2-9-2015

Walking Before and During a Sea Voyage

Chih-Hui Chang

Nicholas Stergiou

Jeffrey P. Kaipust

Eric Haaland

Yi Wang

See next page for additional authors

Authors
Chih-Hui Chang, Nicholas Stergiou, Jeffrey P. Kaipust, Eric Haaland, Yi Wang, Fu-Chen Chen, and Thomas A. Stoffregen

Walking Before and During a Sea Voyage

Chih-Hui Chang Department of Physical Education National Kaohsiung Normal University, Taiwan

Nicholas Stergiou and Jeff Kaipust Biomechanics Research Building University of Nebraska at Omaha

Eric Haaland and Yi Wang School of Kinesiology University of Minnesota

Fu-Chen Chen Department of Recreational Sport and Health Promotion National Pingtung University of Science and Technology, Taiwan

Thomas A. Stoffregen School of Kinesiology University of Minnesota

Abstract

Stationary and moving surfaces impose different constraints on walking. In this study we investigated within-participants differences between walking on a ship before (at the dock) and during (at sea) a sea voyage. Four individuals participated in the study. While on the ship they wore a tri-axial accelerometer (ActiGraph GT3Xþ; ActiGraph LLC, Pensacola, FL) on their waists. Activity data were sampled at 30 Hz. Data were collected on the day before the voyage began and on several days at sea. The number of steps per day was greater at the dock than at sea. The net resultant force per day also was greater at the dock than at sea. However, resultant force per step was greater at sea (79.97 ^ 8.50 vector magnitude counts/ step) than on land (62.94 ^ 10.03 vector magnitude counts/step). In addition, we observed variations in resultant force per step across days at sea. Ship motion decreased overall activity but increased the force per step.

Motion of a ship at sea mandates changes in the control of the body. In qualitative terms, the phenomena of living and working on ships at sea have been known for millennia. Perhaps surprisingly, there has been very little controlled scientific research in which quantitative data on human movement have been collected on ships at sea. Research has shown that standing body sway is powerfully affected by ship motion (e.g., Mayo, Wade, & Stoffregen, 2011) and that sway changes with continued exposure as people get their sea legs (Stoffregen, Chen, Varlet, Alcantara, & Bardy, 2013).

Most studies of body sway at sea have focused on body kinematics, but in one case the data were the magnitude of ground reaction forces during stance (Stoffregen, Villard, Chen, & Yu, 2011). Ground reaction force was measured on land before a sea voyage and separately on each of 4 days at sea. The overall magnitude of ground reaction force was several times greater at sea than on land. In addition, the magnitude of ground reaction force varied across days at sea with daily variations in the magnitude of ship motion.

A classic feature of getting one's sea legs is changes in gait. However, we are not aware of any studies in the peer-reviewed literature of the quantitative kinematics or kinetics of human gait on ships at sea. Studies of gait at sea typically have reported only qualitative measures, such as the number of motioninduced interruptions to gait (Crossland et al., 2007; Dobie, May, & Flanagan, 2003; Graham, 1990). Lawther and Griffin (1988) recorded ship motion and related these data to subjective reports of seasickness but did not include data on walking. Heus, Wertheim, and Havenith (1998) measured oxygen consumption during walking on a motion base ship simulator but did not include any direct measures of either the kinematics or kinetics of walking.

Laboratory research allows for control of stimulus motion but has important limitations. Among these are the brevity of exposure to motion stimuli. For example, in Dobie et al. (2003) and Heus et al. (1998) the total duration of exposure to simulated ship motion was less than 60 min. In addition, the magnitudes of motion that typically occur on ships at sea greatly exceed motion magnitudes that can be generated by laboratory devices. In the present study, we used wireless accelerometry to evaluate daily variations in gait before and during a sea voyage. Wireless accelerometry is a recent technology that has been validated as a monitor of human locomotor activity in settings outside the laboratory (Cavanaugh, Kochi, & Stergiou, 2010; Storti et al., 2008).

In this study, we had two aims. First, we conducted a "proof of concept" to demonstrate that it is possible to collect quantitative data on human gait patterns under operational conditions at sea. Second, we asked whether simple measures of walking would be affected by the presence of ship motion (i.e., comparison of measurements taken before and during a voyage) and by variations in the magnitude of ship motion (i.e., daily changes in motion of a ship at sea). Our results confirm nautical lore about the affects of ship motion on human gait and demonstrate that with contemporary technology it is possible to conduct controlled, quantitative research on human gait at sea.

We obtained data on walking through the use of wireless accelerometers. Accelerometers have been widely used to evaluate human walking in terms of step counts (Brandes, Zijlstra, Heikens, van Lummel, & Rosenbaum, 2006), energy expenditure (Crouter, Clowers, & Bassett, 2006), and gait patterns (Kobsar, Olson, Paranjape, Hadjistavropoulos, & Barden, 2014; Menz, Lord, & Fitzpatrick, 2003). Contemporary wireless accelerometers are small and light, such that they do not interfere with ordinary behavior. Unlike other technologies, such as foot switches, wireless accelerometers allow for continuous data collection outside the laboratory for up to 7 days. Following previous research (e.g., Davis & Fox, 2007; Rowlands, Pilgrim, & Eston, 2008), in the present study we measured walking activity during unconstrained behavior over a period of several days.

In this sense, our study was observational. In terms of research design, the presence of ship motion (at the dock vs. at sea) was an independent variable that was under our control; in this sense, our study was experimental. At sea, we treated daily variation in ship motion as an independent variable. However, because we could not control these daily variations in this study we cannot reach conclusions about causal relationships between parameters of ship motion, such as its amplitude and frequency, and walking.

METHOD

Participants

Four of the authors (all males, mean age ¼ 35.94 ^ 13.30 years; mean height ¼ 179.32 ^ 9.75 cm; mean weight ¼ 79.00 ^ 11.11 kg) participated in the study (Eric Haaland, Jeff Kaipust, Thomas A. Stoffregen, and Yi Wang). The University of Minnesota Institutional Review Board approved the study. Informed consent was obtained from all participants before their participation in any part of the study.

Setting and Apparatus

The study was conducted aboard the R/V Thomas G. Thompson. The ship was 274 ft (83.51 m) long with a 52.5 ft (16 m) beam. The ship displaced 3,500 tons and cruised at 11 knots. The study was conducted before and during a 9-day cruise from Honolulu to Seattle. On Day 0, the ship was stationary at the dock in Honolulu. On Days 2 – 8, the ship traversed the open sea. On Day 9, the ship was in Puget Sound, where wave action was minimal, such that on Day 9 ship motion comprised translation but not oscillation.

Tri-axial accelerometers (ActiGraph GT3Xþ, ActiGraph, LLC, Pensacola, FL) were used to collect data. The ActiGraph registered three directional (anterio-posterial, AP; medio-lateral, ML; and vertical) accelerations. The ActiGraph was not sensitive to angular acceleration. One ActiGraph was attached to each participant by affixing it to an elastic strap that was worn around the waist. The location of the ActiGraph and the corresponding axes of motion are shown in Figure 1. We also monitored ship motion, using an ActiGraph that was rigidly affixed to the ship.

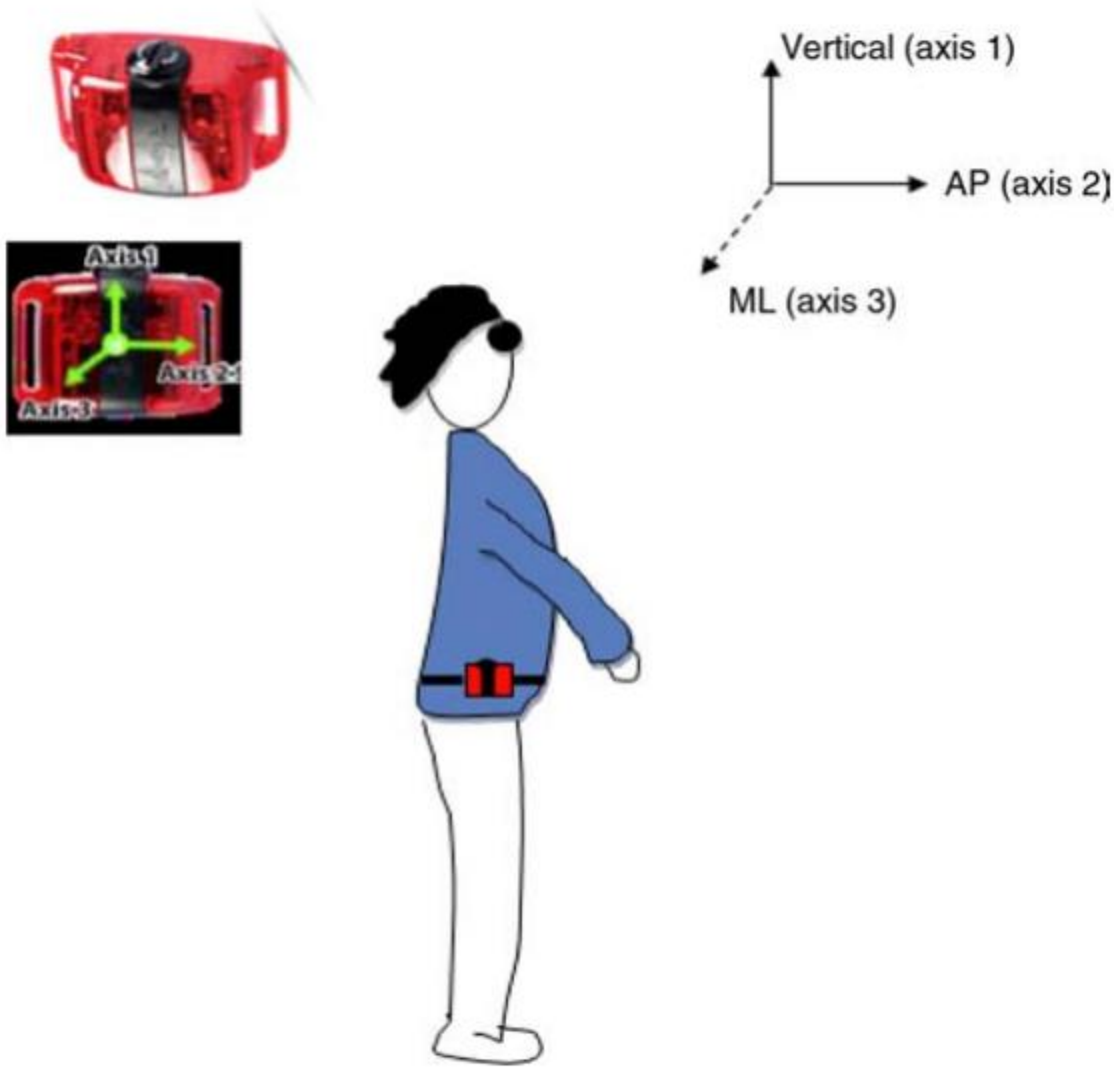

FIGURE 1 The location of an ActiGraph and the corresponding axes of motion.

We used ActiLife Version 6.5.1 to initialize the ActiGraphs and to upload the data. The sampling frequency was set at 30 Hz, and the epoch length was set at 1 s. ActiLife produced counts in three axes (AP, ML, and vertical), vector magnitude (VM), and steps. Counts were a proprietary unit used to represent force. Count is an enduring term. The cycle-count approach produced a "count" when enough force was applied to move a mechanical lever through a full cycle (up and down; ActiGraph, 2011). VM count referred to the magnitude of the resulting vector when the sampled accelerations from all three axes were combined: $VM = \sqrt{AP^2 + ML^2 + Vertical^2}$. We did not control the magnitude or direction of ship motion, and participants walked omnidirectionally. For these reasons, we elected to use VM counts rather than counts in individual directions.

Ship motion occurs in six degrees of freedom with rotation in roll, pitch, and yaw and translation in surge (forward-back), sway (side to side), and heave (vertical). We recorded the motion of the ship along three axes of linear motion (surge, sway, and heave) as registered by an ActiGraph accelerometer. Data were collected continuously throughout the cruise and stored in consecutive files, each 24 hr in duration. The accelerometer was attached to a structural support column located on the main deck on the starboard side of the ship's centerline.

Procedure

Informed consent was obtained prior to boarding. Participants boarded the ship while it was at the dock in Honolulu, approximately 36 hr before the voyage began. They slept on board overnight and donned the ActiGraphs upon rising on the morning before the voyage began (Day 0). The next day (Day 1), the ship departed Honolulu at 08:00. Thus, all data reported in the study reflect behavior while on board the ship. In addition, the absence (at the dock) versus the presence (at sea) of ship motion functioned as a within-participants independent variable. Each day, participants were instructed to position the ActiGraph on the right side of their waists and to wear it from the time they got up each morning until they went to bed at night (with the exception of showering). There were no formal constraints on participants' movement or activity (cf. Davis & Fox, 2007; Rowlands et al., 2008). The principal constraint was that all data were collected on board the ship.

Data Analysis

We evaluated three dependent variables (Storti et al., 2008): (a) the number of VM counts per day, which we interpreted as the total force applied on each day of testing; (b) the total number of steps per day; and (c) for each day, the mean number of VM counts/step, which we interpreted as the resultant force per step.

We used repeated measures ANOVA to analyze the data with days as a withinparticipants repeated measure. For each statistically significant effect we estimated effect size using the partial η^2 statistic. According to Cohen (1988), values of partial $\eta^2 > .14$ indicate a large effect, and values of partial $\eta^2 > .06$ indicate a medium effect. Because we were interested in the differences between walking on land (Day 0) and at sea (Day 4 to Day 9), for post hoc tests we used Helmert contrasts, which compare levels of an independent variable at one point in time with means at subsequent times.

RESULTS

Ship Motion

The weather was rough. On Days 1–8, the sea state was approximately 7 on the Beaufort scale (Beer, 1997), a 10-point scale used to characterize surfaces waves and swell. On the scale, 0 corresponds to a flat calm and 10 corresponds to wave motion during a hurricane. On this cruise, the roughness arose from steady trade winds rather than from a storm. On Day 9, the ship traversed the Strait of Juan de Fuca and Puget Sound, where the sea state was approximately 0. The ActiGraph that was attached to the ship registered zero VM counts across the entire testing period, indicating that the magnitude of acceleration associated with ship motion never reached the level categorized as a "step" by the ActiLife software application. To evaluate ship motion we extracted the raw accelerometer data, which were analyzed separately. Quantitative data on ship motion are presented in Figure 2.

Activity of Participants

When the ship was at the dock each participant wore the ActiGraph for at least 8 hr but this was not true for each of the days at sea. The seas near Hawaii were especially rough, and 3 of the 4 participants succumbed to seasickness for all or part of the first 3 days at sea. They retired to their berths such that they engaged in minimal walking. We elected to use a criterion by which data were included in our analyses only for days on which each participant wore the ActiGraph for at least eight hr. Beginning on the 4th day at sea all of the participants had recovered and met our criterion of wearing the ActiGraph for at least eight hr. Accordingly, our analysis of walking at sea comprises the latter 6 days of the voyage.

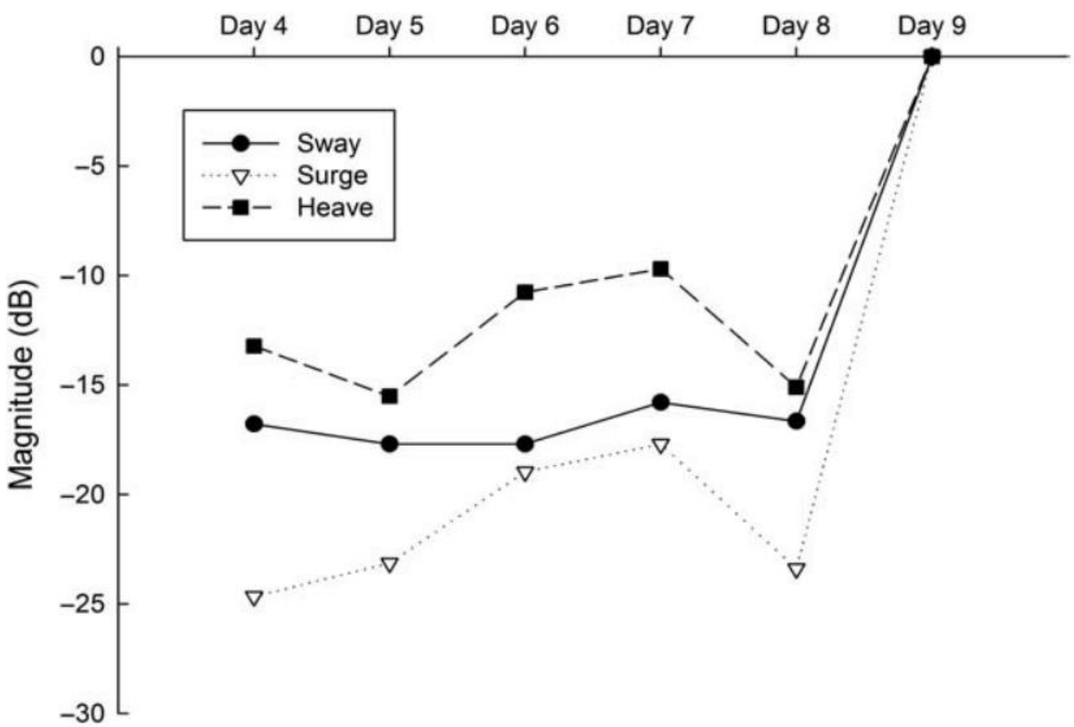

FIGURE 2 Magnitude of ship motion at the dominant frequency for each day of data collection in the ship's sway, surge, and heave axes.

Walking Data

Data on total resultant force per day are summarized in Figure 3. The main effect of Days was significant, $F(6, 18) = 13.10$, $p < .001$, partial $\eta^2 = .814$, with observed power = 0.999. The Helmert contrasts revealed that total resultant force was greater on Day 0 (823,728.58 ± 79,672.10 VM counts) than on days at sea (mean across days at sea = 349,752.27 ± 125,078.03 counts). In addition, resultant force at sea was greater on Day 5 (430,129.55 ± 113,960.66 VM counts) than on subsequent days (mean across Days 6–9 = 311,145.71 ± 132,917.60 counts). Finally, the total resultant force on Day 9 (440,146.45 ± 159,963.52 VM counts) was greater than on Day 8 (222,039.08 ± 38,072.95 VM counts).

Data on the number of steps per day are summarized in Figure 4. The main effect of Days was significant, $F(6, 18) = 26.13$, $p < .001$, partial $\eta^2 = .897$, with observed power = 0.999. Post hoc tests (Helmert contrasts) revealed that the participants walked more steps on Day 0 (13,210.25 ± 1,321.44 steps) compared with days at sea (mean across days at sea = 4,389.00 ± 1,420.73 steps). At sea, there were more steps on Day 5 (5,740.25 ± 1,311.30 steps) than on subsequent days (mean across Days 6– 9 = 3,805.00 ± 1,413.01 steps). Finally, there were more steps on Day 9 (5,508.75 ± 1556.21 steps) than on Day 8 (2,599.75 ± 323.03 steps).

Data on resultant force per step are summarized in Figure 5. The main effect of Days was significant, $F(6, 18) = 4.80$, $p = .004$, partial $\eta^2 = .616$, with observed power = 0.946. Post hoc tests (Helmert contrasts) revealed that resultant force per step was reduced on Day 0 (62.94 ± 10.03 VM counts/step) relative to days at sea (mean across days at sea = 79.97 ± 8.50 VM counts/step). While at sea, resultant force per step was lower on Day 6 (73.93 ± 6.67 VM counts/step) than on subsequent days (mean across Days 7– 9 = 83.55 ± 8.81 VM counts/step).

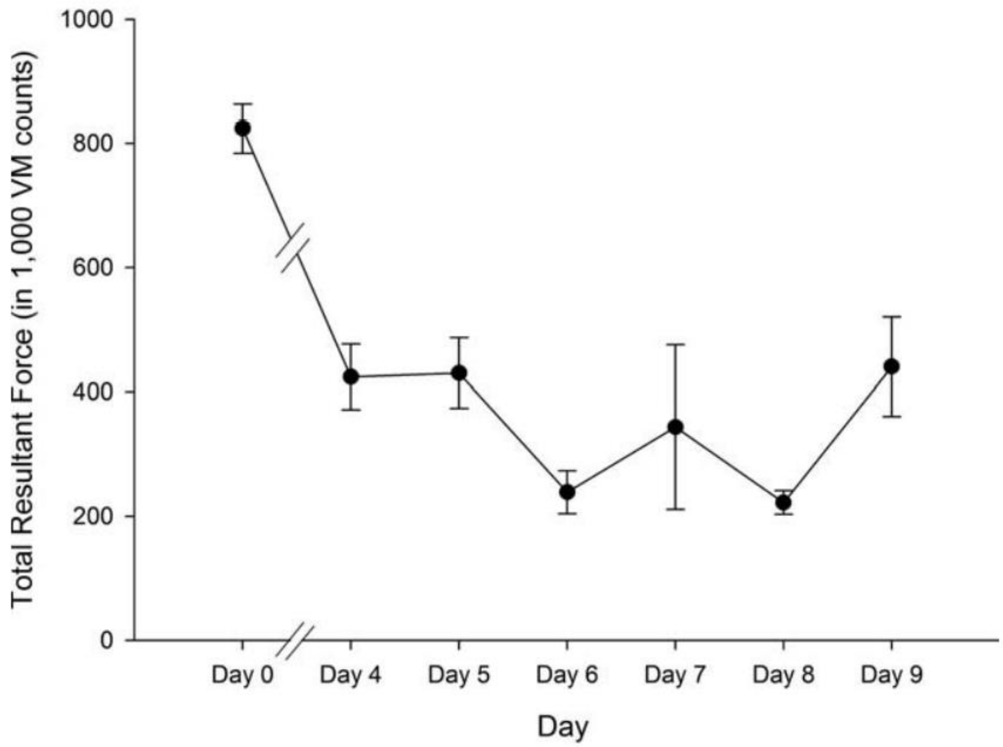

FIGURE 3 Resultant force for each day in thousands of vector magnitude counts. Error bars depict standard error of the mean.

DISCUSSION

Participants wore a wireless accelerometer while living on board a ship both before and during a sea voyage. We collected activity data 1 day before the beginning of the voyage (Day 0) and on each of the last 6 days of a 9-day voyage. The fact that participants did not leave the ship on Day 0 meant that we could directly compare activity on the ship before and during the voyage. The total resultant force per day and the number of steps per day were lower at sea than before the voyage began. By contrast, the resultant force per step was greater at sea than when the ship was at the dock. The results demonstrate the usefulness of wireless accelerometry for the study of human movement on ships at sea and confirm walking at sea is associated with greater force than walking on land.

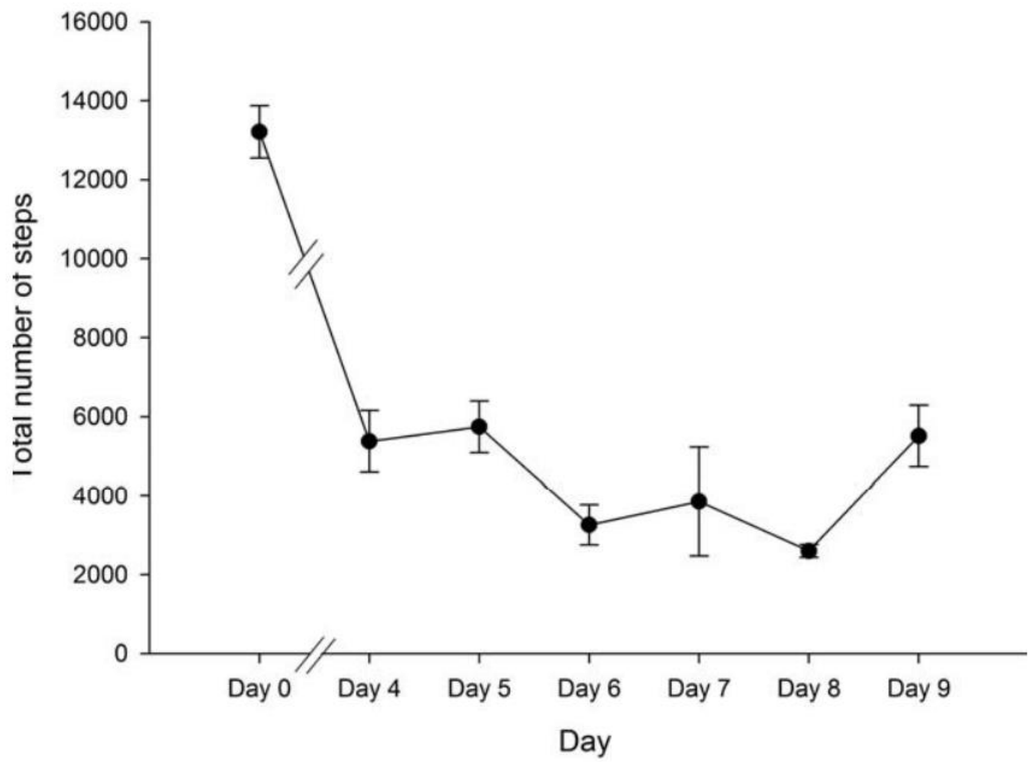

FIGURE 4 Number of steps per day. Error bars depict standard error of the mean.

The Number of Steps and Overall Activity

The fact that the accelerometer attached to the ship recorded zero VM counts suggests that our data collection system (the ActiGraph devices and the ActiLife software application) successfully differentiated steps from motion of the ship. This interpretation is supported by the fact that participants' overall resultant force per day was lower at sea than when the ship was at the dock (Figure 3). Participants walked more steps on the day before the voyage began (Day 0) than when the ship was at sea (Figure 4). In addition, they walked more steps on the final day at sea (Day 9) compared with the previous day (Day 8). Day 0 and Day 9 were characterized by the absence of oscillatory ship motion; on Day 0 there was no ship motion, whereas on Day 9 there was only nonoscillatory translation (i.e., movement of the ship across the water). Accordingly, Day 9 can be interpreted as a test of the role of nonoscillatory ship motion. The results suggest that walking was more strongly constrained by the oscillatory components of ship motion.

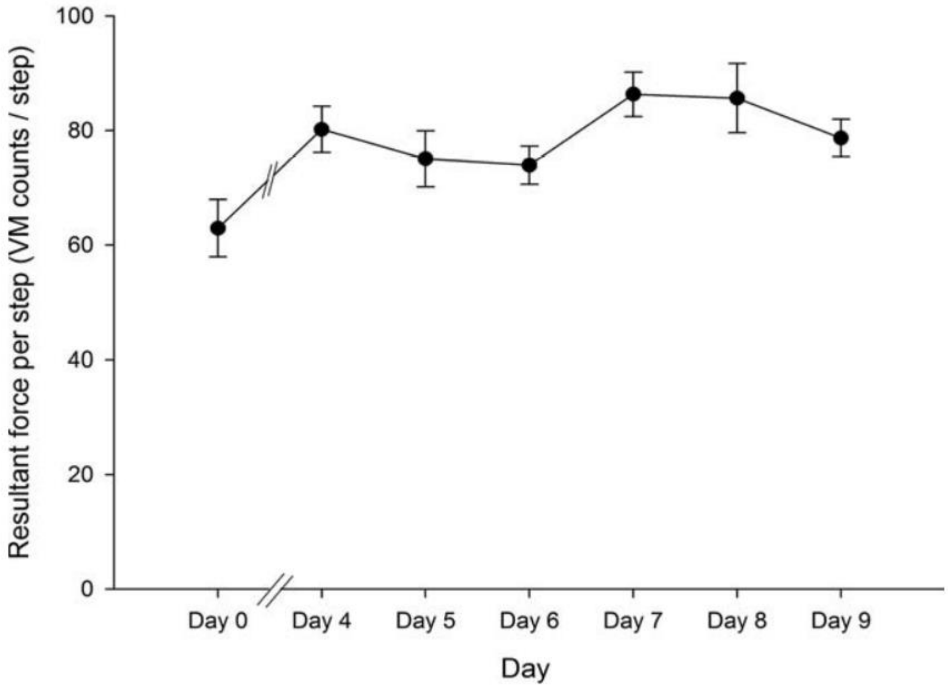

FIGURE 5 Mean resultant force per step in counts. Error bars depict standard error of the mean.

The Force per Step

The resultant force per step was greater when the ship was at sea than when it was at the dock (Figure 5). In interpreting this result it is important to understand that the devices registered force but were not sensitive to the source or origin of forces. The fact that the resultant force for each step was greater when the ship was at sea does not imply that participants exerted greater effort in making each step (e.g., in each step, bringing the foot down with greater force). The increased force may have arisen from the motion of the ship (e.g., the ship rising under the foot). The relative contributions of body movement and ship motion to the net registered force can be determined only through future research. However, our results demonstrate that during walking participants were exposed to (and obliged to cope with) higher levels of force when the ship was at sea than when it was at the dock.

A similar situation obtains with regard to the control of standing body sway at sea. Stoffregen et al. (2011) evaluated the magnitude of ground reaction force during stance on a force plate on land and when the same individuals were on a ship at sea. The force plate was sensitive to force as a unitary quantity; it could not distinguish between forces applied by the body (e.g., active body sway) and those generated by the ship (e.g., ship motion). However, to maintain orientation of the body relative to the ship participants were obliged to adjust the body in response to gravitoinertial force as a unitary quantity, that is, to the gravitoinertial force vector (cf. Stoffregen & Riccio, 1988). The same applies in the context of gait: walking at sea requires adjustment to all forces at the surface of support, regardless of their source. To be sure, in both stance and walking the nature of adjustments should differ depending on whether forces originate within or outside the body. However, this issue is separate from the fact that the net magnitude of forces is greater at sea than at the dock. Stoffregen et al. (2011) found that ground reaction forces at sea were higher than on land, consistent with our finding that resultant force per step was higher at sea than when the ship was at the dock.

The increase in resultant force during walking at sea indicates that walking on a ship at sea is hard work. This result is not surprising, but to obtain statistical significance for this effect with only four individuals is remarkable. Previous studies showed that walking on a motion base simulator resulted in 30% greater energy cost compared with walking on a stationary surface (Heus et al., 1998). Our finding is consistent with Heus et al. (1998), and we extended this effect to walking on an actual ship at sea. Our results illustrate the challenge that ship motion imposes on human walking and help to explain the fact that work at sea is often characterized by greater subjective fatigue (Stevens & Parsons, 2002; Wertheim, 1998).

Additional Issues

A natural question concerns relations between our data and previous studies that have used accelerometers to evaluate activity patterns on land. Masse et al. (1999) used ActiGraph devices to record physical activity continuously over 3 days. On days when participants were instructed to complete 30 m of brisk walking the mean number of VM counts per person was 425,250. On days when participants were not instructed to engage in any specific physical activity the mean number of VM counts per person was 264,487. These numbers are similar to our data for activity at sea but are lower than our data for activity on board before the ship sailed. The sample in the study of Masse et al. was entirely female, whereas in the present study each participant was male. In addition, the mean age of participants in the present study (M = 33.9, SD = 13.3 years) was lower than in the study of Masse et al. (43.6 years, SD = 5.7 years). These differences may account for the fact that our data suggest higher overall activity levels.

The primary limitation of this study was the small sample size. Although larger samples generally are preferred, the high levels of observed power suggest that sample was sufficient to detect within-participants effects (e.g., Singer & Willett, 2003). Moreover, clinical researchers have reported statistically significant effects in movement-related quantitative measures in studies using the same sample size (e.g., Lockley, Skene, & Arendt, 1999; Pilkar, Yarossi, & Nolan, 2014). In addition, the finding of statistically significant effects with relatively small sample sizes is consistent with experimental studies of standing body sway on ships at sea. For example, with 9 participants tested on only 2 days Chen and Stoffregen (2012) reported F values > 60 with effect sizes (partial η^2) up to 0.896. Comparing standing body sway on land versus at sea Stoffregen et al. (2011), using a sample size of 10, obtained a $t = 93.20$. At sea, they found a statistically significant main effect of days on body sway, with $F = 41.20$ and partial $\eta^2 = 0.821$. Similar effect sizes were observed in the present study, suggesting that the statistically significant effects we observed reflect real effects rather than artifacts of our sample size. The use of authors as research participants is unusual but has precedent in the literature. A well-known example is the work of Stratton (1897) on adaptation to inverting prism spectacles, which is still widely cited. More recent scholars have pursued Stratton's method of using the author as a research participant (e.g., Dolezal, 1982; Yoshimura, 2002).

It is likely that adaptation to ship motion includes an increase in the ability to coordinate stepping patterns with moment-to-moment variations in ship motion. That is, it may be that through adaptation people become better able to increase the coupling of gait with ship motion. Evaluation of this possibility will require quantitative analysis of patterns of gait (e.g., step timing patterns) relative to motions of a ship. Measures of coupling have been used in the context of standing body sway at sea (Varlet et al., 2014). The present study may help to motivate future research that can evaluate possible coupling of gait patterns with ship motions.

In this study, our main goals were to determine whether wireless accelerometry could be used to collect data on the activity patterns on a ship and whether standardized measures of activity would be affected by the presence and magnitude of ship motion. The results suggest that these modest goals were met. Building on this "proof of concept," future research can employ experimental methods (e.g., control of independent variables relating to ship motion and/or specific behavioral tasks; cf. Chen & Stoffregen, 2012). It is important to understand that multiple aspects of gait at sea can be addressed using differing technologies. In a companion study, we used foot switches to evaluate patterns of step timing on a ship at sea (Haaland, Kaipust, Wang, Stergiou, & Stoffregen, 2014). Foot switches cannot be worn on an extended basis (e.g., continuously over many hours) but are appropriate for use in brief sessions that permit the manipulation of independent variables. In the present study, participants were free to walk in any direction such that our data cannot be used to evaluate the possibility that walking was differentially affected by ship motion in different axes (e.g., roll vs. pitch). By contrast, Haaland et al. (2014) conducted experimental variation of the direction of walking relative to the long and short axes of the ship and found that patterns of step timing were differentially affected by ship motion in roll and pitch.

CONCLUSION

We used wireless accelerometers to obtain data on human activity patterns before and during a sea voyage. In addition, we successfully used a wireless accelerometer to obtain data on the motion of a ship at sea. Because all data were collected on board a ship we could directly compare activity with and without ship motion. Participants chose to walk more before the voyage than at sea. In addition, the force needed to walk a single step was greater during the voyage than before departure. Our results provide quantitative confirmation of the ancient observation that at sea, walking is effortful. Adjustment of gait patterns to accommodate the required changes in force may be part of the overall process of adaptation to life at sea, that is, part of "getting your sea legs." The increased effort required for walking at sea might be exploited for therapeutic purposes, for example, in strengthening gait and preventing falls in older people. The fact that ship motion is present 24 hr per day may have benefits in terms of compliance.

ACKNOWLEDGMENTS

We thank Professor Zan Gao, who generously allowed us to use ActiGraph devices from his laboratory. We also thank Captain Russell DeVaney and the crew of the R/V Thomas G. Thompson and Bill Rall, Port Captain at the University of Washington.

FUNDING

The study was supported by a Grant in Aid of Research from the University of Minnesota.

REFERENCES

ActiGraph. (2011, December 3). What are counts? Retrieved from https://help.theactigraph.com/ entries/20723176-What-are-counts

Beer, T. (1997). Environmental oceanography. Boca Raton, FL: CRC Press.

Brandes, M., Zijlstra, W., Heikens, S., van Lummel, R., & Rosenbaum, D. (2006). Accelerometry based assessment of gait parameters in children. Gait Posture, 24, 482–486. doi:10.1016/j.gaitpost. 2005.12.006

Cavanaugh, J. T., Kochi, N., & Stergiou, N. (2010). Nonlinear analysis of ambulatory activity patterns in community-dwelling older adults. Journal of Gerontology: Medical Sciences, 65A, 197–203. doi:10.1093/gerona/glp144

Chen, F.-C., & Stoffregen, T. A. (2012). Specificity of postural sway to the demands of a precision task at sea. Journal of Experimental Psychology: Applied, 18, 203 –212. doi:10.1037/a0026661

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Erlbaum.

Crossland, P., Evans, M. J., Grist, D., Lowten, M., Jones, H., & Bridger, R. S. (2007). Motion-induced interruptions aboard ship: Model development and application to ship design. Occupational Ergonomics, 7, 183 –199.

Crouter, S. E., Clowers, K. G., & Bassett, D. R. Jr., (2006). A novel method for using accelerometer data to predict energy expenditure. Journal of Applied Physiology, 100, 1324–1331. doi:10.1152/ japplphysiol.00818.2005

Davis, M. G., & Fox, K. R. (2007). Physical activity patterns assessed by accelerometry in older people. European Journal of Applied Physiology, 100, 581–589.

Dobie, T. G., May, J. G., & Flanagan, M. B. (2003). The influence of visual reference on stance and walking on a moving surface. Aviation, Space, and Environmental Medicine, 74, 838–845.

Dolezal, H. (1982). Living in a world transformed. New York, NY: Academic Press.

Graham, R. (1990). Motion-induced interruptions as ship operability criteria. Naval Engineers Journal, 102, 65–71.

Haaland, E., Kaipust, J., Wang, Y., Stergiou, N., & Stoffregen, T. A. (2014). Human gait at sea is differentially affected by ship motion in roll and pitch. Manuscript submitted for publication.

Heus, R., Wertheim, A. H., & Havenith, G. (1998). Human energy expenditure when walking on a moving platform. European Journal of Applied Physiology and Occupational Physiology, 77, 388 –394. doi:10.1007/s004210050349

Kobsar, D., Olson, C., Paranjape, R., Hadjistavropoulos, T., & Barden, J. M. (2014). Evaluation of age-related differences in the stride-to-stride fluctuations, regularity and symmetry of gait using a waist-mounted tri-axial accelerometer. Gait Posture, 39, 553–557. doi:10.1016/j.gaitpost.2013.09. 008

Lawther, A., & Griffin, M. J. (1988). Motion sickness and motion characteristics of vessels at sea. Ergonomics, 31, 1373–1394.

Lockley, S. W., Skene, D. J., & Arendt, J. (1999). Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. Journal of Sleep Research, 8, 175– 183.

Masse, L. C., Fulton, J. E., Watson, K. L., Heesch, K. C., Kohl, H. W., Blair, S. N., & Tortolero, S. R. (1999). Detecting bouts of physical activity in a field setting. Research Quarterly for Exercise and Sport, 70, 212–219.

Mayo, A. M., Wade, M. G., & Stoffregen, T. A. (2011). Postural effects of the horizon on land and at sea. Psychological Science, 22, 118–124.

Menz, H. B., Lord, S. R., & Fitzpatrick, R. C. (2003). Age-related differences in walking stability. Age and Ageing, 32, 137–142. doi:10.1093/ageing/32.2.137

Pilkar, R., Yarossi, M., & Nolan, K. J. (2014). EMG of the tibialis anterior demonstrates a training effect after utilization of a foot drop stimulator. Neuro Rehabilitation, 35, 299 – 305. doi:10.3233/ NRE-141126

Rowlands, A. V., Pilgrim, E. L., & Eston, R. G. (2008). Patterns of habitual activity across weekdays and weekend days in 9- to 11-year-old children. Preventive Medicine, 46, 317–324. doi:10.1016/j. ypmed.2007.11.004

Singer, J. D., & Willett, J. B. (2003). Applied longitudinal data analysis: Modeling change and event occurrence. New York, NY: Oxford Press.

Stevens, S. C., & Parsons, M. G. (2002). Effects of motion at sea on crew performance: A survey. Marine Technology, 39, 29–47.

Stoffregen, T. A., Chen, F.-C., Varlet, M., Alcantara, C., & Bardy, B. G. (2013). Getting your sea legs. PLOS ONE, 8, e66949, doi:10.1371/journal.pone.0066949

Stoffregen, T. A., & Riccio, G. E. (1988). An ecological theory of orientation and the vestibular system. Psychological Review, 95, 3–14.

Stoffregen, T. A., Villard, S., Chen, F.-C., & Yu, Y. (2011). Standing posture on land and at sea. Ecological Psychology, 23, 19 –36. doi:10.1080/10407413.2011.539102

Storti, K. L., Pettee, K. K., Brach, J. S., Talkowski, J. B., Richardson, C. R., & Kriska, A. M. (2008). Gait speed and step-count monitor accuracy in community-dwelling older adults. Medicine & Science in Sports & Exercise, 40, 59–64.

Stratton, G. M. (1897). Vision without inversion of the retinal image. Psychological Review, 4, 341–360.

Varlet, M., Stoffregen, T. A., Chen, F.-C., Alcantara, C., Marin, L., & Bardy, B. G. (2014). Just the sight of you: Postural effects of interpersonal visual contact at sea. Journal of Experimental Psychology: Human Perception and Performance, 40, 2310–2318.

Wertheim, A. H. (1998). Working in a moving environment. Ergonomics, 41, 1845–1858. doi:10. 1080/001401398186018

Yoshimura, H. (2002). Re-acquisition of upright vision while wearing visually left– right reversing goggles. Japanese Psychological Research, 44, 228–233.