants.

Identifying positions and activities

We identified positions involving the hip joints on the basis of information culled from three accelerometer logging units, attached to the thorax and to both thighs (Supplemental figure 1). Each logging unit was an AccStick (Techno Next, Chiba, Japan), weighing 6 g and 33×16×10 mm in dimension. The thoracic logging unit was placed over the sternum. The logging unit for each thigh was placed 5 cm proximal to the patella, along a line from the anterior superior iliac spine to the middle of the superior edge of the patella. The unit was attached to the skin with double adhesive tape and reinforced by covering it with 3M™ Medipore™ +Pad 6×10 cm tape (3M Company, Maplewood, MN). Under the control of a personal computer, data were collected from all three logging units at 2 Hz and subsequently transferred to a storage device. Based on the acceleration information that each logging unit contained, the body segment to which it was attached could be classified as being oriented vertically or horizontally and, if the latter, as facing upward, downward, rightward, or leftward (Supplemental figure 2).[13] Each of these orientations covered a range of 90 degrees. Particular combinations of the orientations of these three segments yielded assertions about how the body as a whole was positioned (Supplemental table 1).

Eight fundamental positions were judged to cover static body configuration quite comprehensively over the course of an ordinary day: right and left windswept-hips positions, prone, supine, right and left sidelying, seated, and standing. In children with cerebral palsy, the windswept-hips positions may occur due to differences in muscle tone between the left and right sides. The participants in this study were healthy individuals and did not have windswept-hips deformity, so they were asked to lie on their backs with their knees bent at 90 degrees. Then, we instructed them to relax and lean their legs to the right or left to demonstrate the windswept-hips position. This posture can be achieved not only through the adduction of one hip joint and abduction of the other side but also through rotation of the spine. It's worth noting that our definition of the windswept-hips position slightly differs from the Person-Bunke definition.[4] We defined it as the position between the trunk and the thighs because our aim was to assess the left-right asymmetrical posture in daily life. The right windswept-hips position was asserted, for example, if the thorax was horizontal and facing upward while both thighs were horizontal and facing rightward (Figure 1).

Two other positions were added as tests to see if judgment of fundamental positions might be confounded. The supine position was assumed with the knees flexed slightly and directed outward. And the seated position was assumed on the floor with the legs crossed.

In addition, to distinguish whether or not the body was in motion, we used the Euclidean norm minus one (ENMO) of the resultant acceleration of the thoracic logging unit as a criterion.[14] The ith instance of the resultant r(i) of accelerations in the unit's x, y, and z directions was calculated as

$$\mathrm{r}(i) = \sqrt{x(i)^2 + y(i)^2 + z(i)^2}\text{-}1$$

with the peak range of amplitude p(i) determined over the surrounding two seconds as

$$\mathrm{p}(i) = \mathrm{Max}\big(\mathrm{r}(j)\big) - \mathrm{Min}\big(\mathrm{r}(j)\big), j = i-2, i-1, \ldots, i+2$$

The p(i) values (Figure 2, middle panel) were grouped into 20 successive 3-second averages for each minute of data collection. Each 3-second average was classified into one of four levels of movement: still (0-0.05 mG), slight (0.05-0.3 mG), intermediate (0.3-0.7 mG), or vigorous (> 0.7 mG). The most frequent of these four levels over a given minute characterized the level of movement in that minute.

If the thoracic logging unit indicated at least slight activity during a given minute while the body was judged to be in a sitting position, that minute could be interpreted as wheelchair motion or riding a bicycle. Similarly, if the thoracic and both thigh logging units all manifested at least slight activity over a given minute while the body was judged to be in a standing position, the body was regarded as probably engaged in walking or brisker activity. All of the recumbent positions, on the other hand, were assumed to be static. These determinations were made through programming with the aid of Matlab (Mathworks Inc, Natick, MA).

Accuracy of distinguishing among positions and activities

The accelerometer logging units were affixed to the thorax and thighs of nine healthy university students (eight men and one woman, 21-23 years old). Each subject was instructed to assume nine static positions and perform three dynamic activities. The subject maintained each position or activity for three minutes, the order of which was randomized. The static positions were seven of the eight fundamental positions (standing was removed) plus the two test positions described above. The dynamic activities were wheelchair propulsion, walking, and going up and down stairs. Since each position or activity was three minutes long, data collection lasted 36 minutes. Accuracy was assessed in terms of the percent time of the accelerometer system’s judgment agreeing with the subject’s actual position or activity.

Validity of distinguishing among positions and activities

Six healthy male university students (21-23 years old) each spent a 24-hour period with the three accelerometer logging units attached, going about the day in a usual manner. Once downloaded, the data were processed to identify occurrences of the eight fundamental static positions as well as both seated and standing dynamic activities. Figure 3 provides an example of these positions and activities in the context of everyday functions. The subject also provided brief narrative descriptions, to the nearest minute, of activities he was performing during data collection, such as sleeping at home or riding on a train.

One investigator reviewed the narratives of all six subjects and organized their descriptions into three categories: recumbent (e.g., sleeping), seated (e.g., studying, eating, watching television), and active (e.g., commuting, shopping, moving around at home). Total time in each of these categories was determined for each subject. Judgments rendered by the accelerometer system during the 24-hour collection period were likewise lumped into three categories. The windswept-hips, supine, prone, and sidelying positions were categorized as recumbent. Static sitting was categorized as seated. Standing and the dynamic activities were categorized as active. For each subject, percent agreement was calculated as the ratio of accelerometer time in a given category that was in concordance with the corresponding narrative category to the total time of that narrative category.

Results

In the accuracy series, all of the fundamental static positions and dynamic activities could be identified with an average sensitivity of 98.9% and an average specificity of 99.9% as depicted by the example in Figure 2. Whenever the windswept-hips position was assumed to either side of the body, the accelerometer system was able to detect it without fail and with no false positives. This complete agreement prevailed in all nine of the subjects.

In the validity series, through the course of a day the windswept-hips position was seen sporadically at bedtime. In one subject, for example, the total amount of time in the windswept-hips position to one side or the other was 93 minutes, with the longest continuous instance lasting 29 minutes (Figure 3). Among the six subjects, the average total time spent in the windswept-hips position was 76 minutes (range from 8 to 179 minutes), with the longest continuous instance averaging 19 minutes (range from 7 to 29 minutes). Category determined from the accelerometer system agreed with the category of activities self-recorded by each subject an average of 98% (range of 96% to 100%) of the time for recumbent positions, 74% (range of 68% to 82%) for seated positions, and 78% (range of 68% to 90%) for dynamic activities (Table 1). Thus the accelerometer system indicated quite accurately when the subjects reported that they were lying down, and otherwise correctly asserted the nature of the subjects' alleged activities at least 68% of the time.

Discussion

The findings in this investigation suggest the feasibility of accurately monitoring body configuration, including the windswept-hips position, throughout the day and as well as at night.

Accelerometer loggers have frequently been used to assess number of steps taken or quantity of activity performed spontaneously in daily life.[15] More recently, as long periods of being seated or of engaging in activities while recumbent have been found to be deleterious to health,[16] efforts have been made to use accelerometers to quantify activity and identify postures.[17-20] Using one accelerometer unit on a person's back and another on one thigh, Stewart et al.[18] devised a system that could distinguish among recumbent, seated, and upright positions with 99% accuracy. With accelerometers on the thorax and both thighs, we achieved 100% accuracy in our laboratory conditions in distinguishing amongst numerous recumbent postures in addition to sitting, standing, and dynamic activities. We believe that the system we fabricated can be further developed into practical instrumentation for clinical use.

The windswept-hips position could be identified in all six healthy subjects of the validity series, the total time in that position ranging from a few minutes to three hours. It tended to be interspersed with other positions rather than continuously maintained, as illustrated by the example in Figure 3. Although the windswept-hips position may be viewed with concern in children with relatively severe cerebral palsy, it quite likely occurs also in healthy children when they are relaxed during sleep. A child with cerebral palsy may have more trouble getting out of the windswept-hips position, so would likely stay in that position for relatively long periods, potentially acquiring a veritable deformity.[11]

As a technical consideration, the healthy college students in this study provided large thighs on which to place the accelerometer logging units. For a baby or for a child with cerebral palsy, placing the unit on a small or thin thigh in such a way that it maintains a given orientation may not be easy. A consistent spatial orientation of the device in relation to the body part to which it is attached is essential for the system to work properly. This problem may require further study.

The accelerometer logging system introduced here has been designed to reliably and objectively provide information about posture that has thus far depended on narrative description.[8] Such description is usually obtained from a guardian or caregiver, who cannot be expected to provide detailed information on sleeping position, particularly at night. Our method can change all that. While the child with cerebral palsy and caregiver are sleeping, the accelerometer instrumentation can record in minute-by-minute detail when asymmetrical postures are assumed and for how long. Such basic information would surely be useful for preventing or dealing with postural deformities.

This study has provided evidence that a system using three acceleration loggers can accurately determine the postures of healthy adults, including the wind-swept posture. Our next objective is to utilize this system to assess the frequency and duration of wind-swept hip positions in children with cerebral palsy during their daily activities and compare them to children with typical development. Though we have not yet demonstrated the system's ability to precisely identify postures in children with cerebral palsy and those with typical development, we will validate the reliability of our system by analyzing the data collected from these children.

In conclusion, information from accelerometer logging units placed on the sternum and both thighs makes it possible to identify the windswept-hips position and other body configurations. With this method, hip position can be monitored around the clock, in the midst of daily and nocturnal activities in the life of a child with cerebral palsy. This may be useful for preventing deformity.

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Table 1. Minutes self-estimated to be recumbent, seated, or active and agreement with that category by accelerometer system

Subject	Recumbent Minutes	Recumbent Agree	Seated Minutes	Seated Agree	Active Minutes	Active Agree	Record off (minutes)	Overall agreement
A	478	98%	648	82%	290	74%	24	85%
B	416	100%	571	75%	389	68%	64	81%
C	678	96%	571	71%	119	90%	72	86%
D	394	99%	463	68%	506	81%	77	83%
E	437	99%	782	71%	148	81%	73	84%
F	442	97%	598	78%	372	76%	28	84%
Mean	474	98%	606	74%	304	78%	56	84%
SD	104	2%	106	5%	149	8%	24	2%

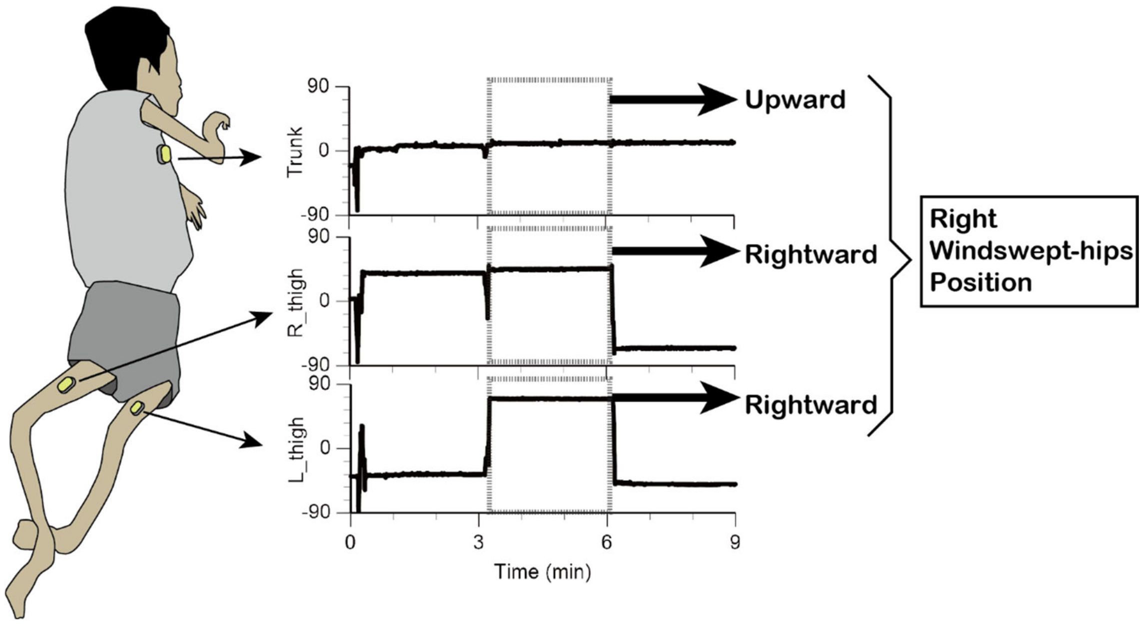

Figure 1. Illustration of how the body was positioned as a whole based on the acceleration information from the loggers attached to the trunk and the thighs in a child with windswept hips. Data from the trunk, the right and the left thigh were derived from calculated angle of the y-axis in the horizontal plane. In this illustration, the windswept-hips deformity is to the right.

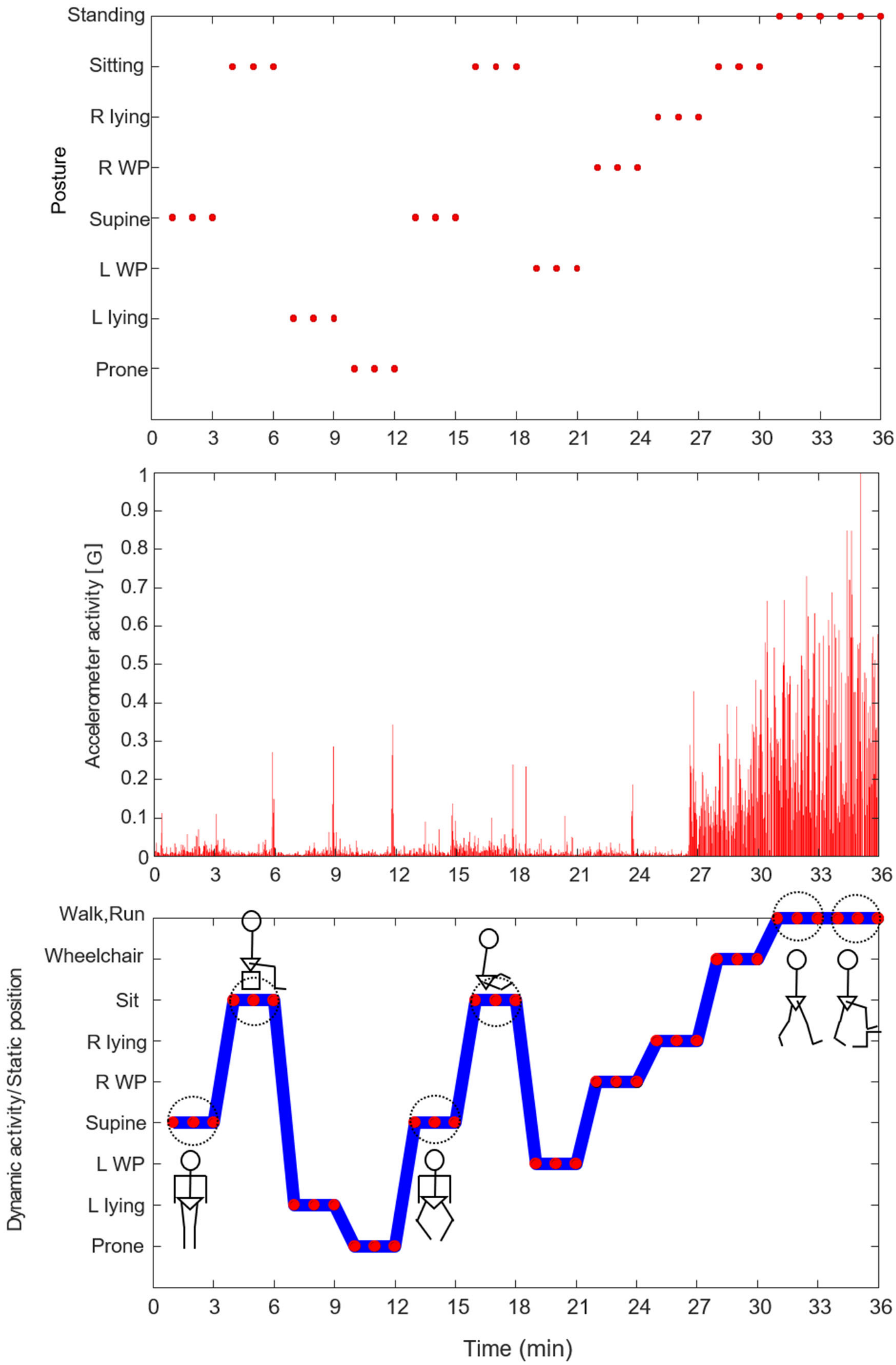

Figure 2. Synchronized histories, in one subject of the reliability series, of posture (top), accelerometer activity (middle),

and correspondence between requested positions and activities and their identifications by the accelerometer system (bottom). WP: windswept-hips position. Blue band in bottom panel indicates requested sequence; red dots in bottom panel are identifications by the accelerometer system. Dot-circled instances, showing that variations are classified correctly, are, from left to right, fundamental supine, fundamental sitting in a chair, supine with flexed knees outward, sitting cross-legged, fundamental walking, and going up and down stairs.

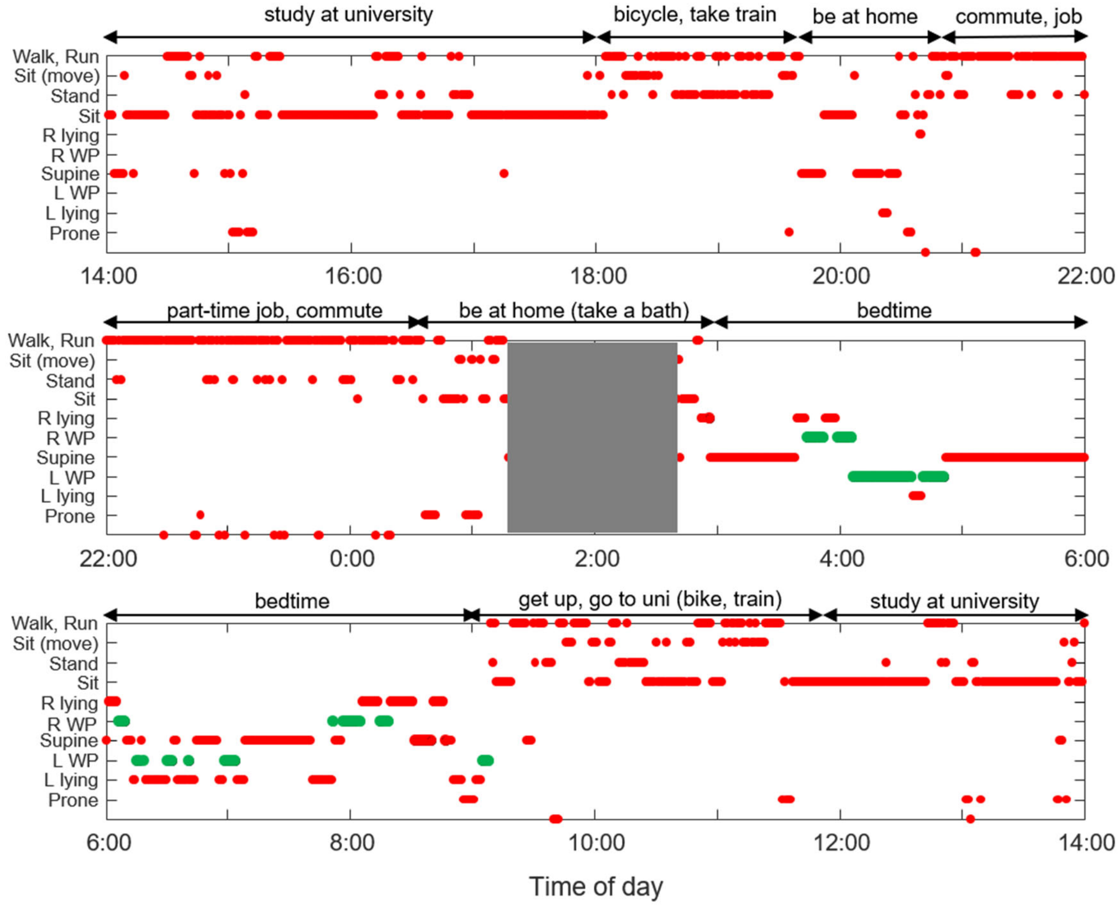

Figure 3. Full-day recording of one subject. Ordinate shows which position or activity was identified. Situations described across top are self-recorded. Windswept-hips positions (WP, in green) occupied 93 minutes of sleeping time. Gray block indicates when accelerometer logging system was off. Bottommost marks in each panel indicate undetermined positions.

Graphical abstract