The effects of self-motion expectation on the amount of postural sway

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Abstract

After centuries, still no consensus regarding the exact mechanisms behind motion sickness has been achieved. However, it seems to be related to the amount of postural sway, either via a causal effect, the "Postural Instability Theory" (PIT), or because they are both influenced by a common factor, the "Subjective Vertical Theory" (SVT). Besides distraction, no cognitive aspects of motion sickness had been examined yet, despite proof of it having an effect on self-motion perception. Cognitive manipulation of the self-motion expectation was tested using a custom built parallel swing, as participants were exposed to an oscillatory lateral movement while imagining the direction of their self-motion either correctly or incorrectly. COP data were gathered before and after exposure. Differences in postural sway, defined as RMS amplitudes in AP/ML direction and length of COP path, were calculated. A significant increase in postural instability after exposure was found for all measures. No significant effect of imagination on the amount of postural instability was found. Furthermore, no differences in sway increase between non-sick and sick participants were found, arguing the PIT being false. The absence of the imagination effect could indicate that imagination of self-motion is not powerful enough to influence the subjective vertical. This could be due to the motion not being ambiguous enough to be misinterpreted, as the majority of participants reported not being misled by the incorrect imagination. Thus, further research should increase ambiguity of the motion to properly address the effects of self-motion expectation on motion sickness and postural instability.

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Literature Overview

With the upcoming presence of driver-assistance technology, and steps being made to fully autonomous cars, future drivers tend to be less attentive to the outside world. Although these developments ease the load on drivers in terms of attention and vigilance, they can also impact the willingness to engage in non-driving related secondary tasks like checking their phones (Llaneras, Salinger & Green, 2013). Besides the increase of safety risks related to this reduced situational awareness, another concomitant problem is the increased chance of motion sickness.

Motion sickness is characterized by a group of symptoms including nausea, dizziness, sweating and even vomiting that can occur in many different situations, occurring in a variety of passive motions like being the passenger of a moving car. There is still no consensus in describing the exact mechanisms behind motion sickness. One of the most popular theories is the Sensory Conflict Theory (SCT), stating that motion sickness occurs when contradictory information is perceived from different sensory modalities. This theory has been expanded by Oman (1982), based on an earlier explanation by Reason & Brand (1975), where he states that it is linked with postural stability.

One often cited, yet controversial theory is that motion sickness is even caused by prolonged postural instability (Riccio & Stoffregen, 1991), which is based on the assumption that postural control is needed during almost every dynamic and static interaction between a human-being and its environment. As keeping an upright posture can be regarded as balancing an inverted pendulum

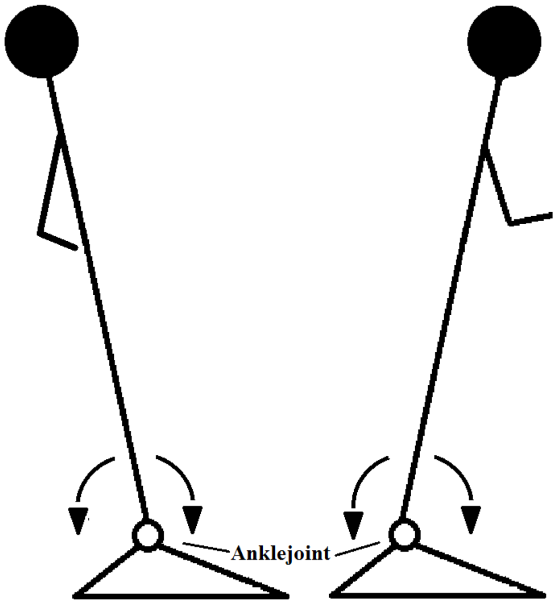

Figure 1. Schematic presentation of keeping an upright posture, represented as an inverted pendulum. The feet function as a base of support, as rotational forces of the muscles around the ankle joint keep the body upright.

(see figure 1), corrections must be made continually by the Central Nervous System (CNS) to prevent falling. For the muscular system to make adequate corrections, a feedback system is used. This system uses integrated information from visual, vestibular and/or somatosensory senses, after which they are compared to information from earlier experience (Oman, 1982; Bles, Bos, de Graaf, Groen & Wertheim 1998).

A proper control of posture ensures that the body provides a minimum of movements that can interfere with proper perception or with performance on any intended secondary actions (e.g. not spilling coffee while standing still or reading while sitting in a moving car). If one is able to keep his/her body in line with the resultant of every working force of his/her environment, keeping a stable posture is possible with minimum effort. However, if a person is exposed to an environment in which the previously learned procedures to keep a stable posture do not work (i.e. walking on a rocking boat), it is possible he/she is not able to perform a given secondary motor task with intended precision. Under normal circumstances, one can adapt to the new situation by relaxing the goals for the behavior that is affected by the instability. For instance, one can decide to stop trying to read while in a moving car. However, if decreasing the precision for the secondary task is merely not an option (e.g. keeping control of a high-performance vehicle) a prolonged state of instability will lead to a disrupted performance of the feedback system, which will eventually lead to motion sickness. After being brought back into a familiar and stable environment, an increased amount of postural sway can be detected due to re-adaptation. In fact, the theory of Riccio and Stoffregen (1991) suggests that disrupted postural control and thus increased postural sway is a needed and even sufficient condition for motion sickness to occur.

In later research, however, both positive (Bos, Ledegang, Lubeck, & Stins, 2013) and negative (Stoffregen, Faugloire, Yoshida, Flanagan & Merhi, 2008) correlations have been found between postural sway after exposure to a provocative stimulus and the occurrence of motion sickness. Examples of people becoming sick while no difference in postural instability was detected are known as well (Warwick-Evans, Masters & Redstone, 1991; Flanagan, May & Dobie, 2004) These contradictory findings question the existing theory of Riccio and Stoffregen (1991). A theory with more explanatory power for the occurrence of motion sickness would be as stated in the Subjective Vertical Theory (SVT; Bles et al., 1998), which is a specification of the earlier formed Heuristic Motion Sickness Model. The SVT states that it finds an internal conflict at the base of every provocative stimulus: a mismatch between one’s ‘sensed vertical’, as formed by a combination of multisensory information, and one’s ‘subjective vertical’ as someone would expect it to be, based on earlier experience (Bles et al., 1998). A mismatch between these two verticals would function as an error signal to optimize postural control and experiencing this will eventually lead to motion sickness. Concluding, this theory states that there is a common cause for postural instability and motion sickness, rather than instability being a requisite for motion sickness.

According to the mathematical model stated in this theory, besides sensory input, also cognitive processes influence the shaping of this subjective vertical. However, mostly sensory aspects of motion sickness have been subject to research: to our knowledge, no cognitive aspects besides distraction (Bos, 2015) have been studied yet. Because cognitive information can affect self-motion perception (e.g., Wertheim, Mesland & Bles, 2001) and imagining motions can activate similar brain areas as executing them (Jiang, Edwards, Mullins, Callow, 2015) it is expected that cognition can in fact influence one’s perception of their subjective vertical and therefore motion sickness severity and postural instability as well. If the statement that motion sickness is directly correlated with the amount of postural instability is true (Stoffregen & Riccio, 1991), the same influence can be expected between cognition and postural instability.

The present study therefore examines the role of cognitive manipulation of motion perception on the amount of postural instability, by employing an experimental design in which participants experience passive self-motion, while they – simultaneously – are being provided with cognitive information regarding this self-motion. This information is either congruent to their actual motion (CON) or incongruent to their actual motion (INC), representing the independent variable. The dependent variable is defined as the amount of postural instability. As of yet, there is no consensus on the definition of instability. However, proven to be suitable in the cause of measuring stability is the Center Of Pressure (COP) in both anteroposterior (AP) and mediolateral (ML) planes (Harris, Riedel, Matesi & Smith, 1999), determined using a force plate as depicted in figure 2. The COP refers to the point at which the pressure of the body over the soles of the feet would be if it were concentrated in one spot. This COP shifts as the CNS tries to keep the body’s Center Of Mass (COM) inside the boundaries of support, as surpassing these boundaries could lead to falling.

Still, shifting of the COP does not necessarily indicate instability, as indications have been found of postural sway having an exploratory role (Carpenter, Murnaghan & Inglis, 2010).

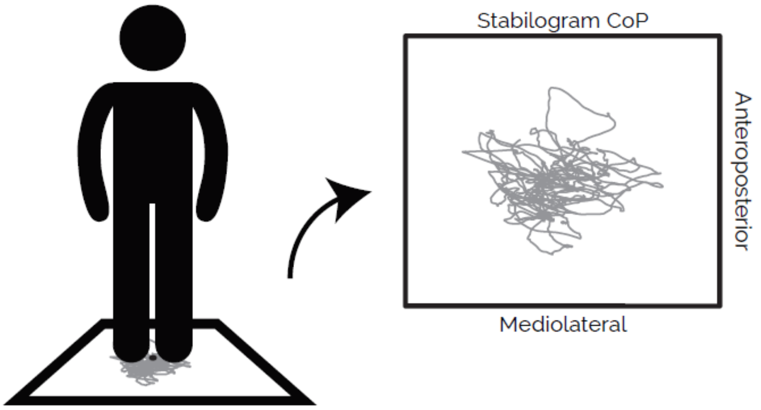

Figure 2. Schematic presentation of a COP measurement on a force platform (left). The COP (black dot) is in the case of quiet stance located somewhere in the base of support and moves constantly (grey line). The stabilogram (right) depicts an example of the movement of the COP in fore-after (anteroposterior) and left-right (mediolateral) directions. (Lubeck, 2016)

Especially in stances approaching the boundaries of stability, relatively high-frequency postural sway is used to gain critical information to maintain balance (Riccio, 1993). Nonetheless, an increase of Root-Mean-Squared (RMS) amplitudes in the AP and ML planes are likely to represent a decreased ability to maintain an upright stance (Geurts, Nienhuis & Mulder, 2005). Also, intersession reliability was stated to be high in these variables (Le Clair & Riach, 1996). Besides RMS amplitudes, another measure capable of illustrating the extent of postural instability is sway path length (SPL), where an increased SPL will imply a decreased function of the postural system (Donath, Roth, Zahner & Faude, 2012; Ferdjallah et al., 1999). Therefore, in the current study, it is hypothesized that cognitive information regarding one’s self-motion, will decrease the SPL and RMS amplitudes in both the ML and AP-plane if this information is congruent, compared to being incongruent with the actual sensed self-motion. It is also expected that this effect is more prominent after using low-pass filtering to exclude the frequencies known to be associated with exploratory behaviour.

The experimental setup used for this experiment served to test two hypotheses simultaneously. While the current paper focused on the effects of cognition on postural sway, a simultaneously written paper by Keppel (2017) focused on findings regarding the effects of cognition on the severity of motion sickness. If it would be found the severity of motion sickness can be influenced by congruent or incongruent cognitive information, the explanations of Bles et al. (1998) would be strengthened. If it would be found that postural instability is influenced by cognitive information or that participants become sick while not getting instable or the other way around, another weakening of the theory of Riccio and Stoffregen (1991) is found.

Method

Participants

A total of sixteen subjects (three males, thirteen females) participated in this study, with an average age of 23.6 ± 5.7 years. Recruitment was done using an online recruitment platform and posters that were spread throughout different universities. All participants were assigned to both conditions of the cognitive manipulation during two separate days (one condition per day) to check for within-subjects differences. With the experiment consisting of 2 separate sessions, participants received 10 euros per session and a bonus of 10 euros for participating in both sessions, leading to 30 euros in total. If a session was ceased due to occurring nausea in the participants, they were still compensated with the full 10 euros for that session.

Prior to participation in the experiment, participants were asked to fulfill an online screening questionnaire, in which certain exclusion criteria were checked. A shortened Dutch version of the Motion Sickness Susceptibility Questionnaire (MSSQ) was used to screen candidate subjects for motion sickness susceptibility (Golding, 1989), see Appendix A for the full questionnaire. Candidate subjects who were not susceptible to motion sickness (scoring 0 on every question) were excluded from participation. Also, a Dutch version of Bett’s Questionnaire upon Mental Imagery (QMI: Sheehan, 1967) was used to exclude participants with a less vivid imagination (scoring the minimum of 35 points, see Appendix A) to increase the probability of the cognitive manipulation being effective. For the same reason, participants reporting to have trouble differentiating left from right were excluded. Last of all, having a dysfunctional vestibular system and the use of medications affecting alertness or balance were considered exclusion criteria, as these factors could influence the postural measurements in a non-predictive way. All participants had to declare they did not meet one of these last three criteria by checking a box after completing the two questionnaires.

Apparatus and materials

To be able to manipulate one’s sense of self motion by providing cognitive information, it was of great concern that the perceived movement direction was as ambiguous as possible. This way, imagining another direction would be easier. To achieve this, any cues that could indicate the actual movement direction (either haptic, visual or aural) were brought to a minimum. Minimizing this was the main motive for multiple choices in the used materials and procedures.

Motion exposure. A custom-made 2.4 x 2.4 m parallel swing was used to expose subjects to a linear lateral back-and-forth motion (figure 3). The benefit of a swing for this experiment was the smoothness of a swing-movement: no sudden acceleration changes occur that could be a clear cue for participants to determine the direction of their actual self-motion, especially at the position turning points. Moreover, a parallel swing results in mere linear acceleration, thus resulting in a physically unambiguous simple stimulus without a complicating angular component. Although a parallel swing also results in a vertical acceleration, this component will be negligible for angles of the suspending ropes less than 15 degrees. Furthermore, the vertical acceleration varies with twice the frequency of the lateral acceleration. As the peak frequency for instigating motion sickness is close to 0.20 Hz, the vertical component is of less importance than the horizontal. The swing was manually driven using elastic luggage straps. Elastic straps were used to minimize the detectability of a ‘jerk’-motion by participants, which might enable them to deduct from which side the swing was pulled. The setup was visually symmetrical to this same cause: upon entering the experimental room, participants could not determine from which side the swing was going to be pulled.

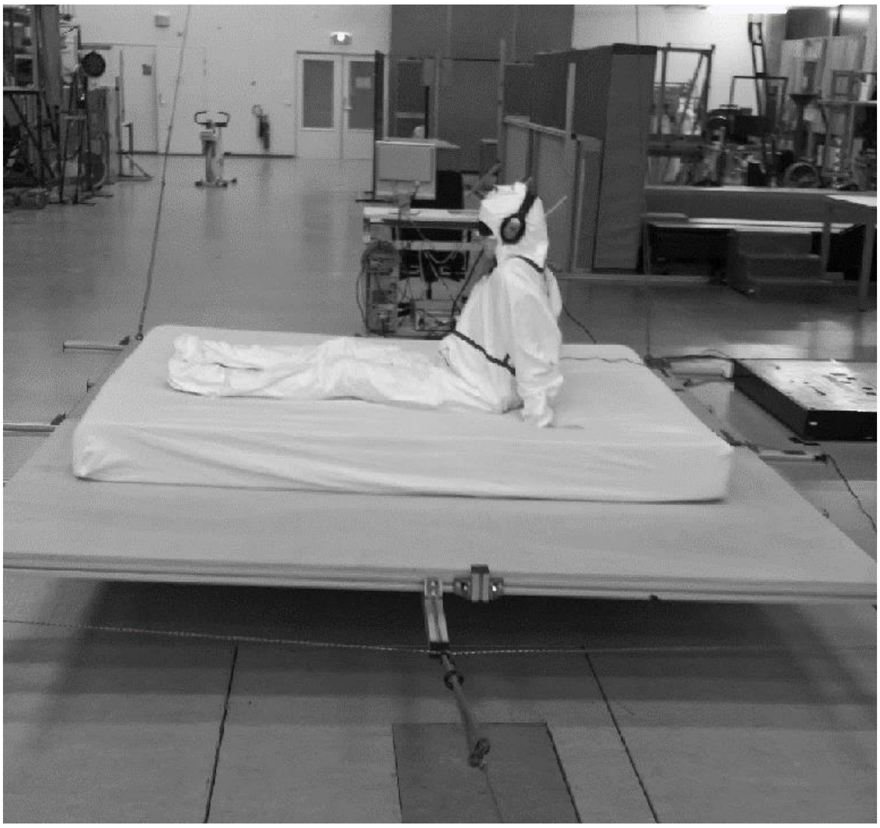

Figure 3. Experimental setup during swing motion. Participants were positioned on a memory-foam mattress in the middle of the swing while wearing all sensory-inhibiting attributes. Instructions were to straighten back and legs during the swing motion

Due to the choice of manually moving the swing (for practical reasons), a slight variability in amplitude did occur (1.375±0.125 meter). Nevertheless, in accordance with the formula for a simple gravity pendulum, i.e.,

$$T = 2\Pi * \sqrt{\frac{L}{g}}$$

the period for the swing motion only depends on the arm (rope) length L and the gravitational acceleration g, but is independent of its amplitude.

Suspending ropes were attached to all four corners, joining at two hooks at the ceiling positioned above the center of both sides, creating an inverted v-shape (figure 4, right). Given a rope length of 6.52 meters diagonally, the effective length for the swing was 6.41 meters vertically (figure 4, right). Subsequently, a movement with a period T of 5.08 seconds was achieved, indicating a frequency of 0.20 Hz: one known to be the optimum in inducing motion sickness (Golding et al., 1996, 1997, 2001).

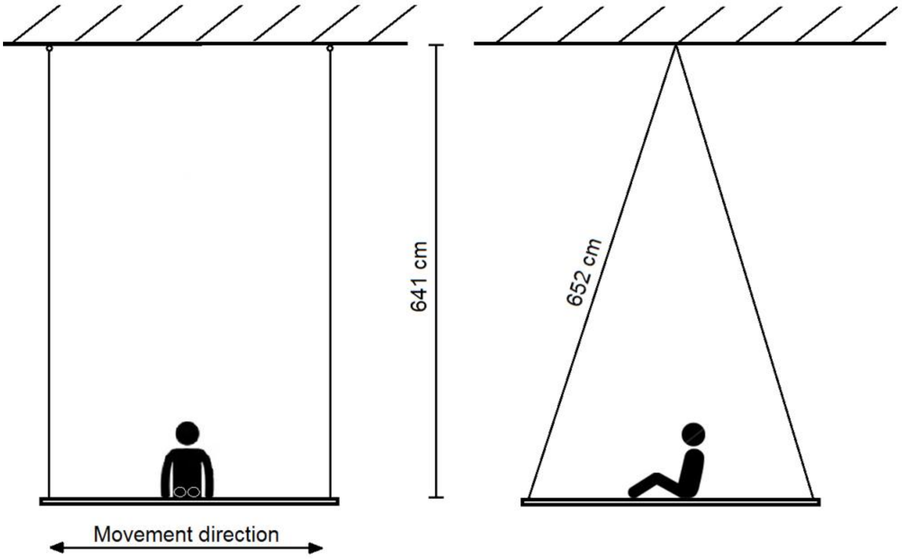

Figure 4. **left** Front view of the suspended swing to show movement direction **right** Side view of the suspended swing to show effective length of ropes

Sensory inhibition.

Headphones. Over-ear headphones, Sennheiser HD 201, were used to provide verbal instructions to the participants. During the entire experiment, constant pink noise of 70 dB was presented to mask environmental sounds, as these could give participants aural cues regarding their actual self-motion.

Blindfold. A Mindfold relaxation mask was used to obscure subjects' vision during the actual experiment (Mindfold Inc., 2016), hereby excluding external visual cues.

*Clothing. S*ubjects wore an overall with an attached hood (type Tyvek Classic plus) and latex gloves to minimize haptic information regarding the direction of the self-motion due to wind.

Measurements.

Custom force plate. To measure postural (in)stability, a custom made 1 x 1 m strain gauge force plate with a sensitivity of 120000 N/mV/V was used to gather COP data at 100Hz. Three time series of 60 seconds were measured per participant per condition. This duration was chosen to increase reliability and stability of measurements and to be able to capture low frequency movements (Carpenter, Frank, Winter & Peysar, 2001). Before the experiment, one measure with eyes opened (pre-test EO) and one with eyes closed (pre-test EC) were taken. After the experiment, one was taken with eyes closed (post-test EC). The measure with eyes opened was taken to be able to compute a Romberg-coefficient (pre-test EC/pre-test EO) for each variable. This coefficient is interpreted as an indicator of proprioceptive contribution to postural stability (Furman, 1994), which could be used to account for variability in outcomes between subjects. Different people use a different weighting for visual and proprioceptive information to determine the subjective vertical (Bles et al., 1998).

Questionnaires. During the experiment, a misery scale (MISC) was used to assess subjects' feeling of discomfort on an 11-point scale (Table 1). Answers were filled in by the experimenter, based on the subjects' verbal rating of their discomfort. A score of 0 indicates no discomfort at all, 10 indicates vomiting. At any point during the experiment, when a score of 6 or higher was reported, indicating nausea, the experiment was ceased immediately.

Table 1

11-point Misery Scale (MISC)

Symptoms		MISC
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, headache, stomach/throat awareness, sweating, blurred vision, yawning, burping, tiredness, salivation, …but no nausea	Vague	2
	Little	3
	Rather	4
	Severe	5
Nausea	Little	6
	Rather	7
	Severe	8
	Retching	9
Vomiting		10

Tasks.

Preloading. During an earlier pilot study, it was revealed that in some participants, the lateral motion itself did not induce motion sickness fast enough (under 20 minutes). To reduce experimental time and heighten the chance of occurring motion sickness, a ‘preloading interval’ was included. During this interval participants were instructed to rotate their head, combining a yaw and pitch motion, while on the moving swing. Every 90 seconds, subjects were asked to report a MISC score. If MISC ≥ 3 reported, the preloading interval was stopped and the second (experimental) interval started. The cut off score of 3 was chosen to allow both a decrease (to the minimum of 0, i.e., no discomfort) or an increase (to a maximum of 6, nausea, the stop criterion) in the experimental interval. Because of the strain this movement could form on the necks of the participants, a maximum of 10 minutes was chosen for the preloading interval, irrespective a MISC = 3 was reached.

Imagining. Two objects in the experimental room served as ‘anchor points’ for the cognitive manipulation during the experiment. The first was the entrance door through which the subjects entered the room, which was positioned left from the swing (figure 5, left). The second was a computer desk, which stood on the right side of the swing (figure 5, right). These anchor points gave subjects a sense of position and orientation in the experimental room during the experiment. Participants were instructed to keep these anchor points in mind, as detailed as possible, and according to given instructions, had to imagine moving to either one of them.

While imagining this motion, participants were explicitly instructed to ignore any other cue they felt concerning their actual self-motion.

Figure 5. Picture of the two used anchor points for cognitive manipulation. **left** entrance door through which participants entered experimental room. **right** computer desk

Procedure

The Scientific and Ethical Review Board (Vaste Commissie Wetenschap en Ethiek, VCWE) of the Faculty of Behavior & Movement Sciences, VU University Amsterdam, has reviewed this study according to principles expressed in the Declaration of Helsinki, and found no objections. Prior to participation, subjects received general information (see Appendix B) about the experimental procedure. They were informed that the study concerned visual imagery during motion and they would be exposed to motion while sitting on a platform. The true study goal was withheld since prior knowledge concerning the (in)congruency of the given self-motion information could interfere with possible effects of the manipulation.

In the experimental room, after the informed consent was signed (see Appendix B), subjects' COP measurements were taken. They were instructed to stand straight and still on the force plate for one minute, their feet positioned in a natural stance (roughly 15 centimeters apart), opened eyes, and arms hanging relaxed along their sides. After this first measurement, another followed under the same instructions, only this time with their eyes closed.

After this, subjects put on an overall and gloves and were instructed to sit in the middle of the swing with their legs and back straightened. Then, they were asked to observe both anchor points in detail. Subjects were asked to describe the objects with their eyes closed while the experimenter checked if that description was correct. If the description was not, subjects were allowed to take another look until the description was right. Then, the MISC was explained to the subjects, and they were asked for their current MISC score.

Next, subjects were blindfolded and asked to keep both the anchor points in mind during the swing motion. They were also asked not to focus on the sensed movement itself, but solely on the information that would be provided through the headphones.

The first (preloading) interval started, lasting for maximum of 10 minutes or until MISC = 3 was reached. At the end of the preloading interval, subjects were instructed to keep their head positioned as if looking forward during the rest of the experiment.

The goal of the second (experimental) interval was to apply the manipulation and to gather data. It was divided into three different blocks that were carried out consecutively, repeating this sequence of three blocks three times.

Block 1 was used to apply the experimental manipulation. For 60 seconds, subjects continually received verbal information about the direction of their movement, stimulating motion imagination. The verbal information consisted of alternately the object they were moving towards and their direction of motion (i.e., “towards the entrance” / “to the left”, or “towards the computer” / “to the right”). During the CON session, this verbal information was correct (i.e. “towards the entrance” while moving towards the entrance). This way, the subjects’ vestibular input was compliant with the cognitive information. During the INC session, the verbal information was incorrect (i.e., “towards the entrance” when they were moving towards the computer desk). This way, the subject’s vestibular input was deliberately mismatched with the cognitive information.

The goal of block 2 was to stimulate subjects to actively imagine the instructed self-motion without distraction. For 30 seconds, no verbal information was provided so that subjects could focus solely on their imagination.

The goal of block 3 was to obtain data from the participants. This block took 45 seconds in which three questions were asked. Firstly, subjects were asked if their imagery regarding the entrance and computer was still vivid, as this was used in Keppel’s analysis. Next, subjects were asked to report their motion direction during the ‘beep’. This ‘beep’ was presented on a randomly chosen point in time within 10 seconds following this question, either during moving leftward of rightward. This enabled to check if participants could detect their direction of motion correctly. At the end of this third block, subjects were asked to report their MISC score.

After completing this sequence for three times, the swing was stopped and participants were asked to return to the force plate for the post-test COP measurement. Here, same instructions as pre-test EC were given. After completing all procedures participants were debriefed, thanked for their participation, and asked if they had any questions or concerns. They were advised to stay in the experimental room until MISC ≤ 2. The order of the sessions, i.e. CON first or INC first, were randomized between subjects.

Data analysis

This study used a within-subjects design. The independent variable is cognitive information with respect to the subject's actual self-motion, either CON or INC. The dependent variables were SPL and RMS amplitudes in both the AP and ML plane. These output variables were computed in Matlab (version R2013a) using the 60-second time series obtained via the force plate. Before calculation, fourth-order Butterworth low-pass filters have been used to remove excessive noise in the signal and to extract frequency bands expected to be influenced by the experiment. A low-pass cutoff frequency of 12Hz was chosen to remove the noise caused by the hardware and still include all typical frequency ranges of postural sway (Riccio, 1993; Yamamoto et al., 2015). A low-pass cutoff of 0.5Hz was chosen in addition to focus on movements in the frequency range congruent to the motion manipulation of 0.2Hz, thus removing possibly exploratory behavior thought to occur at higher frequencies. In Figure 6, the effects of applying the filters on the same COP time-series can be seen. The variables obtained from both filtered datasets from the time-series measured with eyes closed were compared before and after exposure using repeated-measures two-way ANOVA's.

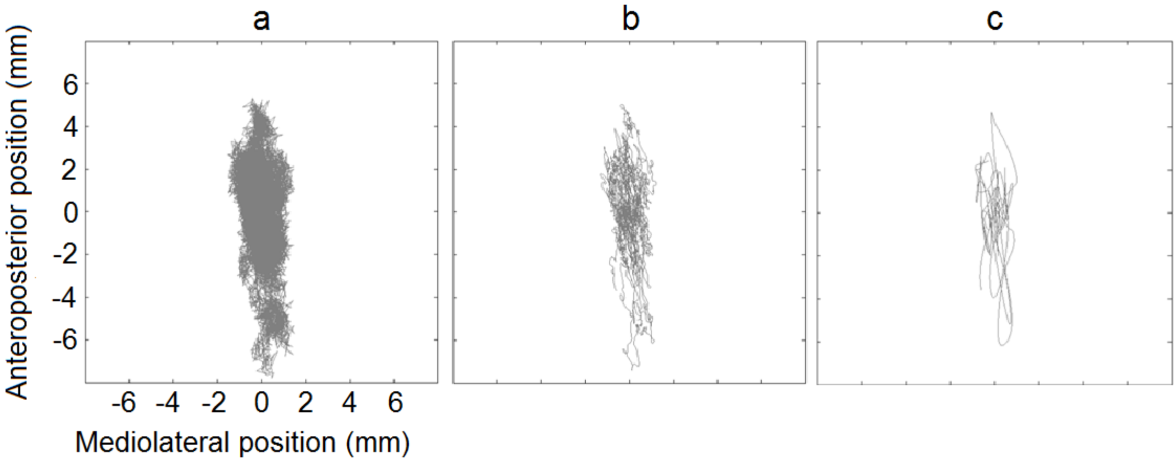

Figure 6. Typical stabilogram using **a** raw data **b** 12 Hz low-pass filtered data **c** 0.5Hz low-pass filtered data.

Results

Two participants reported nausea during their first session of the experiment, after which they declined to participate in the second session: without a full dataset for comparison, these two participants were excluded from further analysis. The remaining sample consisted of fourteen participants.

All fourteen remaining datasets were tested for normality using Shapiro-Wilk's W-test, from which could be concluded some of the variables obtained were not normally distributed. However, transforming the data had no effect and no non-parametric two-way repeated-measures ANOVA is known for an analysis comparing only two points in time. To still be able to visualize any possible effects, comparisons were made between pre-test EC values and post-test EC values. Before interpreting any results, it should be taken into account that, except for the 0.5 Hz filtered ML RMS amplitudes and 12Hz filtered SPL's, all analyses had the assumption of normality violated. Because using the Romberg-coefficients provided no difference in outcomes, they are disregarded from further analyses to not complicate interpretation.

0.5 Hz

Results after using the 0.5 Hz low-pass filter are presented in figure 7. For the RMS amplitudes in AP direction (see figure 7a), values were higher after exposure both after CON (*M* = 2.20, *SD* = 0.71) and INC (*M* = 2.26, *SD* = 0.62), compared to values before exposure EC, both for CON (*M* = 1.74, *SD* = 0.30) and INC (*M* = 1.87, *SD* = 0.40). A repeated-measures two-way ANOVA indicated a significant main effect for time, *F*(1,13) = 13.185, *p* = .003, but no main effect for condition, *F*(1,13) = 0.209, *p* = .655, and no significant interaction effect, *F*(1,13) = .034, *p* = .858.

For the RMS amplitudes in ML direction (see figure 7b), values are higher after exposure both for CON (*M* = 0.50, *SD* = 0.19) and INC (*M* = 0.60, *SD* = 0.31 compared to values before exposure, both for CON (*M* = 0.48, *SD* = 0.15) and INC (*M* = 0.45, *SD* = 0.18). A repeated-measures two-way ANOVA, however, indicated no significant main effect for time, *F*(1,13) = 3.386 *p* = .089, no main effect for condition, *F*(1,13) = 0.401, *p* = .538, and no significant interaction effect, *F*(1,13) = 1.802, *p* = .202.

Regarding sway path lengths (see figure 7c), values were higher after exposure both for CON (*M* = 12.46, *SD* = 3.70) and INC (*M* = 10.77, *SD* = 2.64), compared to values before exposure, both for CON (*M* = 10.82, *SD* = 2.02) and INC (*M* = 9.63, *SD* = 1.76). A repeated-measures two-way ANOVA indicated a significant main effect for time, *F*(1,13) = 4.747, *p* = .048, but no main effect for condition, *F*(1,13) = 3.861, *p* = .071, and no significant interaction effect, *F*(1,13) = .347, *p* = .566.

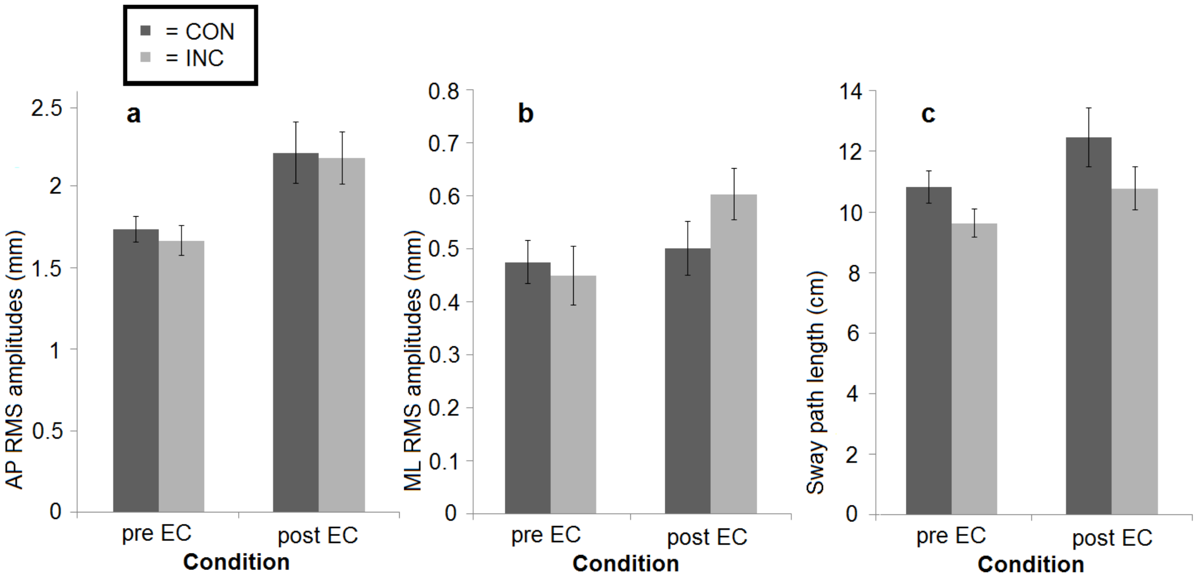

Figure 7. **a** Mean RMS amplitudes (mm, ±SEM) in AP direction **b** Mean RMS amplitudes (mm, ±SEM) in ML direction **c** Mean SPL (cm, ±SEM) for all measures after using 0.5 Hz low-pass Butterworth filter.

12 Hz

Results after using the 12 Hz low-pass filter are presented in figure 8. For the RMS amplitudes in AP direction (see figure 8a), values were higher after exposure both after CON (*M* = 2.35, *SD* = 0.71) and INC (*M* = 2.26, *SD* = 0.62), compared to values before exposure EC, both for CON (*M* = 1.94, *SD* = 0.37) and INC (*M* = 1.87, *SD* = 0.40). A repeated-measures two-way ANOVA indicated a significant main effect for time, *F*(1,13) = 8.269, *p* = .013, but no main effect for condition, *F*(1,13) = 0.652, *p* = .434, and no significant interaction effect, *F*(1,13) = .007, *p* = .933.

For the RMS amplitudes in ML direction (see figure 8b), values are higher after exposure both for CON (*M* = 0.57, *SD* = 0.22) and INC (*M* = 0.64, *SD* = 0.3) compared to values before exposure, both for CON (*M* = 0.52, *SD* = 0.15) and INC (*M* = 0.51, *SD* = 0.18). A repeated-measures two-way ANOVA indicated no significant main effect for time, *F*(1,13) = 3.456 *p* = .086, no main effect for condition, *F*(1,13) = 0.220, *p* = .647, and no significant interaction effect, *F*(1,13) = 0.839, *p* = .376.

Regarding sway path lengths (see figure 8c), values were lower after exposure both for CON (*M* = 45.63, *SD* = 10.77) and INC (*M* = 42.29, *SD* = 6.81), compared to values before exposure, both for CON (*M* = 46.76, *SD* = 7.67) and INC (*M* = 45.32, *SD* = 8.76). A repeated-measures two-way ANOVA indicated no significant main effect for time, *F*(1,13) = 2.381, *p* = .147, no main effect for condition, *F*(1,13) = 3.385, *p* = .460, and no significant interaction effect, *F*(1,13) = .580, *p* = .460.

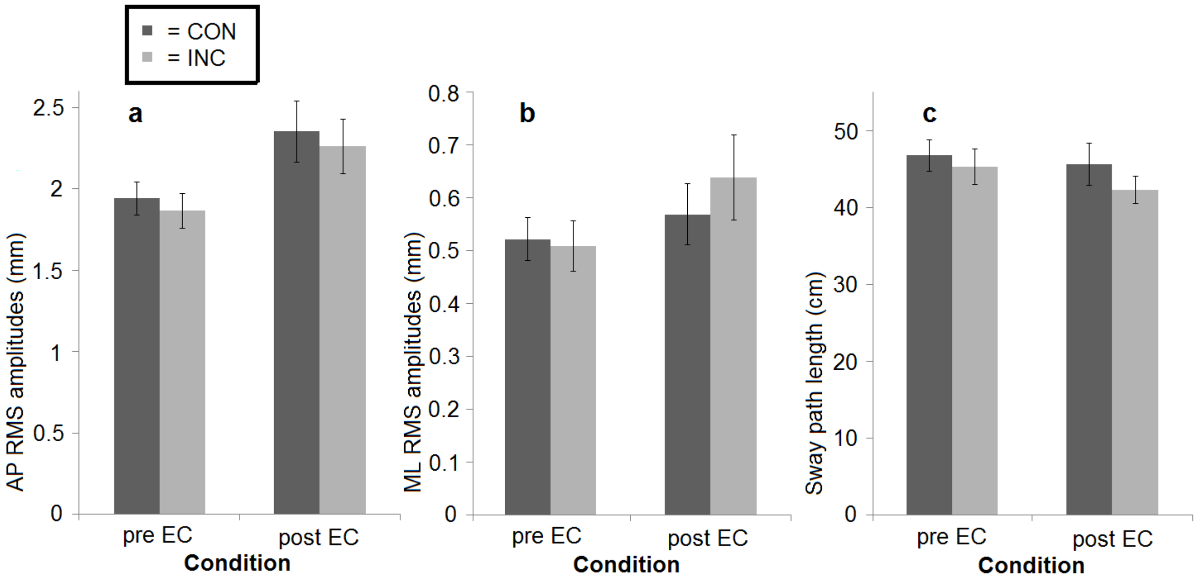

Figure 8. **a** Mean RMS amplitudes (mm, ±SEM) in AP direction **b** Mean RMS amplitudes (mm, ±SEM) in ML direction **c** Mean SPL (cm, ±SEM) for all measures after using 12 Hz low-pass Butterworth filter.

General

Kruskal Wallis tests showed no significant differences between participants who reported no symptoms of motion sickness and participants who did, in terms of a change in the different measures of postural instability after the experiment, as can be seen in table 2.

Table 2

Chi-square values and p-values per measurement

Measure	Condition	Filter frequency			
		0.5 Hz		12Hz	
		$\chi^2(1)$	p-value	$\chi^2(1)$	p-value
AP	CON	.180	.671	.720	.396
	INC	.180	.671	.180	.671
ML	CON	.720	.396	.980	.322
	INC	.320	.572	.020	.888
SPL	CON	.020	.888	1.280	.258
	INC	.500	.480	.000	1.000

To test the effectiveness of the provided cognitive information in manipulating one's motion perception, a chi-squared goodness of fit test was calculated, comparing the number of correct answers regarding their sense of direction with numbers expected if randomly answered during the INC condition. If participants reported the direction the way they were really moving instead of the one they should be imagining, this was considered correct. Participants scored significantly higher than chance levels $\chi^2(3) = 69.042$, $p < .001$. Exact numbers of correct answers per condition can be found in table 3.

Table 3

Number of correct answers regarding one's direction of self-motion per condition

# of correct answers	Condition	
	CON	INC
0 answers	0	0
1 answers	0	0
2 answers	1	2
3 answers	13*	12

Note. *One participant only answered 2 questions due to occurring nausea, stopping the experiment prematurely. Because both answers were correct, participant was treated as a fully correct.

For examining the test-retest reliability between the two sessions for the chosen variables, intraclass correlation coefficients have been determined. As can be seen in table 4, after using the 0.5 Hz filter, no measure was significant. After using the 12 Hz filter, RMS amplitudes for AP direction had a significant reliability ranging from "poor" to "good" (Koo & Mae, 2015). The SPL had a reliability reaching significance ranging from "poor to "good".

Table 4

Intraclass Correlation Coefficients, 95% confidence intervals, F-values and corresponding p-values per measurement

Measure	Filter Frequency							
	0.5 Hz				12 Hz			
	ICC	95% CI	*F*(2,1)	*p*-value	ICC	95% CI	*F*(2,1)	*p*-value
AP	.197	(-.378, .651)	1.470	.249	.487	(-.039, .801)	2.834	.036
ML	.098	(-.482, .594)	1.205	.371	.189	(-.407, .650)	1.433	.263
SPL	.314	(-.142, .694)	2.137	.092	.678	(.260, .883)	5.111	.003

Discussion and conclusion

The goal of this study was to examine the effects of cognitive information regarding one’s self-motion on the amount of postural sway. Using the results of this study, the effectiveness of the procedure has been proven as sway path lengths showed that participants swayed significantly more and the RMS of sway amplitudes showed that participants swayed significantly further in AP direction after the experiment as compared to before. However, no significant differences have been found between providing congruent or incongruent information.

Still, according to the results of Keppel’s paper, the majority of the participants reported an increase in MISC scores over time. Moreover, the used procedure caused an overall increase in postural instability as well. Because only a pre-test and post-test measurement were taken, the order of occurrence could not be determined to validate the statement of Riccio and Stoffregen (1991) that decreased postural stability appears before motion sickness. Although, comparing participants who never reported any symptoms of motion sickness during this experiment with participants who did, no different patterns of changed postural stability after the experiment could be detected. This would either indicate that the not-sick participants would eventually turn sick as well, or that the correlation between motion sickness and postural stability is not as irrefutable as stated by Riccio and Stoffregen (1991). This finding can be interpreted as strengthening the assumption that motion sickness and postural instability are influenced by a common system (Kennedy & Stanney, 1996; Bos, 2011).

One notable effect the current study revealed was that participants consistently showed less sway in ML direction compared to the AP direction. This can be explained by the stance participants adopted, as participants stood with their feet roughly 15 centimeters apart. This wide stance provides a wide but variable base of support and will thus have caused less sway in ML direction (Kirby, 1987). In order to increase instability and be able to detect differences in sway more easily, in subsequent research another stance should be considered. By using a standardized stance (i.e. heel-to-toe) instead of a ‘natural’ stance, the reliability of the sway measures would also increase (Brouwer et al., 1998; Elliot & Murray, 1998).

Another noteworthy effect is that, after using the low frequency filter, sway path lengths were smaller post-test during INC compared to CON. Although this result seems to be directly contrary to the hypothesis, it is clear that pre-test SPL’s were already shorter during CON sessions than during INC sessions. As within-day measurements have proven to be more reliable than between-day measurements of postural sway (Benvenutti et al., 1999; Lin, Nussbaum & Madigan, 2008), post-test SPL's should be judged relatively to the pre-test measure. This way, no difference between the two conditions can be found.

Overall, SPL is found to be a measure that is highly affected by filtering, and shows vastly different patterns and order of magnitudes after applying the 0.5Hz or 12Hz filter, whereas RMS amplitudes are regarded more robust to filtering. This can be explained by the nature of these measures, as higher-frequency/low-amplitude exploratory behavior adds up to the total sway length, so filtering out the higher frequencies reduces the total sway length. Because the amplitudes of these frequencies are smaller, filtering them out does not have an as potent effect on the RMS amplitude of sway.

Also, RMS amplitudes showed very similar patterns between the AP and ML directions. This means that they are influenced in similar ways and could indicate that these two measures indeed represent measures of the same postural balance system.

Although it is the gold standard in postural research, COP data tends to have a high interpersonal variability, but a high intrapersonal variability has been reported as well (Santos, Delisle, Larivière, Plamondon & Imbeau, 2008), making it a difficult measure for a small sample group. The relatively large spread in the data of the current research could have prevented the results to reach significant values. Besides this, for the current study a minimum interval of 24 hours between sessions has been pursued to minimize any accumulation of motion sickness symptoms and postural instability. This could have influenced the results and reliability tests as well, regarding the decreased reliability of between-day measurements of postural sway (Benvenutti et al., 1999; Lin, Nussbaum & Madigan, 2008).

Another aspect of the current study in terms of COP data gathering that could be regarded as a limitation is the used order of procedure. All participants performed three trials of quiet standing on the force plate, two before the manipulation and one after, all in the same order. The danger of keeping the same order in every participant is that people 'learn' to keep a stable posture due to adaptation to every new standing surface (Horak & Nashner, 1986). However, the reason for choosing not to randomize this order is that the effects of the cognitive manipulation had to be determined, and therefore the procedure for every participant was tried to be kept as equal as possible. Moreover, as participants adopted a wide stance, no learning effects were expected influencing the sway path length (Tarantola, Nardone, Tacchini, & Schieppati, 1997). Still, these decisions were a matter of trade-off between emphasizing the manipulation or preventing unwanted effects in measurements. In further research, decreasing the timespan between sessions is not recommended as some participants reported to be free of symptoms as fast as 4 hours, but others reported having a mild headache for up to 12 hours.

The most important finding of the current study is that, even though in the used procedure it was tried to minimize any sensory input from which participants could deduct the direction of their self-motion, a goodness of fit-test proved that participants were still right about this direction most of the time. This could explain the absence of an effect of the used manipulation, as this implies that the movement was not ambiguous enough to ‘trick’ the sensory system by imagination. This indicates that people are extremely well adapted to use any kind of information they can get to determine their motion direction and improve their stability. One other explanation for the manipulation not being effective enough is that people perform less on cognitive spatial processing tasks while maintaining balance (Kerr, Condon & McDonald, 1985). It is plausible that, because participants had to stay seated with an upright body on the swing, participants had a reduced performance on imagining their position vividly.

As the assumption that the used manipulation could alter the participants’ sense of motion, and thereby their subjective vertical, was the fundament of the experiment, the differentiating power of the two conditions CON and INC that were used should be questioned. Still, as participants were not right in all the cases (even during congruent information), this indicates that the used combination of motion and manipulation provides a good starting point. In further research, it should be attempted to construct a motion that is even more ambiguous than currently used. One possible solution may be the use of a normal swing instead of a parallel one. The use of a parallel swing was justified as a horizontal motion has proven to be sickening (Golding, 1996, 1997, 1999; Gu, Pei, Tong & Liu, 1999), but the adverse effect was that multiple participants reported to have felt an obvious increase of pressure on one of their wrists during the direction changes. This cue was felt as participants were allowed to use their hands to prevent themselves from toppling over. As even a slight touch of the fingertip can provide enough feedback to improve postural stability (Jeka et al., 1994, 1997; Reynolds & Osler, 2014), it can be assumed that the haptic cues felt in the wrists improves stability as well. While on a normal swing, as the base of support will always be perpendicular to the centripetal force, toppling will happen significantly less easy, obviating the need for extra support using hands and thus providing more cues for increasing stability. Whereas the rotational nature of a normal swing movement will help to keep balance, this will add a more complicated angular component as well. Although continuous rotation around x-, y- and z-axis (Leger, Money, Landolt, Cheung & Rodden, 1981) and a combination of vertical oscillation and pitch or roll (McCauley et al., 1976) have proven to be sickening, direct effects of an oscillatory rotational movement have not yet been studied sufficiently.

The cognitive manipulation was not as effective as expected but, still, these results can be regarded as a stepping stone in research on motion sickness using a swing motion. The efficiency of this motion for instigating motion sickness has been proven once more, just like the capacity of the human sensory system to use limited information to correctly determine the direction of a physically ambiguous motion. Furthermore, a starting point for examining the effects of using imagining in influencing motion-expectation and its effect on postural instability and motion sickness has been found. Concluding, although not significantly, another weakening seems to be found of the direct correlation between postural imbalance and motion sickness, hereby contradicting the postural instability theory of Riccio and Stoffregen (1991) while the SV Theory by Bles et al. (1998) may still be valid.

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Appendix A

MSSQ

Bewegingsziekte

De volgende vragen gaan over hoe gevoelig je bent voor bewegingsziekte, en welke bewegingen je het vervelendst vindt. Met bewegingsziekte wordt hier bedoeld een duidelijk gevoel van onbehagen, misselijkheid, dan wel overgeven ten gevolge van bewegen.

9. **Hoe vaak voelde je jezelf als kind (jonger dan 12 jaar) ziek in / bij** *

Markeer slechts één ovaal per rij.

	n.v.t	nooit	zelden	soms	vaak
auto's	○	○	○	○	○
bussen	○	○	○	○	○
treinen	○	○	○	○	○
vliegtuigen	○	○	○	○	○
kleine boten	○	○	○	○	○
grote schepen	○	○	○	○	○
schommels	○	○	○	○	○
draaimolens	○	○	○	○	○
pretpark-attracties	○	○	○	○	○

10. **Heb je hierbij als kind wel eens moeten overgeven?** *

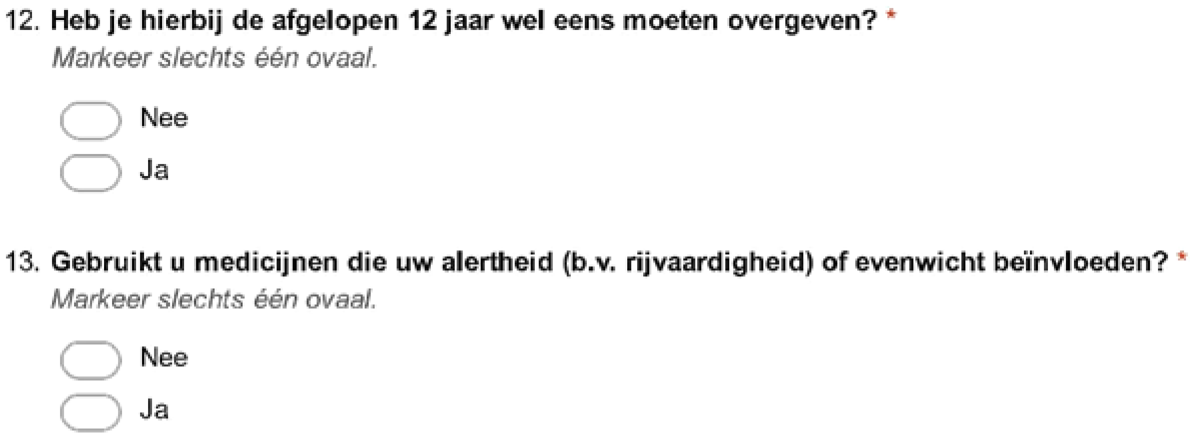
Markeer slechts één ovaal.

○ Nee
○ Ja

11. **Hoe vaak voelde je jezelf de afgelopen 12 jaar ziek in** *

Markeer slechts één ovaal per rij.

	n.v.t	nooit	zelden	soms	vaak
auto's	○	○	○	○	○
bussen	○	○	○	○	○
treinen	○	○	○	○	○
vliegtuigen	○	○	○	○	○
kleine boten	○	○	○	○	○
grote schepen	○	○	○	○	○
schommels	○	○	○	○	○
draaimolens	○	○	○	○	○
pretpark-attracties	○	○	○	○	○
computerspelletjes	○	○	○	○	○
geprojecteerde beelden	○	○	○	○	○
rij- of vliegsimulatoren	○	○	○	○	○



12. **Heb je hierbij de afgelopen 12 jaar wel eens moeten overgeven?** *

Markeer slechts één ovaal.

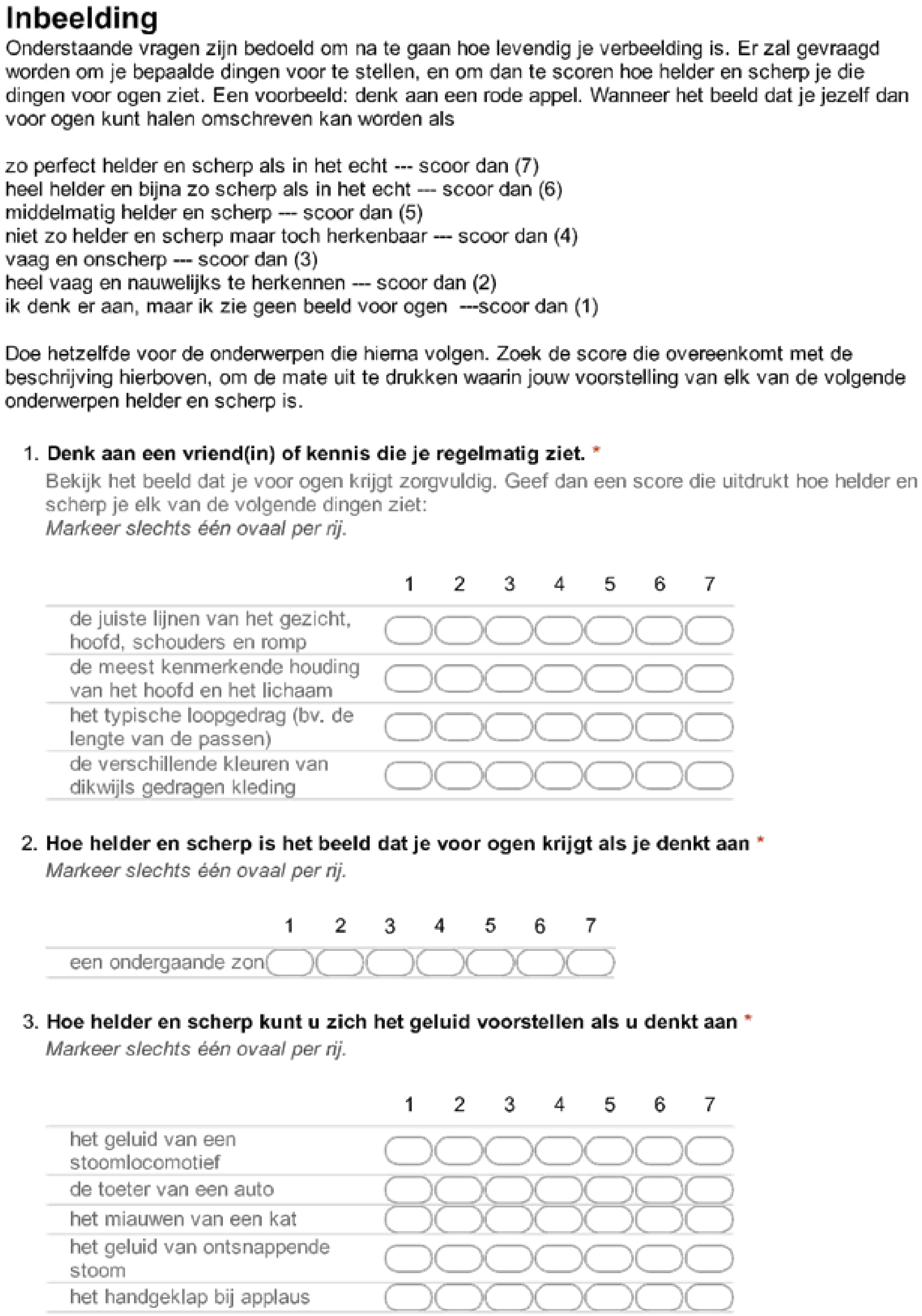
○ Nee
○ Ja

13. **Gebruikt u medicijnen die uw alertheid (b.v. rijvaardigheid) of evenwicht beïnvloeden?** *

Markeer slechts één ovaal.

○ Nee
○ Ja

QMI



Inbeelding

Onderstaande vragen zijn bedoeld om na te gaan hoe levendig je verbeelding is. Er zal gevraagd worden om je bepaalde dingen voor te stellen, en om dan te scoren hoe helder en scherp je die dingen voor ogen ziet. Een voorbeeld: denk aan een rode appel. Wanneer het beeld dat je jezelf dan voor ogen kunt halen omschreven kan worden als

zo perfect helder en scherp als in het echt --- scoor dan (7)
heel helder en bijna zo scherp als in het echt --- scoor dan (6)
middelmatig helder en scherp --- scoor dan (5)
niet zo helder en scherp maar toch herkenbaar --- scoor dan (4)
vaag en onscherp --- scoor dan (3)
heel vaag en nauwelijks te herkennen --- scoor dan (2)
ik denk er aan, maar ik zie geen beeld voor ogen ---scoor dan (1)

Doe hetzelfde voor de onderwerpen die hierna volgen. Zoek de score die overeenkomt met de beschrijving hierboven, om de mate uit te drukken waarin jouw voorstelling van elk van de volgende onderwerpen helder en scherp is.

1. **Denk aan een vriend(in) of kennis die je regelmatig ziet.** *
   Bekijk het beeld dat je voor ogen krijgt zorgvuldig. Geef dan een score die uitdrukt hoe helder en scherp je elk van de volgende dingen ziet:
   Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
de juiste lijnen van het gezicht, hoofd, schouders en romp	○	○	○	○	○	○	○
de meest kenmerkende houding van het hoofd en het lichaam	○	○	○	○	○	○	○
het typische loopgedrag (bv. de lengte van de passen)	○	○	○	○	○	○	○
de verschillende kleuren van dikwijls gedragen kleding	○	○	○	○	○	○	○

2. **Hoe helder en scherp is het beeld dat je voor ogen krijgt als je denkt aan** *
   Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
een ondergaande zon	○	○	○	○	○	○	○

3. **Hoe helder en scherp kunt u zich het geluid voorstellen als u denkt aan** *
   Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
het geluid van een stoomlocomotief	○	○	○	○	○	○	○
de toeter van een auto	○	○	○	○	○	○	○
het miauwen van een kat	○	○	○	○	○	○	○
het geluid van ontsnappende stoom	○	○	○	○	○	○	○
het handgeklap bij applaus	○	○	○	○	○	○	○

4. **Denk aan het gevoel dat ontstaat bij het aanraken van elk van de volgende dingen.** *

Hoe helder en scherp kun je jezelf het gevoel voorstellen van

Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
zand	○	○	○	○	○	○	○
linnen	○	○	○	○	○	○	○
vacht	○	○	○	○	○	○	○
een speldenprik	○	○	○	○	○	○	○
de warmte van een lauw bad	○	○	○	○	○	○	○

5. **Denk aan wat je doet met armen en benen, handen, lippen enz., wanneer je elk van de volgende activiteiten uitvoert.** *

Hoe helder en scherp kun je jezelf voorstellen wat je doet bij

Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
een trap oplopen	○	○	○	○	○	○	○
over een beek heen springen	○	○	○	○	○	○	○
een cirkel op papier tekenen	○	○	○	○	○	○	○
reiken naar een voorwerp op een hoge plank	○	○	○	○	○	○	○
iets voor de voeten wegtrappen	○	○	○	○	○	○	○

6. **Denk aan de volgende smaken.** *

Hoe helder en scherp kun je jezelf elke smaak voor de geest halen?

Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
zout	○	○	○	○	○	○	○
witte kristalsuiker	○	○	○	○	○	○	○
sinaasappel	○	○	○	○	○	○	○
jam	○	○	○	○	○	○	○
uw lievelingsgerecht	○	○	○	○	○	○	○

7. **Denk aan elk van de volgende geuren.** *

Hoe helder en scherp kun je jezelf de geur van elk van de volgende situaties of voorwerpen voor de geest halen?

Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
een muffe kamer	○	○	○	○	○	○	○
het koken van spruitjes	○	○	○	○	○	○	○
het braden van vlees	○	○	○	○	○	○	○
pas uitgestreken verf	○	○	○	○	○	○	○
een stuk leer	○	○	○	○	○	○	○

8. **Denk aan elk van de volgende gevoelens.** *

Hoe helder en scherp kun je jezelf elk gevoel voor de geest halen?

Markeer slechts één ovaal per rij.

	1	2	3	4	5	6	7
vermoeidheid	○	○	○	○	○	○	○
honger	○	○	○	○	○	○	○
keelpijn	○	○	○	○	○	○	○
slaperigheid	○	○	○	○	○	○	○
voldaan zijn na een uitgebreide maaltijd	○	○	○	○	○	○	○

Appendix B

Informed Consent

Toestemmingsformulier proefpersoon

Verantwoordelijke onderzoeker naam: Jelte Bos
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Uitvoerende onderzoekers naam: Maks Keppel
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Te lezen en in te vullen door de proefpersoon

- Ik ben op een voor mij duidelijke wijze [mondeling en schriftelijk] ingelicht over de aard, de methode, het doel, de risico's en de belasting van het onderzoek. Ook kon ik vragen stellen. Mijn vragen zijn voldoende beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.

- Ik weet dat meedoen vrijwillig is. Ook weet ik dat ik op ieder moment kan beslissen om toch niet mee te doen of te stoppen met het onderzoek. Daarvoor hoef ik geen reden te geven.

- Ik weet dat sommige mensen mijn gegevens kunnen inzien. Die mensen staan vermeld in de informatiebrief.

- Ik geef toestemming voor het verzamelen en gebruiken van mijn gegevens op de manier en voor de doelen die in de informatiebrief staan. Ik weet dat de gegevens vertrouwelijk zullen worden behandeld en dat resultaten van het onderzoek alleen anoniem aan derden bekend gemaakt zullen worden.

- Ik geef toestemming om mijn gegevens nog 10 jaar na dit onderzoek te bewaren.

- Ik geef toestemming om mijn gegevens geanonimiseerd voor gelijksoortige andere studies te gebruiken.

- Ik zal in de komende 2 maanden geen informatie delen met potentiële participanten over de procedures binnen het experiment en het doel van het onderzoek.

- Ik wil meedoen aan dit onderzoek.

Naam proefpersoon:
Handtekening: Datum : __ / __ / __

In te vullen door de uitvoerende onderzoeker

- Ik verklaar dat ik deze proefpersoon volledig heb geïnformeerd over het genoemde onderzoek.

- Als er tijdens het onderzoek informatie bekend wordt die de toestemming van de proefpersoon zou kunnen beïnvloeden, dan breng ik hem/haar daarvan tijdig op de hoogte.

Naam onderzoeker:
Handtekening: Datum: __ / __ / __

De proefpersoon krijgt een volledige informatiebrief mee, samen met een kopie of duplicaat van het getekende toestemmingsformulier.

General information for participants

Beste deelnemer,

Hartelijk dank voor je interesse in deelname aan dit onderzoek aan de VU te Amsterdam. Voor dit onderzoek zal je meedoen aan een experiment waarin zal worden gekeken naar inbeeldingsvermogen over zelfbeweging en je houdingsevenwicht. Lees deze informatiebrief rustig door zodat je weet wat er gaat gebeuren. Als je na het lezen van deze brief nog vragen hebt met betrekking tot dit onderzoek, kun je deze altijd stellen aan de aanwezige onderzoekers: deze zullen je zo goed mogelijk te woord staan. Meer informatie over dit onderzoek kan worden gegeven zodra het hele onderzoek is afgerond.

Om onze onderzoeksvraag te kunnen beantwoorden vragen we je om op twee verschillende momenten deel te nemen. Tijdens het experiment zal worden gevraagd om geblinddoekt en met een koptelefoon op een platform te gaan zitten dat langzaam zal worden bewogen. Ondertussen zul je via de koptelefoon instructies krijgen met betrekking tot de beweging die je jezelf dient in te beelden aan de hand van een aantal ijkpunten die je ter plekke worden uitgelegd. Belangrijk is hierbij dat je jezelf niet laat afleiden door wat je voelt, maar je volledig concentreert op die inbeelding. Aangezien je op een bewegend toestel ligt, bestaat de kans dat je jezelf hierbij wat oncomfortabel voelt. Omdat het niet de bedoeling is om je echt ziek te maken, vragen we regelmatig hoe je jezelf voelt. Zodra je jezelf op enig moment daadwerkelijk misselijk voelt, geef je dat direct aan en zal het experiment voor dat moment worden gestopt. We hopen wel dat als dit je eerste moment was, je toch de tweede ook nog komt. Je krijgt gegarandeerd een bonus als je beide meetmomenten hebt deelgenomen. Elke sessie duurt in totaal ongeveer 30 minuten, waarvan je 20 minuten op het platform zit. Daarnaast zal voordat je plaatsneemt op het platform een vragenlijst met je worden doorgenomen en zal je gevraagd worden kort stil te staan op een balansbord. Ditzelfde zal nog een keer gebeuren na afloop.

Je persoonlijke gegevens zullen alleen inzichtelijk zijn voor de onderzoekers verbonden aan dit onderzoek. Voor een eventuele publicatie zullen de gegevens worden geanonimiseerd en deze zullen na afloop op geen manier aan je gekoppeld worden. Wel zullen deze geanonimiseerde gegevens, volgens protocol, 10 jaar bewaard worden in het archief. Duidelijk moet zijn dat je te allen tijde, zonder opgaaf van reden, mag stoppen met deelname. Hier zijn dan uiteraard geen nadelige gevolgen voor je aan verbonden.
Voor deelname aan dit experiment krijg je 10 euro per dag plus een bonus van 10 euro als je aan beide dagen hebt deelgenomen. In dat laatste geval krijg je dus totaal 30 euro. Reiskosten worden niet apart vergoed.

Indien je deze brief goed hebt doorgelezen en begrepen, en je besluit deel te nemen aan dit onderzoek, vragen we je om het toestemmingsformulier te ondertekenen.

Met vriendelijke groet,

Het onderzoeksteam