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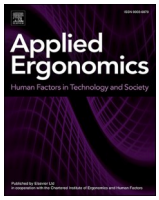

How do we sleep? Towards physical requirements for space and environment while travelling

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ABSTRACT

To establish guidelines for sleeping space in vehicles, the sleeping postures of 189 participants are studied, 105 of them were asked to take the position in which they fall asleep and 84 have been asked to assume the position in which they lie most of the time. Seven percent slept on the stomach, 19% on the back and 74% on the side and 49% slept on the side with both legs flexed. For all participants a bed size of 200 × 90 cm will do. It is discussed that for one night while travelling a bed size of 171 × 76 cm might be sufficient as it results in a reasonably good sleep according to another study and in almost half of the cases in this study people sleep on the side with both legs folded. Apart from the sleeping space for a good sleep, attention is needed for a dark environment with a good temperature and relative silence.

1. Introduction

Passengers want to sleep while travelling. Eighty percent of the aircraft passengers like to sleep on long haul flights (Bouwens et al., 2018), sleeping is among the top four activities observed in trains (Groenesteijn et al., 2014) and occupants of automated driving cars like to spend a part of their time sleeping as well (Wilson et al., 2022). However, sleeping in vehicles has some downsides due to space restrictions. Sleep facilities in vehicles (such as aircrafts, trains, busses, ships, submarines, (automated) cars) often have a limited space due to vehicle design, economic and/or operational reasons (Smulders, 2018; Stanglmeier et al., 2020). For the future self-driving car, a dimension of 191 × 66cm is reported by Caballero-Bruno et al. (2022). The dimension of a navy rack is 182 × 76 cm (https://www.fleetsheets.com/blogs/ship-rack/what-size-bed-is-a-navy-rack, August 1st, 2024). Sleeper trains in Europe recorded by Out (2024) are for instance 174 × 66 cm, 183 × 70 cm and 200 × 75 cm and in business class aircrafts dimensions could be 188 × 66 cm and 208 × 53 cm (https://suitesmile.com/blog/2020/05/09/business-class-beds-visualised/, August 1st, 2024). The question is if these dimensions are large enough to facilitate postures to have a comfortable sleep. People do like to sleep as people can feel recovered after sleeping while travelling and this might be a way to spend the time effectively in order to arrive rested. This might be one of the reasons why business class travellers are willing to pay more as they have the privilege of a good sleep, partly due to a full-flat bed, which was introduced in the airline industry in 2000 by British Airways and followed by many airlines.

There are more environments where there is a restricted space for a sleep, like in submarines, ships, busses, crew rest areas and micro hotels. Of course, many aspects of sleep and dreaming have been studied extensively (De Koninck et al., 1983). There are minimal standards for sleep facilities in safety critical environments such as aircrafts (Simons and Spencer, 2007), but no guidelines exist on minimal sleep space envelopes in relation to sleep comfort. To establish guidelines, it might be helpful to estimate the bodily positions assumed during sleep and the dimensions needed to facilitate these sleep positions. This received little attention in the scientific literature.

De Koninck et al. (1983) studied the body postures while sleeping. They observed 200 participants and used only 16 participants for deeper analysis. Also, the study is more than 50 years old, but still relevant of course. The BBC reported on body postures (BBC, 2003). However, the source and number of participants is not known. More recently, Skarpsno et al. (2017) studied sleep positions and movements with the use accelerometers, 363 men and 301 women were tested. They reported: '*During their time in bed, participants spent 54.1% (SD 18.1%) in the side position, 37.5% (SD 18.2%) in the back position, and 7.3% (SD 12.3%) in the front position. Increasing age and BMI were associated with increased time in the side position and a proportional reduction in time in the back position*'. There is some research on the effect of the backrest angle on the quality of sleep. Roach et al. (2018) studied the sleep quality of

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six subjects while lying on a flatbed (180°). Nicholson and Stone (1987) studied nine participants. Aeschbach et al. (1994) studied 11 participants lying flat. Caballero-Bruno et al. (2022) tested sleep in a 177° backrest angle (almost flat) while driving in a van in a laying on the back position. In all these studies no data on the needed space was given, which is very relevant for a bed design. Smulders and Vink (2021) presented data on dimensions using 41 participants. They slept in three different conditions: night 1) in their normal bed space, night 2) in a limited space (170 × 70 cm), and night 3) in a minimal space which the participant could design themselves. Night 2 was rated least comfortable, where night 1 was most comfortable. However, no significant difference in sleep quality and sleep effectiveness between the normal bed (night 1) and the minimal space designed by the participant (night 3) were found, although space on average was reduced by 25%.

Most beds in Europe are 90, 100 and 120 cm wide for single beds and 200 cm long (Consumer Media, 2019). For areas with restricted space this is too much as it is economically not feasible, but it is unknown what is really needed for a comfortable sleep. This paper aims to gather information on the space people need in areas where the space is limited to support designers and engineers of those areas in designing beds in restricted spaces. This study also gathers information on other environmental requirements needed for a good sleep while travelling.

2. Research questions

What physical space do humans use while sleeping and which environmental conditions do also play a role for humans to have a good sleep while travelling?

3. Methods

3.1. Participants and protocol

To answer the research questions two studies were performed. One study consisted of asking 75 students as part a master course to take a position on their bed in which they normally get to sleep and measure the dimensions in x-axis (width of the bed) and y-axis (length of the bed) of their body. The measurement was done using a measuring tape or using the smart phone. They were also asked to put a camera or smart phone on the ceiling and take a picture of themselves in that posture and send it in. They were also asked to measure and follow the same procedure using someone else, preferably an older person. Adding elderly was done as much data in the literature are based on the age category of students. Additionally, they were asked to complete the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) for themselves and let the other person complete it. Also, a questionnaire was added with general information on gender, body height and age and there were three open questions in which they were asked to write what will hinder them if they want to sleep in a car, train or airplane. For each type of travel, they had to answer this open question. This had to be completed by the participant and the other person that was invited to participate.

The experimental setup and the protocol were approved by the Human Research Ethical Committee (HREC) of Delft University of Technology and consent forms had to be signed by all subjects. In the consent form there was the option to opt out. No reason had to be given for opting out and no effect on the grade for the course was ensured as assignments were given a score before checking the consent form.

In the second study an additional group of 105 students was approached and asked to record themselves during sleep with a camera on the ceiling. They were asked to use a timelapse system, which records every 10 or 15 min as checking a complete video of 8 h would take too much time and send in a picture of the most seen posture. Additional information was asked regarding gender, body height and age as well. This part was approved as well by the HREC of the TU-Delft and an informed consent was used as well.

All data were stored on a secured TU-Delft server and data are only accessible by the TU-Delft researchers involved in the study and staff/teachers of the TU-Delft involved in the course. An overview of the data is available at https://data.4tu.nl/. The body height of the participants is not given in the data base but categorized to prevent that individuals can be traced.

3.2. Data analysis

All x-axis and y-axis data will be put together in one graph and all pictures were observed by two persons and categorized in: 1. lying on the side with two legs bended; 2. lying on the side with one leg bended, 3. lying on the side with two legs stretched, 4. lying on the back and 5. lying on the front (stomach). Three times differences were found between the two observers (all considering the situation: both legs stretched or bended; after discussing it was decided to classify these three as bended, as the legs were not completely stretched).

Differences between situations were tested using the *t*-test ($p < .05$). It was assumed that elderly stretch more, therefore it was tested whether the elderly group (older than 35) needed more length (more y-axis). Also, it was assumed that the laying in the side would give a higher PSQI score than the one observed sleeping on their back as De Koninck et al. (1983) state that poor sleepers spend more time on their back. It was also tested if elderly take other positions than the younger persons as Skarpsno et al. (2017) found more side sleepers among older persons.

4. Results

In the first study, out of the 75 students 52 did sign for opt in and were able to find a second person. So, the first study consisted of 104 participants of which 30 participants were in the age between 40 and 67 years old (average 57 (STD 5.5); average body height 173 cm (STD 9.8; 16 male, 14 females; 32 Asian; 68 European and 4 from other countries). The other (younger) 74 participants had an average age 24.6 years old (STD 2.9; average body height 173.8, STD 10.8; 32 males; 41 female and 1 other). No significant differences could be found between the younger and older group regarding, sleep posture, length needed and PSQI scores. Also, between the back laying posture and side ward sleepers no significant difference in PSQI could be found.

Between the side sleepers and back sleepers there was a significant difference in bed length ($p = .0001$; $t = 4.16$). The participants sleeping on the side needed on average 1.60 m (STD 0.189) on the y-axis and those sleeping on the back 1.78 m (STD 0.113). In Fig. 1 all data on the space needed on the x-axis and y-axis are shown. 95% of this population fits within .88 × 1.9 m in this posture. If we take the size of 1.70 × .76m of Smulders and Vink (2021) 39% would fit in this posture. If we take the persons lying on the side with both legs flexed and exclude the persons with their arms above their head for this group a space of 1.71 × 0.88 m would do (see Fig. 2)

In Fig. 3 the data in the answers to the open questions are shown. These results are estimates of the participants as it is unknown how much experience the participants have while sleeping the car, train or airplane. Noise/sound is mentioned most in hindering a good sleep, especially in the train this is seen as a problem. In the car, movement is mostly mentioned as an issue hindering a good sleep. One participant mentioned “frequent cornering and shaking disturbs sleeping”. Space prevents sleeping in the airplane and often leg room is reported as the cause. Temperature is mentioned also frequently. One participant mentioned “cold feet hinder sleeping” and another “it’s too hot in the airplane”. In the car there is no issue with other people, but in the train and airplane talking from other people or people passing by is seen as a problem. Smell is also mentioned as a problem in the train, like “smelly food” or “passengers not smelling well”. Light is often too bright for a good sleep and in posture/position it is mentioned that sleeping while sitting upright is a challenge.

In the second study 105 participants were invited. They used a time lapse of every 10 min (59) and 15 min (40) and in some cases (6) a

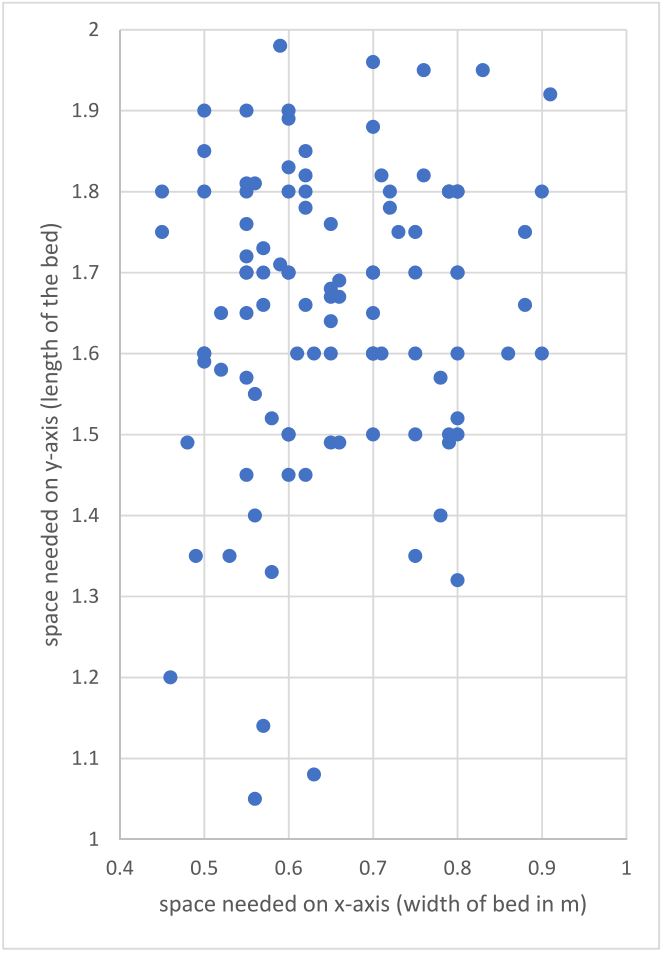


Fig. 1. Data on space needed by the 104 participants in the position when they go to sleep.

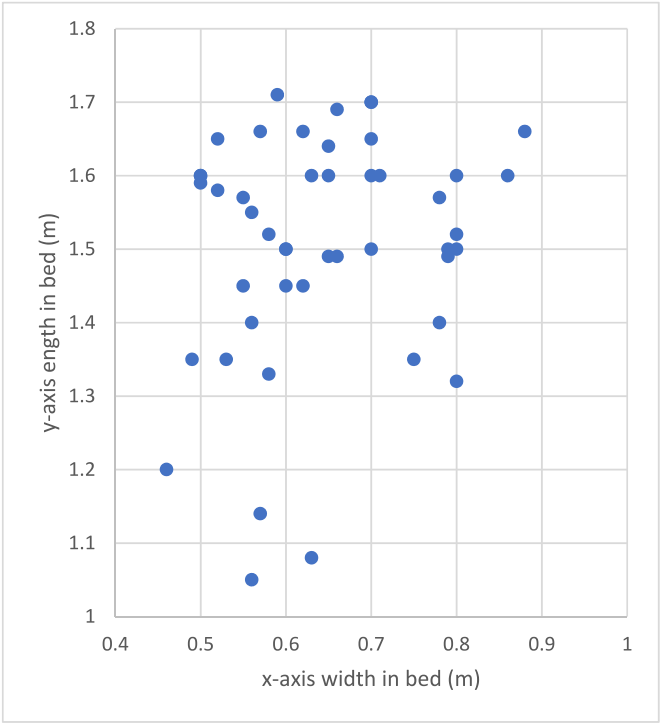


Fig. 2. The space needed by the persons lying on the side with both legs flexed (the 3 with their hands above the head are excluded, n = 48).

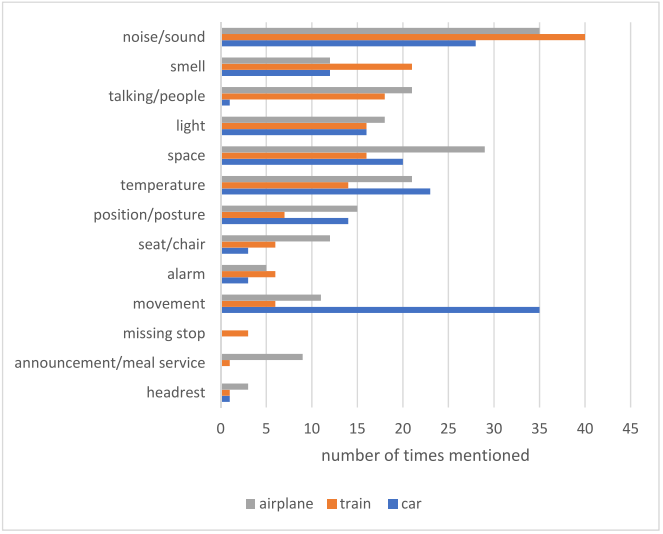


Fig. 3. Counted topics found in the answers to the question "which factors could disturb your sleep in an airplane/train/car ". Data from the answers to the open questions.

camera which takes a picture every 10 min (2) or every 15 min (4). However, in 20 cases participants were not able to define the posture which is seen the most as the bed sheet and blanket or duvet blocked the view too much in combination with a dark environment. Out of the 105, 85 did report the most common posture. Also, 6 out of these 85 reported that they estimated the posture and send in a drawing of what might have happened under the duvet (see Fig. 4). The rest did send in a picture (see Fig. 4).

The average age of the 85 participants of the second study was 23.3 (STD 2.25) year and the average body height was 172.9 m (STD 9.23; 20 males participated, 64 female and 1 other; 13 Asian; 71 European and 1 from another country).

The postures in bed are shown in Table 1. The most frequent observed posture is on the side with two legs bended followed by on the side with one leg bended and one leg stretched. If we combine all lying on the side situations, this is observed 74% of the cases. The third most observed posture is lying on the back (19%). There are not many differences between the two studies as can be seen in Table 1. Perhaps lying on the back is a bit less observed when comparing the most frequently seen posture with the getting to sleep position (13% vs 19%).

5. Discussion

Regarding the question what physical space humans need to sleep, a bed size of 200 × 90 cm is safe if we want to give the space to 100% of the population of this study. However, in the study of Smulders and Vink (2021) no significant differences in sleep quality and sleep effectiveness between the own bed and a smaller space designed by the participant were found. This space on average was reduced by 25% (which was in their study a space of 166 × 76 cm). The 48 participants in our study lying on the side with both legs flexed needed 171 × 88 cm. Approximately half of our participants took this position. So, a bed length of 171 cm would do for half of the participants in this study and will give a reasonably good sleep according to the study of Smulders and Vink (2021). If we use DINED.nl and estimate the hip angle on the side at 45° and the knee angle at 90°, the body height of p95 Dutch population 20–60 years would be (sitting height + $\sqrt{(\text{popliteal height}^2 + \text{buttock knee depth}^2)}$: 169 cm. The Dutch are relatively tall, so a bed length of 171 mm would accommodate sideward sleeping with two legs flexed to

Fig. 4. Example of a drawing (left) and a picture (right) that was submitted by the participants.

a majority of people. The width of their bed in this position was in this study mostly determined by the position of the arms. Some even stretch one of the arms in the x-axis direction. The majority fits within the 76 cm determined by Smulders and Vink (2021).

The conclusion from this study is that for the perfect sleep for everyone a bed of 200x90 is needed, but for half of the population of this study 171x76 might do and for the total population this gives a fairly good sleep based on the study of Smulders and Vink (2021). For vehicles where the sleeping space is limited and where people only spend one night this might be a good solution. Comparing this with a navy rack the width seems just sufficient, but for the smaller train beds, car bed and business class flat beds mentioned above, the 66 cm width could be a problem for a comfortable sleep.

The assumption that laying on the side would give a higher PSQI score than the one observed sleeping on their back was not affirmed in this study as no significant difference could be found, while De Koninck et al. (1983) stated that poor sleepers spend more time on their back. Perhaps a larger sample is needed to support this statement or PSQI might not be sensitive enough and more objective measurements like ECG are needed.

Also, the finding of Skarpsno et al. (2017) that older people lay more on the back is not found in this study, but perhaps the sample size in our study is too small.

Comparing the sleeping postures of this study to those of De Koninck et al. (1983) and data published by the BBC (2003), there is some similarity (see Table 2). Most people sleep on the side. However, De Koninck et al. (1983) reported more front and back sleeping positions. They recorded the mean percentage of time spent in two nights, which might have caused the difference. The results of our study show more similarities with the BBC data that were gathered by Idzikowski. However, the scientific base for this study is not described, which makes it hard to compare. In all studies it is clear that almost half of the population sleeps sideward with both legs folded. Skarpsno et al. (2017) recorded more time sleeping on the back and less on the side. This could be due to the self-reporting in our study. However, the BBC data show even lower on the back sleeping percentages, but it should be mentioned that the total in the BBC data is 89%, which means there are positions not reported.

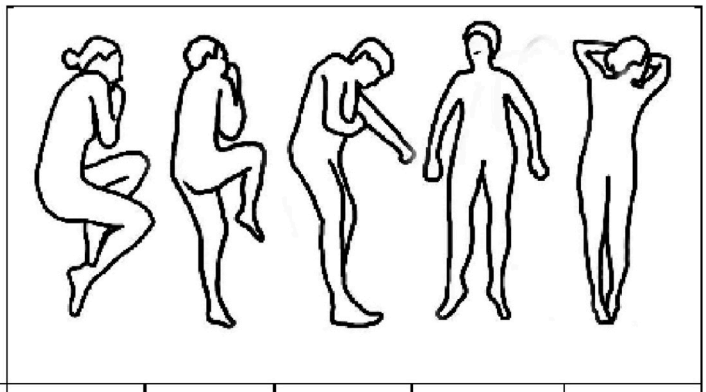
Previous studies also stress other factors important for a good sleep. He and Vink (2020) report that factors like privacy, hygiene and neighbours play a role in having a good sleep. Privacy was also mentioned by Kantelaar et al. (2022) in night trains. Also, in this study other persons are mentioned as a disturbing factor for sleep. Bouwens et al. (2018) describe that apart from the physical factors of fitting in the aircraft seat, factors like noise, temperature, light, smell and vibration influence the comfort during sleep as well (presented in the order of importance). These factors are mentioned by our participants as well, except for vibration. Perhaps a part of the vibration is in the category 'movement' mentioned by our participants. Vledder et al. (2023) did mention that movement in the form of Jerk could be an influential factor on sleep in a night train 'It was found that for sleeping comfort and quality, vibration, vehicle speed/movement, and noise levels on sleep should be balanced, and abrupt changes in any factor, e.g. jerk or distinctive sounds should be avoided'. Also based on this research, it should be mentioned that vibration doesn't need to be negative it can also help in the sleep onset. Although in this study it was mainly mentioned as a factor playing a role in cars. Vink et al. (2023) describe on the question 'what do you need for a good sleep?' 55% answered darkness, 33% good temperature and 28% silence, again showing that noise, temperature and light are important factors as well apart from the space needed for a good sleep.

Of course, this study also has some drawbacks. All data are self-reported and no validity or reliability tests were done, which is a limitation of this study. On the other hand the study population is large and the outcomes are comparable to other studies and the two studies had different approaches and resulted in similar outcomes. The majority of the population is around 24 years of age and a small group (30) around 57 years old. Different aged persons could have different sleeping habits. Also, the majority was a European population. The population was also healthy. Less healthy people could have other sleeping positions. Also, the first study considered only the position people get to sleep and the participants were asked to take this position, which could have been different in reality. Skarpsno et al. (2017) show that there are on average 1.6 (SD 0.7) position shifts per hour, while sleeping. Therefore, it is the question whether taking the position to go asleep is representative for the bed size. On the other hand the data have some value as the number of postures observed when falling asleep vary a lot, which is comparable to other studies. The second study only considered the most frequent taken position in the night. On the other hand, the study might give indications as there were similarities with two other studies (BBC, 2003; De Koninck et al., 1983).

For the environmental factors influencing sleep, the participants' reactions were based on previous experiences. Their answers might be depending on the amount of experience they have sleeping in certain mobility modes. E.g. many people sleep in trains, but the things bothering in a normal travel might be different than when using a sleeper train. This should be considered when interpreting the outcomes of this research.

Caddick et al. (2018) are very specific on ideal sleeping conditions. They describe that all forms of noise in the sleep environment should be reduced to below 35 dBA and complete darkness is optimal for sleep. They also describe that the optimal ambient temperature varies based on humidity and the bedding microclimate, ranging between 17 and 28 °C at 40–60% relative humidity. It shows that apart from size: darkness, silence and a good temperature are important for a good sleep, factors that are also mentioned by our participants. This study shows that for travel situations, the bed area could be reduced while still being acceptable for a 'reasonable' night's rest. Additionally, the fact that legs are folded in many cases, gives opportunities in shaping the bed accordingly.

Table 1
The sleep positions observed in the two studies categorized in 5 groups. The first study (n = 104) is based on the sleep positions on how people get to sleep. In the second study (n = 85) participants are asked to take the most observed sleep position.



		lying on the side with two legs bended	lying on the side with one leg bended	lying on the side with two legs stretched	lying on the back	lying on the front
all 189	%	49%	22%	4%	19%	7%
104 pp go to sleep position	%	49%	20%	5%	22%	4%
	n=	51	23	5	23	4
	mean body height	174(10.4)	173 (9.3)	188(10.0)	171(10.2)	171(8.96)
	mean age	31.4(13.8)	35.5 (15.0)	39.2(22.7)	37(16.6)	30.7(15.5)
	mean PSQI	68%	64%	75%	68%	61%
85 pp most seen position	%	46%	22%	2%	13%	11%
	n=	41	20	2	12	10
	mean body height	172 (8.0)	172 (10.6)	185(14.1)	173.5(9.66)	176(8.95)
	mean age	23.7 (2.57)	23 (2.11)	23 (1.4)	23.3(1.97)	22.9(1.54)

Table 2
Comparison of percentage of sleeping positions of this study with other studies.

sleeping position	De Koninck	Idzikowski (BBC)	Skarpsno	this study
front	11.5%	7%	7.3%	7%
back	32%	13%	37.5%	19%
side	56.5%	69%	54.1%	74%
both legs folded	46%	41%	–	49%

6. Conclusion

To facilitate all sleeping positions for the majority of people a bed of 200 × 90 cm is preferred. For one night while travelling a bed size of 171 × 76 cm might do as it allows sideward sleeping and in almost half of the cases people sleep on the side with both legs folded. Apart from the sleeping space, for a good sleep attention is needed for providing a dark environment with a good temperature and relative silence, which includes prevention of disturbance by neighbours, and which takes into account the movement of the vehicle.

CRediT authorship contribution statement

P. Vink: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **G. Vledder:** Conceptualization, Investigation, Methodology, Writing – review & editing. **M. Smulders:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing. **Y. Song:** Conceptualization, Investigation, Methodology, Writing – review & editing.

Declaration of competing interest

How do we sleep?: towards physical requirements for space and environment while travelling.

The data of this paper are gathered in courses and only the data are used of the participants that gave explicit permission to use the data. There is no conflict of interest in this paper as the authors are interested in designing sleep areas for vehicles and these data are gathered to get an indication of the needed space.

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