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# Subjective Reports and Postural Performance Among Older Adult Passengers on a Sea Voyage

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## Abstract

We sought to evaluate changes in subjective experience and postural performance among older adult passengers during the first 2 days of a sea voyage. On a vacation cruise, volunteer passengers gave verbal ratings of subjective bodily stability and awareness of ship motion followed by performance on the tandem Romberg test while facing fore-aft and athwartship. Data were collected when the ship was at the dock and on each of the first 2 full days at sea. Ship motion reduced subjective bodily stability and performance on the Romberg test and increased awareness of ship motion. On the first day at sea, Romberg performance was more strongly impacted by motion of the ship in roll (i.e., when facing fore-aft) than in pitch (i.e., when facing athwartship). Also on the first day at sea, subjective bodily stability was correlated with Romberg performance when facing fore-aft but not when facing athwart. In summary, at the beginning of the voyage older adult passengers on a sea voyage exhibited consistent changes in subjective awareness and postural performance. Subjective reports were correlated with postural performance in ways that appeared to be functional. We suggest that this finding may help to illuminate the role of conscious awareness within ecological analyses of perception and action.

Aging is associated with an increased risk of falling. Among older adults, falls are more likely to carry serious health complications (Hill, Schwarz, Flicker, & Carroll, 1999; Sattin, 1992). It may not be a coincidence that older adults often exhibit heightened fear of falling (e.g., Vellas, Wayne, Romero, Baugartner, & Garry, 1997). The increased risk of falling and the increased adverse consequences of falls, coupled with the heightened fear of falling, might suggest that older adults would choose to avoid situations that pose a challenge to the stability of stance and locomotion. Consistent with this idea, older adults who fear falling tend to avoid physical activities that they perceive to be risky (e.g., Zijlstra et al., 2007).

A dramatic exception to the common narrative relating fall risk, fear of falling, and avoidance of risky situations is the fact that millions of older adults choose to embark upon sea voyages. In North America alone, there are more than 10 million paid passengers each year, and approximately 45% of these passengers are 55 years of age or older (Cruise Lines International Association, Inc., 2010). To embark on a sea voyage is to experience life on a moving surface. This is true despite efforts to reduce the motion of ships at sea. Cruise companies have attempted to design vessels with increased stability, and cruise ships typically avoid areas of stormy weather. Although these approaches are helpful they do not eliminate ship motion. As one example, ocean swell from a distant storm can be on the order of meters and can last for several days (e.g., Beer, 1997). In ordinary, terrestrial life when we are standing up the surface of support is stationary (e.g., the floor or the ground) or moves primarily in translation along one axis (e.g., an elevator or escalator). By contrast, on a ship at sea the surface of support (the deck) exhibits oscillatory motion simultaneously in six degrees of freedom: three of translation (surge, sway, and heave) and three of rotation (roll, pitch, and yaw). Motions in these six degrees of freedom are weakly coupled and are quasi-periodic. In addition, the primary power of these oscillations is in the same frequency range (0.1–0.4 Hz) as the oscillations that characterize standing body sway. Finally, as noted earlier the amplitude of movement can be on the order of meters, even in mild weather. For all of these reasons, ship motion presents significant challenges to the control of stance. Presumably, those challenges will be amplified among persons whose postural control is independently challenged by other factors, such as aging.

The motion of ships at sea leads to changes in posture (e.g., Stoffregen, Chen, Varlet, Alcantara, & Bardy, 2013) and gait (e.g., Stevens & Parsons, 2002). Sea travel also leads to changes in subjective experience. Collectively, these changes are known as getting your sea legs (Stevens & Parsons, 2002). Some of the subjective effects of sea travel have been evaluated through surveys of sea passengers. The most comprehensive such study was conducted by Lawther and Griffin (1988), who evaluated subjective aspects of sea travel among approximately 20,000 passengers. With respect to the present study the work of Lawther and Griffin had three limitations. First, Lawther and Griffin focused on seasickness and did not include data on other aspects of subjective experience. Second, the study of Lawther and Griffin was limited to ferries, that is, to relatively short voyages lasting no more than a few hours. Such trips are so brief that many passengers do not get their sea legs. Finally, Lawther and Griffin did not measure perceptual-motor performance in the control of the body, and they did not evaluate relations between subjective experiences and actual bodily control. In the present study, we addressed relations between ship motion, postural performance, and subjective experiences among older adult passengers on a multiday sea voyage. Unlike Lawther and Griffin, we did not collect data relating to seasickness.

On land, researchers have compared reports of subjective postural steadiness with data on actual postural performance. For example, Hauck, Carpenter, and Frank (2008) measured subjective balance efficacy before a series of challenging balance tasks, which included the duration of one-leg stance. After completing the balance tasks, participants rated their perceived stability. Both subjective balance efficacy and perceived stability were positively correlated with the duration of one-leg stance ($r = .388$ and $.652$, respectively, each $p < .05$). We used a similar method with older adult passengers on a ship at sea.

To evaluate the effects of ship motion we collected data before and during a sea voyage. We selected a vessel of moderate size (~1,000 passengers) and of recent construction. To evaluate adaptation to ship motion we collected data on successive days at sea. We designed a testing protocol that allowed us rapidly to characterize both postural performance and subjective experiences of bodily stability. We evaluated postural performance using the sharpened Romberg test. We hypothesized that scores for Romberg tests and subjective body stability would be highest when the ship was at the dock. On Day 1, we expected lower Romberg and body stability scores while awareness of ship motion would increase. On Day 2, we expected lower scores than Day 2 but higher scores than Day 1 for Romberg and body stability. On Day 2, ship motion awareness scores were expected to be higher than Day 0 but lower than Day 1.

On land, the spatial magnitude of standing body sway tends to be greater in the body's anterioposterior (AP) axis than in its medio-lateral (ML) axis (e.g., Balasubramaniam, Riley, & Turvey, 2000). At sea, relations between sway in the body's AP and ML axes are powerfully affected by the orientation of the body relative to the long and short axes of a ship. When facing the port or starboard side of a ship at sea (i.e., when facing athwartship) relations between sway in the body's AP and ML axes are similar to what has been reported on land. However, when facing either the bow or stern (i.e., when facing fore-aft), the relation is qualitatively reversed: sway is greater in the body's ML axis than in its AP axis (e.g., Chen & Stoffregen, 2012; Varlet et al., 2014). This qualitative change occurs in both the spatial magnitude and the temporal dynamics of body sway. Effect sizes for these effects are very large (e.g., 0.89 for Chen & Stoffregen, 2012; 0.85 for Varlet et al., 2014). These effects may be related to facts of naval architecture. In general, ships are longer than they are wide. A consequence of this is that in most situations ship motion in roll tends to be greater than ship motion in pitch. This factor also affects gait. Haaland, Kaipust, Wang, Stergiou, and Stoffregen (in press) recorded the timing of individual footfalls while maritime crewmembers walked back and forth along either the fore-aft or athwart axis of a ship at sea. They found that this simple manipulation affected patterns of step timing: The variability of stride time intervals and the coefficient of variation of stride intervals were greater when walking athwart than when walking fore-aft. For these reasons, we separately assessed balance performance as participants stood facing along the ship's long and short axes, that is, when participants were facing fore-aft versus athwartship. We predicted that this manipulation would significantly affect postural performance at sea.

# METHODS

## Participants

There were 104 participants (39 men and 65 women), ranging in age from 60 to 91 years (mean age = 70.38 years), in height from 1.47 m to 2 m (mean height = 1.69 m), and in weight from 49.89 kg to 139.7 kg (mean weight = 73.25 kg). All participants were community ambulators without assistive devices or prosthetic limbs.

The experimental protocol was approved in advance by the University of Minnesota Institutional Review Board. Due to the nature of the study participants did not complete a formal written informed-consent procedure. Doing so would have doubled (at least) the time required for data collection from each participant, with consequent reduction in the number of participants. In asking individuals to participate, we informed them that we were doing a scientific study under the aegis of the University of Minnesota and asked whether they would be willing to participate. Participants' names were recorded solely for the purpose of ascertaining which individuals participated on multiple days. Names were removed from the data before analysis.

**Experimental Setting**

The study was conducted aboard the M/V Explorer during the first three days of a 21-day Enrichment Voyage, including the embarkation day and the first two full days at sea. The passengers comprised 800 persons varying in age across the life span. We limited our sample to passengers 60 years of age and above. Passengers occupied staterooms but were free to ambulate throughout public areas of the ship at their discretion. Numerous scheduled activities were available, including lectures, dance classes, and yoga classes.

The ship was 180 m long with a 26 m beam. It displaced 25,000 metric tons and cruised at approximately 18 knots. It was launched in 2001 and has been in service since 2004. The ship departed from Nassau, The Bahamas, at 17:00 on Wednesday, December 18, 2013 and arrived at Santo Domingo, Dominican Republic, at 08:00 on Saturday, December 21. All data were collected on board the ship.

**Procedure**

Experimenters were positioned in public areas of the ship and solicited volunteer participants from passengers in or passing through these areas. Only individuals who indicated that they were 60 years of age or older were invited to participate. As the purpose of the voyage was vacation we did not ask individuals to commit to repeated participation across days; rather, on each day we accepted those individuals who were willing to participate, regardless of whether or not they had participated on previous days. To maximize the number of participants the amount of information collected from each participant was kept to a minimum. We recorded sex, age, and self-reported height and weight. We next asked participants to rate their current subjective bodily stability and their current subjective awareness of ship motion. For each question participants were asked to respond using a 10-point scale. For subjective bodily stability, 1 represented minimum stability with fear of imminent falling, whereas 10 represented maximum stability. For awareness of ship motion, 1 represented no awareness of ship motion, and 10 represented constant awareness of ship motion. The 10-point rating of subjective bodily stability was adapted from Jang, Hsiao, and Hsiao-Wecksler (2008). Jang et al. did not report formal evaluation of the validity of their rating scale. In this respect our survey was similar to previous surveys used on sea voyages, which also were not subjected to formal validation procedures (e.g., Lawther & Griffin, 1986, 1988).

After obtaining subjective ratings, we measured postural performance utilizing the tandem Romberg test (Vereeck, Truijen, Wuyts, & Van de Heyning, 2006). Participants stood with one foot directly in front of the other (heel to toe) with eyes closed. Participants were free to position or move their arms in any way that they wished. The dependent variable was the number of seconds that stance could be maintained without moving either foot and without touching any object or surface with the hands. For each participant, we evaluated performance once while facing fore-aft and once while facing athwart. Even-numbered participants began with the fore-aft test, and odd-numbered participants began with the athwart test.

We collected data when the ship was docked in Nassau (on the main embarkation day; Day 0) and on each of the two full days at sea (Day 1 and Day 2). Data collected on Day 0, while the ship was docked and immobile, served as a baseline. We used Spearman's r rather than Pearson's r for correlations that included subjective ratings. We did this because of the ordinal monotonic nature of the questions (Lehman, 2005). For correlations that involved only data on postural performance we used Pearson's r.

We evaluated sea state using the Beaufort scale, a standard scale relating surface winds to wave motion (Beer, 1997). On the Beaufort scale, 1 = flat calm and 10 = hurricane.

## RESULTS

The weather was partly cloudy with occasional squalls of rain. On Day 1, the sea state was approximately 3.5 on the Beaufort scale, corresponding to moderate levels of ship motion. On Day 2, the sea state gradually increased from 2 (relatively mild ship motion) to 3 on the Beaufort scale.

There were 43 participants on Day 0 (19 male and 24 female), 32 on Day 1 (11 male and 21 female), and 29 on Day 2 (9 male and 20 female). Each individual participated on only one day.

### Subjective Ratings

The data are summarized in Figure 1. For each survey question we conducted separate 2 (sex) x 3 (days) between-participants analyses of variance. For subjective bodily stability the main effect of days was significant, $F(2, 103) = 17.30$, $p < .01$, partial $\eta^2 = .26$. The main effect of sex and the Days x Sex interaction were not significant. For subjective awareness of ship motion the main effect of days was significant, $F(2, 103) =$

191.38, p < .01, partial $\eta^2$ = .80. The main effect of sex and the Day x Sex interaction were not significant.

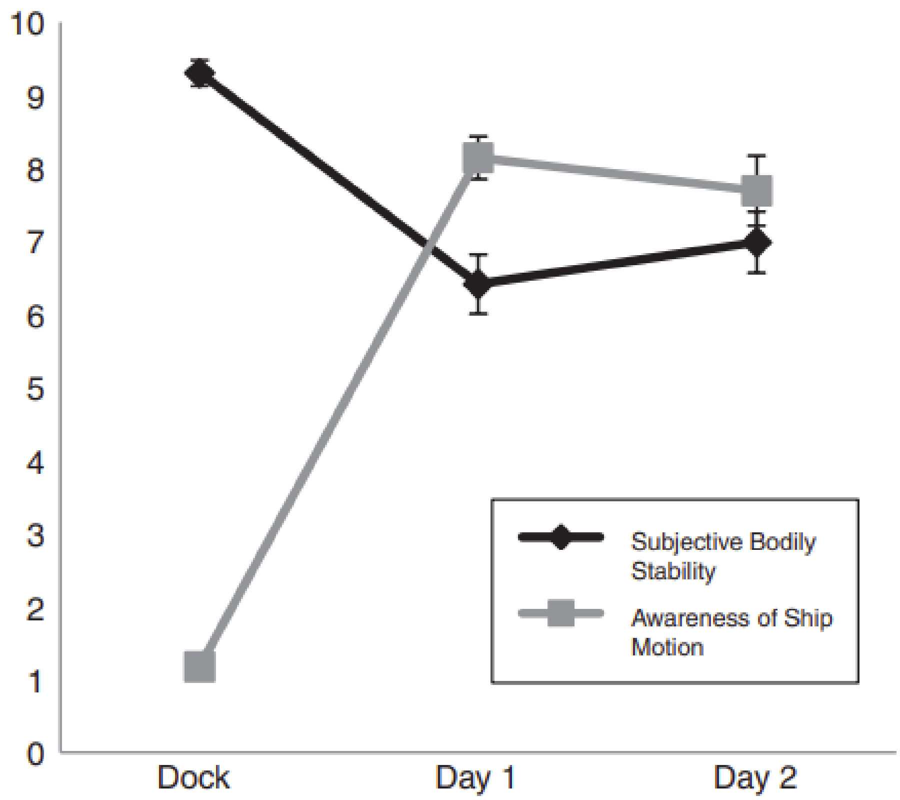


FIGURE 1 Subjective ratings as a function of testing day. Day 0: On the ship, at the dock before the beginning of the voyage. Day 1: First full day at sea. Day 2: Second full day at sea. The error bars illustrate the standard error of the mean.

**Postural Performance**

Data on postural performance as measured via the tandem Romberg are not normally distributed. To account for this fact we used log-transformed data in our inferential statistics (Box & Cox, 1964). For clarity of presentation the figures show untransformed data. The data are summarized in Figure 2. We conducted a 2 (sex) x 2 (direction: fore-aft vs. athwart) x 3 (days) analysis of variance on logtransformed scores, with sex and days as between-participants factors and direction as a within-participants factor. The analysis revealed a significant effect of days, *F* (2, 98) = 16.85, p < .01, partial $\eta^2$ ¼ .26. There were no other significant effects.

For each day, we examined the correlation between scores on the tandem Romberg test while facing fore-aft versus athwart. Because sex did not have any significant effects in our earlier analyses, we omitted it from our correlational analyses. At the dock (Day 0), Romberg scores in the fore-aft and athwart directions were strongly correlated (r = .65, n = 43), p < .01 (Figure 3A). On Day 1, the correlation between the fore-aft and athwart directions was not significant, r = .26, n = 32, p = .14 (Figure 3B). However, on Day 2 the correlation between performance in the fore-aft and athwart directions was again significant, r = .59, n = 29, p < .01 (Figure 3C).

**Correlations Between Subjective**

Ratings and Postural Performance We examined correlations between subjective ratings and postural performance in the fore-aft and athwart directions on each testing day. On the first day at sea (Day 1), the correlation between subjective bodily stability and postural performance was positive and significant when facing fore-aft, p = .40, r = .025 (Figure 4). There were no other significant effects.

Anecdotally, we did not observe any falls on the ship at any time among study participants or among other passengers.

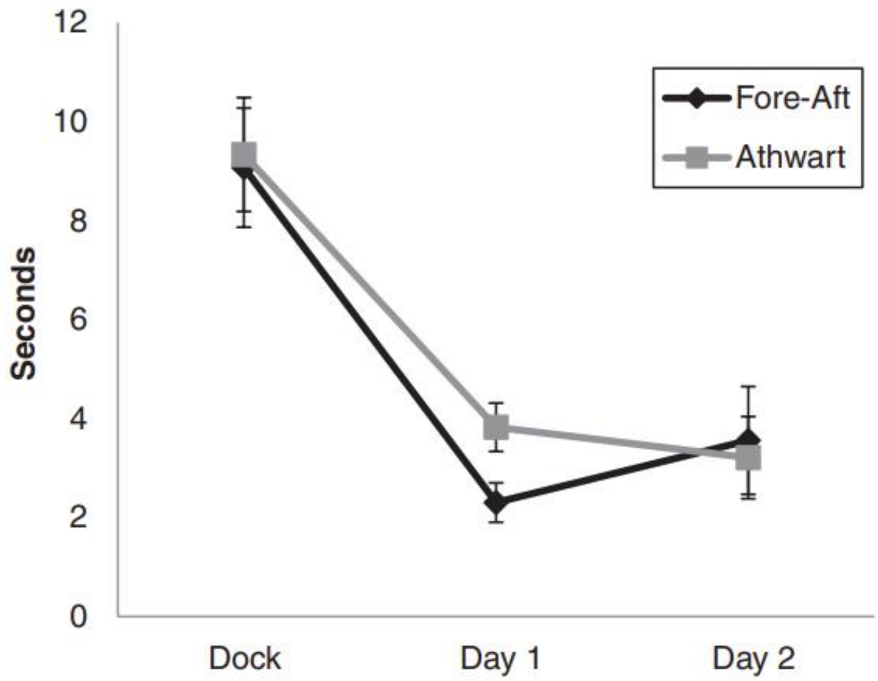


FIGURE 2 Postural performance (mean seconds duration of stance) on the tandem Romberg test as a function of testing day. Athwart: Test conducted while facing the side of the ship (port or starboard). Fore-aft: Test conducted while facing the ship's bow. The error bars illustrate the standard error of the mean.

## DISCUSSION

Before and during a sea voyage we obtained data from older adult passengers on their subjective experiences and on postural performance in the tandem Romberg test. Both subjective bodily stability and postural performance were reduced on the first day at sea. Subjective reports and postural performance changed over successive days at sea, including changes in postural performance that were direction specific. In addition, we found a significant correlation between postural performance when facing fore-aft and subjective bodily stability. We discuss these results here.

### Subjective Reports

Before the voyage began (Day 0) ratings of subjective bodily stability were similar to those reported among healthy young (age range = 24– 39 years) adult nonpregnant women (Jang et al., 2008) and among healthy young (age range 27 – 33 years) pregnant women without morning sickness (Yu, Chung, Hemingway, & Stoffregen, 2013). On the basis of these results we conclude that before exposure to ship motion our healthy older adults experienced typical levels of subjective bodily stability.

Subjective bodily stability declined on the first day at sea (Day 1), relative to prevoyage values (Figure 1). The observed effect may underestimate the real effect, given that our data collection began more than 12 hr after the ship departed. It is likely that some adaptation had already occurred during the initial 12 hr of the voyage (cf. Stoffregen et al., 2013). That is, subjective bodily stability may have been even lower in the initial hours of the voyage.

Subjective awareness of ship motion was high on the first day at sea and remained high on the second day (Figure 1). Anecdotal accounts indicate that persons who have fully adapted to life at sea have a reduced subjective awareness of ship motion (e.g., Stevens & Parsons, 2002). Thus, our results suggest that it may take more than 48hr for the subjective awareness of ship motion to decline to asymptotic level.

### Postural Performance

At the dock, performance on the tandem Romberg test was within one standard deviation of land-based data reported in similar age groups (e.g., Iverson, Grossman, Shaddeau, & Turner, 1990). Accordingly, we conclude that before exposure to ship motion our healthy older adults exhibited typical performance on the tandem Romberg test.

*General impact of ship motion*. On Day 1, ship motion dramatically reduced performance on the Romberg (Figure 2). On Day 2, overall performance was unchanged (Figure 2), but some individuals began to recover, as shown by the outliers in Figure 3C. These results are consistent with studies showing that in healthy younger adults the spatial magnitude of standing body sway is greatly increased by the onset of ship motion (e.g., Mayo, Wade, & Stoffregen, 2011; Stoffregen et al., 2013; Stoffregen, Villard, Chen, & Yu, 2011). In future research it will be important to extend testing over several additional days so as to determine asymptotic levels of performance (for a given sea state). It is unclear, for example, whether performance would ever return to land-based levels. Research with younger adults suggests that adaptation to ship motion may include an increase in self-selected stance width (Stoffregen et al., 2013; Stoffregen, Chen, Yu, & Villard, 2009) and an increased tendency to rely on stepping or staggering to maintain upright stance (e.g., Chen & Stoffregen, 2012). These adjustments to stance have been observed in healthy young adults at sea and reflect an adaptive ability to adjust postural control to the characteristic challenges of ship motion.

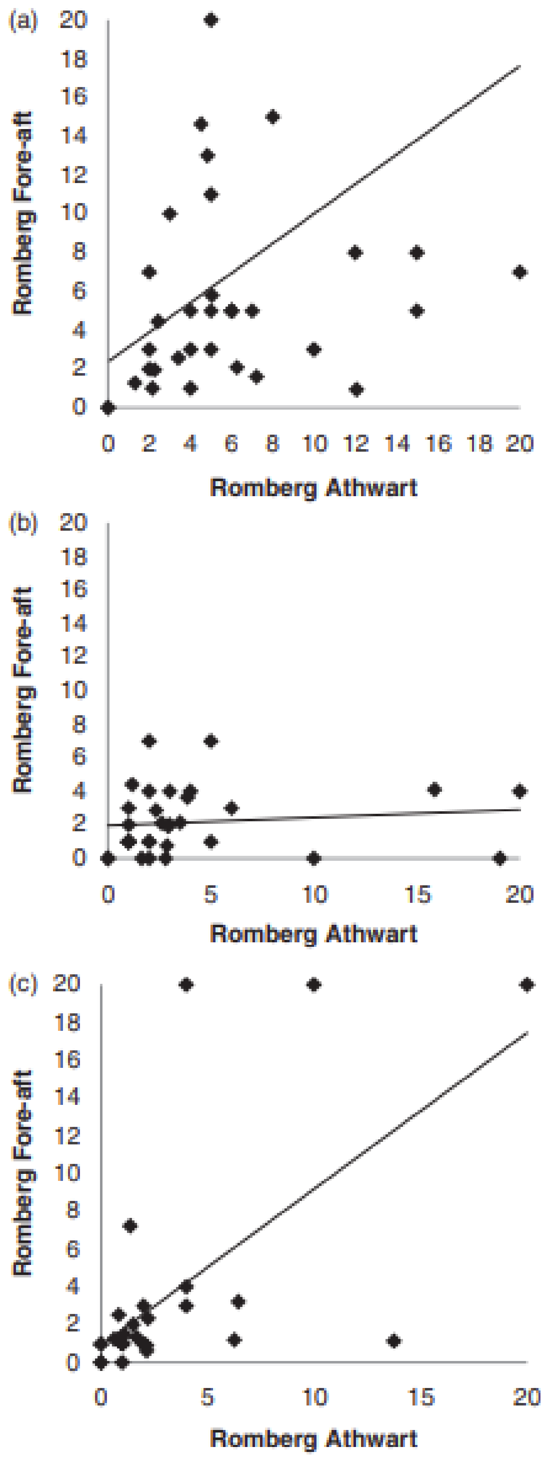


FIGURE 3 Scatterplots illustrating performance on the tandem Romberg test while facing fore-aft versus athwart. (a) Day 0, at the dock ($r = .65$, $p < .01$). (b) Day 1, the first full day at sea ($r = .26$, $p = .14$). (c) Day 2, the second full day at sea ($r = .59$, $p < .01$).

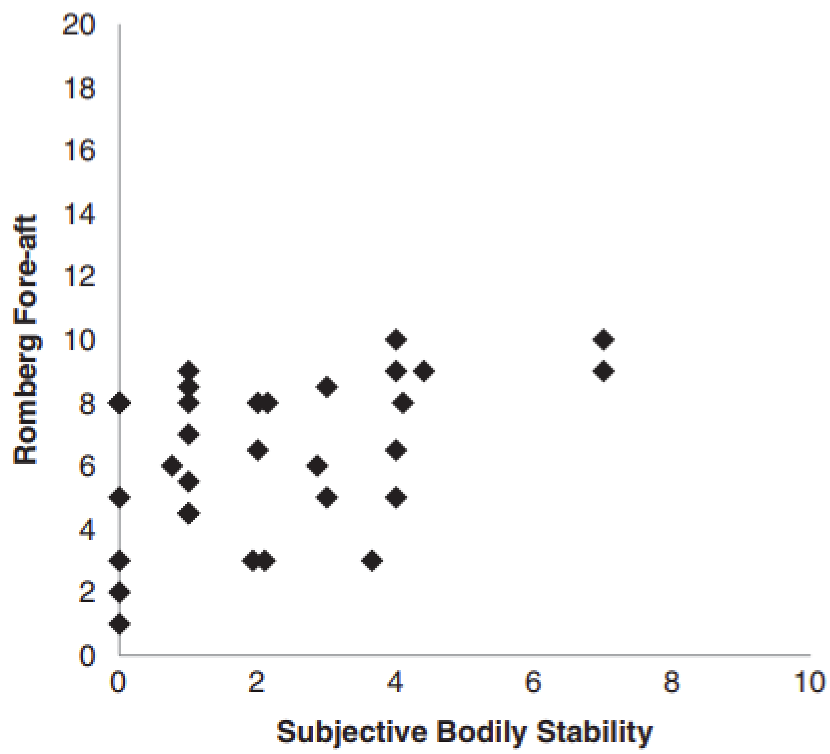


FIGURE 4 Scatterplot for Day 1, the first full day at sea, illustrating the statistically significant correlation between rated subjective bodily stability and performance on the tandem Romberg test when facing the ship's bow ($\rho = .4$, $p = .025$).

Under terrestrial conditions stepping and staggering typically are interpreted as signs of instability and as risk factors for falls (e.g., Kimbell, 2002). This interpretation has been applied to older adult populations (e.g., Contreras & Grandas, 2012) but also to clinical populations in other age ranges (e.g., Kloos, Kegelmeyer, Young, & Kostyk, 2010). Very broadly, stepping and staggering typically are interpreted in a negative light as emergency measures that compensate for deficient postural control. At sea these same behaviors may be used to compensate for an external factor (ship motion) rather than an internal factor (deficient postural control). Accordingly, at sea, stepping and staggering may be indicators of stability and resistance to falling. It is to be remembered that among the hundreds of older adult passengers we observed no falls at any time. Passengers who successfully adapted to ship motion would increase their generalized bodily stability but might not improve their performance on the tandem Romberg test. An essential feature of the tandem Romberg is the implication that stepping is compensation for otherwise deficient control of the body. If our interpretation is correct, then sea travel could, in effect, constitute a type of balance training, giving passengers the opportunity (indeed, the requirement) to develop their stepping and staggering skills in a setting in which these adjustments do not stem from internal deficiencies.

*Body orientation relative to pitch and roll*. At the dock (Day 0), postural performance did not differ when facing fore-aft versus athwart (Figure 2), and performance when facing in the two directions was strongly correlated (Figure 3A). On the first full day at sea (Day 1), postural performance was more strongly impacted by ship motion in roll than in pitch (Figure 2). Consistent with this effect, on Day 1 there was not a significant correlation between performance when facing fore-aft versus when facing athwart (Figure 3B). On the second day at sea (Day 2), the difference in performance when facing fore-aft versus facing athwart had disappeared (Figure 2), and the correlation between performance when facing fore-aft versus facing athwart was again significant, although this effect may be related to outliers (Figure 3C). That is, although at an overall level performance on Day 2 was unchanged some participants appeared to have made some improvement in their ability to deal with the unique characteristics of roll motion. These are novel results, but they are consistent with studies in younger adults that have documented differential effects of roll and pitch on the kinematics of standing body sway (Chen & Stoffregen, 2012; Varlet et al., 2014) and gait (Haaland et al., in press). Ships tend to be longer than they are wide. A consequence is that, all other factors being equal, ship motion in roll tends to have higher magnitude and frequency than ship motion in pitch (e.g., Varlet et al., 2014). The greater overall level of ship motion in roll constitutes a greater challenge to upright posture, which is reflected in greater postural sway in the body axis that is perpendicular to the ship's short (i.e., roll) axis (cf. Balasubramaniam et al., 2000; Kinsella-Shaw, Harrison, Carello, & Turvey, 2013).

**Links Between Subjective Reports and Postural Performance**

Postural and subjective measures were not significantly correlated before the voyage began (Day 0). By contrast, studies conducted on land typically report significant positive correlations between subjective reports of balance efficacy and performance on clinical balance tests, such as the Romberg, tandem Romberg, or stance on one leg (e.g., Hauck et al., 2008), and between subjective balance efficacy and the kinematics of standing body sway (e.g., Schieppati, Tacchini, Nardone, Tarantola, & Corna, 1999). In the present study, the absence of such correlations when the ship was at the dock may be related to unique features of our study design, such as the fact that testing was done in public spaces on the ship. It is also possible that our results were affected by the selfselected nature of the passengers. Presumably, persons who believed that they would be adversely affected by ship motion did not embark upon the cruise.

On the first full day at sea (Day 1) subjective feelings of body stability were significantly correlated with postural performance when facing fore-aft but not when facing athwart (Figure 4). These results make sense because performance in the tandem Romberg would be more strongly affected by roll motion when facing fore-aft and by pitch motion when facing athwart. As noted earlier ship motion in roll tends to be greater than ship motion in pitch (e.g., Chen & Stoffregen, 2012; Varlet et al., 2014); therefore, these results suggest that at the beginning of the voyage participants' subjective experiences of bodily stability were related to their actual ability to compensate for motion of the ship in its roll axis. That is, subjective bodily stability appears to have been related to participants' ability to compensate for this more challenging type of ship motion. Such a link between performance and subjective experience would be adaptive.

On land, subjective balance efficacy is related to the degree of threat to balance. Hauck et al. (2008) asked participants to stand on low (40 cm above ground level) and high (140 cm above ground level) surfaces. The duration of one-leg stance was greater for the low surface and was reduced on the higher surface. The high surface was also associated with lower ratings of subjective balance efficacy. Our results confirm the findings of Hauck et al. and extend them to the domain of postural threats arising from motion of the ground surface (the ship). Our results reveal that the subjective experience of bodily stability can be related to variations in the magnitude of imposed motion, in this case, the fact that ship motion was greater in roll than in pitch.

On the second full day at sea (Day 2), postural performance was no longer correlated with subjective bodily stability or awareness of ship motion. Participants continued to feel unstable (relative to when the ship had been at the dock), and they continued to be aware of ship motion, but they appear to have separated these perceptions from their ability to control their own bodies. The fading awareness of ship motion that features in anecdotal accounts may have occurred over longer time spans, that is, several more days.

**Awareness and Action**

Our results relating subjective bodily stability on Day 1 to postural performance (when facing fore-aft) may be relevant to issues that are more theoretical. For centuries, scholarly consideration of perception was focused on subjective awareness. That is, in theoretical accounts the product of perception traditionally was thought to be a person's conscious awareness of some fact about the world, such as the presence, size, or color of an object (e.g., Lindberg, 1976). One way in which the Ecological Approach to Perception and Action differs from such traditional approaches is in its assertion that the primary purpose of perception is to facilitate the control of action. Whereas in traditional accounts conscious awareness is primary, in research inspired by the Ecological Approach the conscious awareness of human perceivers typically has been treated as being of peripheral interest at best. Yet it remains the case that humans (at least) have powerful and persistent subjective awareness of the surroundings and of their own activity in relation to the surroundings. Within the Ecological Approach, many empirical studies have used subjective reports as data, but in most cases these subjective data have been treated as proxies for some underlying, more basic perceptual sensitivity. Few studies have attempted to investigate relations between subjective awareness and the control of action as such. For example, Bootsma, Bakker, van Snippenberg, and Tdlohreg (1992) demonstrated effects of anxiety on the perception of an affordance for reaching to intercept a moving target. Participants judged whether targets were reachable but did not actually attempt to reach them. That is, Bootsma et al. evaluated relations between anxiety and perception but did not evaluate relations between anxiety and the control of action.

If the primary function of perception is to facilitate action, then of what should we be aware? One possibility is that we should be aware of those aspects of situations that are most challenging, that is, most likely to lead to failure in the performance of action. Stabilization of the body is an ongoing interaction between the individual and forces and surfaces in the environment. Thus, awareness of bodily stability implies awareness of an ongoing interaction between the individual and the environment (cf. Riccio, Martin, & Stoffregen, 1992). On the first day at sea we found that subjective bodily stability was correlated with actual postural performance when facing fore-aft but not when facing athwart. These findings are consistent with the idea that selective or differential conscious awareness was related to the fact that actual postural stability was differentially challenged by ship motion in roll and pitch. A connection between awareness and the more challenging of perception –action skills might be to strengthen adaptive relations between perception –action and conscious volition in at least two ways. First, such awareness might aid in volitional decision making. Second, such awareness might dispose the individual deliberately to focus on and test the limits of the more challenging task. Our method, in which subjective reports could be correlated with different perception –action tasks executed within a single testing session, might prove useful for future research on these issues.

## CONCLUSION

We assessed subjective experiences and changes in balance performance that accompanied a multiday sea voyage. In older adult passengers, we evaluated subjective experiences and balance performance before a sea voyage and on each of the first two days at sea. The onset of ship motion led to a reduction in subjective bodily stability and to reductions in balance performance when facing fore-aft and when facing athwartship. Balance performance was more strongly influenced by ship motion in roll than in pitch, and ratings of subjective bodily stability were more strongly correlated with roll-related challenges to balance performance than with pitch-related challenges to balance performance. Our results suggest that among healthy older adult passengers relations between subjective experience and balance performance were functional.

A remarkable albeit anecdotal feature of our study is that none of our participants fell, and we observed no falls among any the hundreds of older adult passengers. An implication is that the challenge of ship motion was met successfully by people from 60–90 years of age, some of who used canes or walkers. Our results raise the possibility that multiday sea voyages may provide a form of safe, enjoyable balance training.

In future research it will be important to determine whether balance skills acquired in “getting your sea legs” are retained after the return to life on land. In future research it will be useful to address relations between shipboard performance and age-related differences in fall risk. One approach might be to use additional biomechanical measures and fall risk-related measures to explore a new research model for posture and gait in aging. The effects of ship motion on standing body posture are similar to effects of healthy aging; that is, ship motion appears to “instantly age” healthy young adults (e.g., Stoffregen et al., 2013). Similarly, the gait of mariners is visibly distinct from terrestrial gait, even to casual observers (Jacobs & Hawley, 2007; Stevens & Parsons, 2002). It may be that the gait of healthy young adults at sea resembles the gait of healthy older adults on land. Thus, the study of posture and gait at sea may permit us to use nonclinical populations (e.g., healthy young adults) as convenient, inexpensive, noninvasive models for aging. Therefore, we plan to evaluate the extent to which young adults’ posture and gait on ships at sea can be an innovative new research model for the effects of aging and may provide general insights into the mechanisms of stability of stance and locomotion.

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