Effects of Motion Cueing on an Attitude Recovery Task

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The present research investigated the impact of a motion cueing seat on a simple attitude recovery task. Participants (*n*=10) used a joystick to level an attitude indicator that was tilted at either a magnitude of 20 or 40 degrees from level (left or right). A dynamic motion seat was used to provide either congruent or incongruent motion cues. Relative to a no-motion baseline, incongruent motion caused performance decrements as indexed by an increase in the number of control reversals, a decrease in time level, and more over corrections. Congruent motion cueing did not affect performance on the attitude recovery task.

As long as flight simulators have been in use as a tool for pilot training, the concept of fidelity has been of particular interest within aviation research. A flight simulator's ability to simulate motion is generally associated with its level of fidelity. Numerous studies have been conducted to further the understanding of not only how realistic a simulator can be, but more importantly, how realistic a simulator *needs* to be in order to provide effective training (Grant, Yam, Hosman & Schroeder, 2006; Jian, Shutao & Hongren, 2011). Much of the research on motion cueing has yielded mixed results (e.g., Hays, Jacobs, Prince & Salas, 1992; Meyer, Wong, Timson, Perfect, & White, 2012). In a recent meta-analysis, de Winter, Dodou and Mulder (2012) suggested that providing vestibular motion cues can enhance pilot performance when engaged in tasks involving disturbance motion (e.g., turbulence, engine failure) or in complex tasks that involve maneuver motion (i.e., motion feedback as a consequence of pilot's input). This performance enhancement is generally not observed when maneuver motion is simulated on simple flying tasks.

Much of the research exploring motion cueing in the context of pilot training has been conducted using 6 degree of freedom (DOF) Stewart platforms – most likely due to Federal Aviation Administration (FAA) requirements for high fidelity simulators (Burki-Cohen, Sparko & Bellman, 2011). However, dynamic motion cueing seats have been investigated in an attempt to find a cost effective and practical alternative to full motion simulators (e.g., Pasma, Grant, Gamble, Kruk & Herdman, 2011). There is some evidence that the vestibular motion cues generated by dynamic motion seats can enhance performance on specific simulated flight tasks to the same degree as that provided by full motion simulators (Sutton, Skelton & Holt, 2010; Holt, Schreiber, Duran & Schroeder, 2011). However, further research is required.

The present study was designed to explore the effectiveness of motion cueing on a basic attitude recovery task. The experiment used a horizontal line on a computer monitor as a proxy for an (outside-in) attitude indicator that was capable of tilting left or right through 180°. Participants used a joystick to bring an attitude indicator back to level (0°) after being rotated by 20° or 40° (left or right). On motion trials, a dynamic motion seat provided motion cues that either matched the direction of the symbology (e.g., left rotation of the AI, left motion cue) or did not match (e.g., left rotation of the AI, right motion cue). If the cues provided by the motion seat affect attitude recovery performance, then performance should be enhanced by the congruent motion cues and impaired by incongruent motion cues, relative to when no motion cues are provided.

Method

Participants. Ten adult participants (mean age 30.6 years, *SD* = 8.4) participated in the study. Participants had normal or corrected-to-normal visual acuity. One participant was a military (CF18) pilot with 900 flight hours experience: the data from this participant was undistinguishable from the non-pilot data.

Materials. The attitude indicator symbology consisted of a green line with a small triangular base to simulate a simplified outside-in attitude indicator. The symbology subtended approximately 11° of visual angle and was presented against a black background on a 47-inch LCD monitor with a 60Hz refresh rate. The monitor screen was placed approximately four feet from the participant's viewpoint and was kept stationary. A PC was used to generate symbology and log data.

Motion cues were provided by isolating the seat-pan-tilt and seatback sway motion functions on a 5 DOF dynamic motion seat built by ACME World Wide Ltd. Participants were fastened to the motion seat using lap and shoulder belts with their feet planted flat on the floor. Motion cues consisted of the seat pan tilting left or right at a maximum rate of 200 deg/s accompanied by the seatback sway motion. On motion cueing trials, the seat continued to mimic, congruently or incongruently, the motion of the symbology from initial upset to the end of the trial. The motion seat was driven using the chassis assembly provided by the manufacturer.

Participants controlled the symbology using a Cyborg Evo Inc. non-force feedback joystick placed on a lapboard. Only inputs along the X-axis were read and used to level the symbology. Participants used a hat switch on the joystick to acknowledge the experimental instructions and to advance from one block of trials to the next.

Procedure. Each participant completed 5 blocks of 24 trials, resulting in a total of 120 trials per participant. Motion condition (no motion vs. congruent motion vs. incongruent motion), rotation magnitude (20° vs. 40°), and rotation direction (left vs. right) were crossed within each block of trials resulting in twelve unique trial types. Each trial type was presented twice (randomly) within each block. Prior to the beginning of the experimental trials, participants familiarized themselves with the apparatus and tasks by completing one block of trials. Each trial began with a visual (digit) countdown from 3, followed by the presentation of the rotated attitude indicator. In the two motion conditions, the seat motion cue was delivered concurrently with the presentation of the attitude indicator.

Participants were required to level the symbology as quickly and accurately as possible and to keep the line level until the end of the trial. Trials were five seconds long, starting from the onset of the attitude indicator. Micro control inputs at the start of each trial were muted until the attitude indicator symbology was presented at which point data recording was initiated. Control reversals, over-corrections, time level, and RMSE were recorded at 60 Hz.

Results

Figure 1 summarizes control inputs collapsed across all trials and graphed across time (0-5000 ms). Control inputs were transformed to equalize direction of correct joystick input (range ± 1) across left and right trials. As shown in Figure 1, control inputs were initiated approximately 100 ms sooner in both motion conditions compared to the no-motion condition. Participants also used more forceful control inputs in both motion conditions relative to the no-motion condition. Finally, control inputs in the congruent motion condition yielded a distinct 'step down' pattern as participants approached level (indicated by mark "1" on Figure 1). This pattern of control input suggests that congruent motion affects attitude recovery by inducing a feedback loop between participants' control inputs and the attitude symbology.

Control Reversals. A control reversal was defined as an initial control input that was 0.5° or greater in the opposite direction from level. For example, if the symbology was rotated left and the participant's input rotated it further left (by 0.5° or more), then this was classified as a control reversal. Control reversals were quantified as time spent (in ms) past the 0.5° thresholds. Table 1 shows the number of control reversals, average duration of control reversals, and average magnitude of control reversals varied across motion conditions. As shown in Table 1, there were more control reversals in the incongruent motion cueing condition and these reversals lasted longer and were or greater magnitude as compared to the no-motion condition and congruent motion conditions.

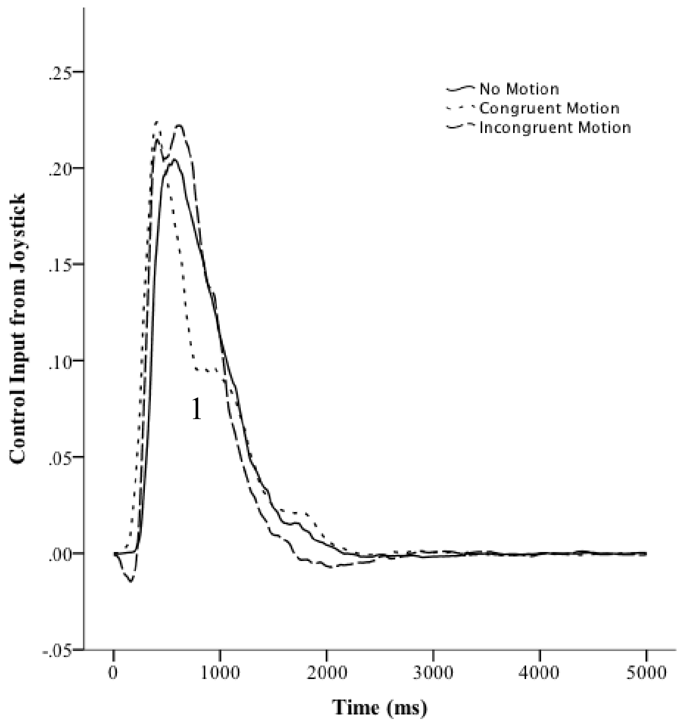

Figure 1. Average control input magnitude across time as a function of motion condition.

Table 1. Descriptive statistics for control reversals.

	No-Motion	Congruent Motion	Incongruent Motion
Number of Reversals	7	15	44
Average Length of Reversal	340ms	309ms	404ms
Average Size of Reversal	3.25°	4.22°	11.37°

Figure 2 shows the amount of time spent in a control reversal averaged across all trials. A 2 (Magnitude: 20° vs. 40°) x 3 (Motion Congruency: no motion vs. congruent motion vs. incongruent motion) repeated measures ANOVA showed a main effect of motion congruency, $F(2, 18) = 3.33$, $MSE = 2591.09$, $p < .059$. Control reversal times were longer in the incongruent motion condition (M = 44 ms) than in the no-motion and congruent motion conditions (M = 6 ms and M =12 ms, respectively). No other effects were significant.

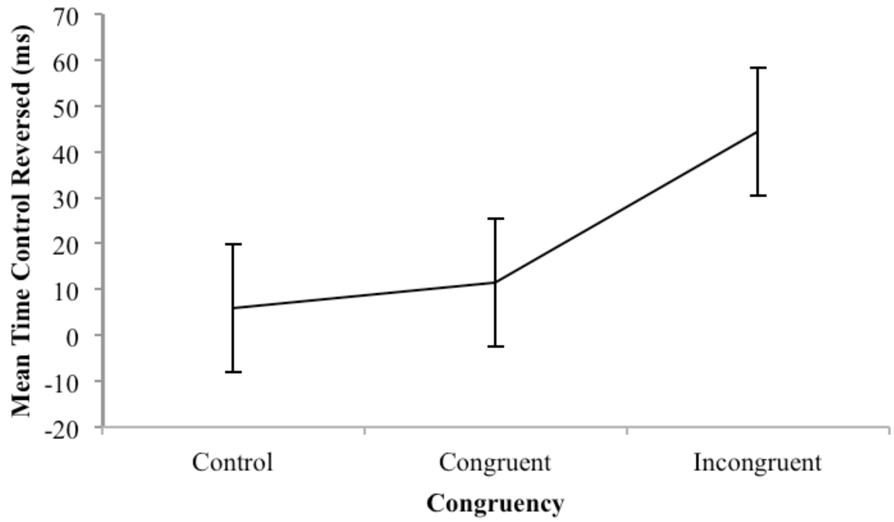

Figure 2. Average control reversal time (ms) as a function of motion congruency and 95% CI [± 15.8ms] (Jarmasz & Hollands, 2009).

Over-corrections. Over-corrections were defined as instances where participants corrected through (past) level by more than 2° and quantified as time spent (in ms) beyond 2° past level. Over-corrections (Figure 3) were analyzed using a 2 (Magnitude: 20° vs. 40°) x 3 (Motion Congruency: no motion vs. congruent motion vs. incongruent motion) repeated measures ANOVA. There was a significant effect of motion congruency, F (2, 18) = 14.27, MSE = 19760.64, $p < .001$, with more time spent over-correcting in the incongruent condition (M = 485 ms) than in the no-motion and congruent motion conditions (M =314 ms and M = 257 ms, respectively). No other effects were significant.

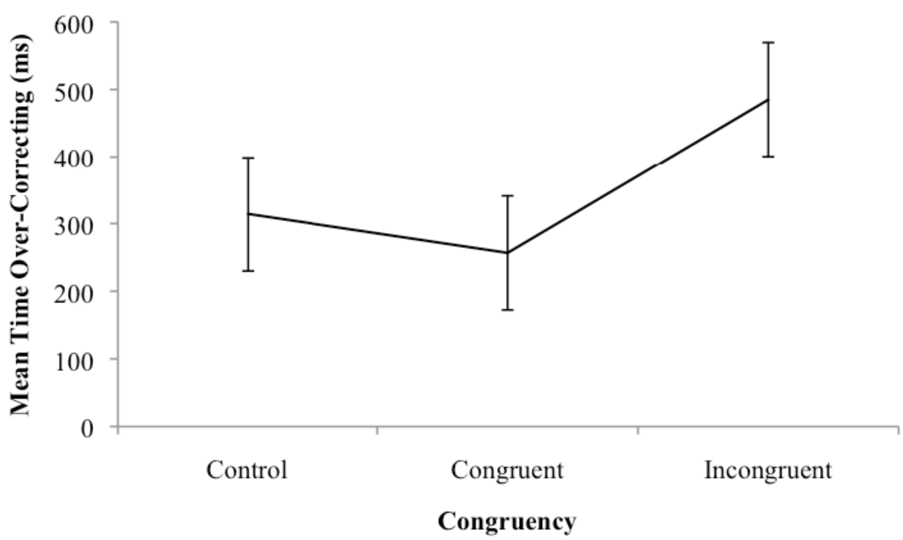

Figure 3. Average over-correction time (ms) as a function of motion congruency and 95% CI [± 84.4ms].

Time Level. Time level was quantified as time spent (in ms) within 2° of level. Time level (Figure 4) was analyzed using a 2 (Magnitude: 20° vs. 40°) x 3 (Motion Congruency: no motion vs. congruent motion vs. incongruent motion) repeated measures ANOVA. There was a significant main effect of Magnitude on time level F (1, 9) = 82.84, MSE = 21406.04, $p < .001$. Not surprisingly, less time was spent level in the 40° condition (M = 3174 ms) than in the 20° condition (M = 3518 ms), simply because trials in the 40° condition began further from level and therefore took longer to correct. There was a significant main effect of motion congruency on time level $F(2, 18) = 3.40$, $MSE = 18635.76$, $p < .06$, with less time spent level in the incongruent condition. ($M = 3285$ ms) than in both the no-motion and congruent motion conditions ($M = 3356$ ms and $M = 3396$ ms, respectively). There was also a significant Magnitude x Motion Congruency interaction, $F(2, 18) = 3.65$, $MSE = 27181.73$, $p < .05$. This interaction appears to be primarily driven by the performance enhancement provided by congruent motion cues when visual motion cues are less dramatic (i.e., in the 20° magnitude condition). These data show that congruent motion cueing may be beneficial for attitude recovery in small upset conditions, but less beneficial for recovery from larger attitude upsets.

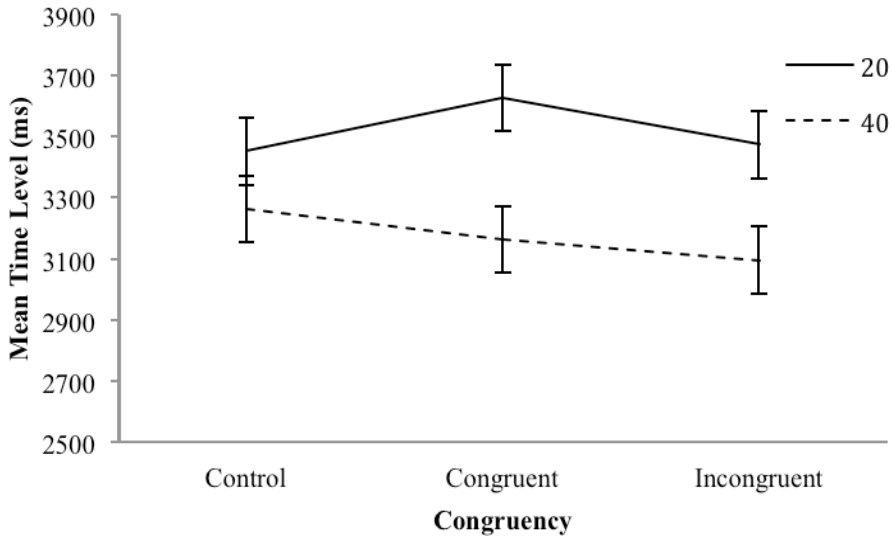

Figure 4. Average mean time level (ms) as a function of motion congruency and magnitude and 95% CI [± 109.5ms].

RMSE. RMSE was calculated as the root of the average squared error (distance from level in degrees) recorded at 60 Hz. RMSE (Figure 5) was analyzed using a 2 (Magnitude: 20° vs. 40°) x 3 (Motion Congruency: no motion vs. congruent motion vs. incongruent motion) repeated measures ANOVA. There was a significant main effect of magnitude $F(1, 9) = 189.83$, $MSE = .97$, $p < .001$, with more error in the 40° condition ($M = 7.17$°) than in the 20° condition ($M = 3.66$°). There were no other significant effects.

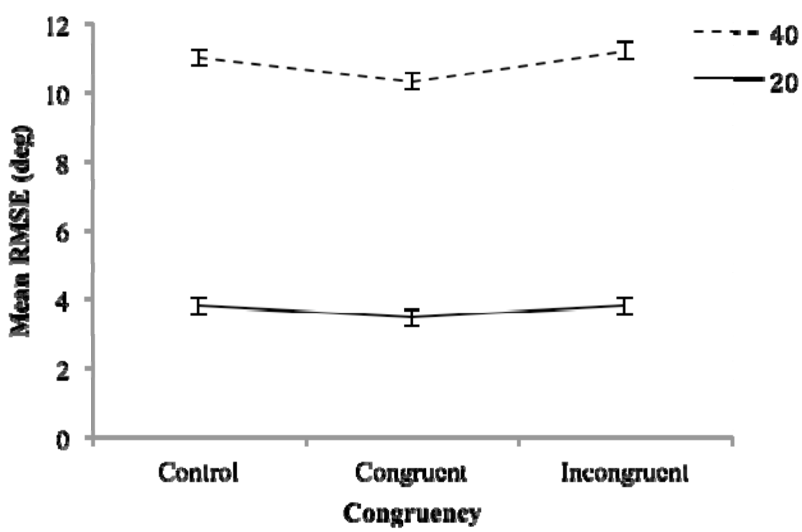

Figure 5. RMSE (deg) as a function of motion congruency and magnitude and 95% CI [± .24 deg].

Conclusion

This study contributes to the research literature on the use of motion cueing in flight training devices. Motion cueing was provided by a motion cueing seat. Incongruent motion cueing was found to result in performance impairments on a basic attitude recovery task as indexed by increased number and time spent in a control reversal, over corrections past level, and decreased time level. It is clear, therefore, that the present experimental paradigm was sensitive and able to index a role for motion cueing on attitude recovery performance. The effect of congruent motion on attitude recovery, however, was not significant in the present research. There are several possible reasons why congruent motion cueing did not impact performance in the present study: (1) the use of congruent motion cues may have been dampened because no-motion, congruent and incongruent motion trials were randomly presented, (2) an outside-in attitude indicator was utilized, which although intuitive, is less representative of commonly used attitude indicators, (3) the onset of the attitude displacements were predicable whereas in flight simulator training unusual attitudes are often introduced without specific countdowns, (4) the attitude recovery task was simplified to left/right bank and did not include pitch or yaw displacements, and (5) the overall task workload was minimal insofar as other concurrent flight-tasks were not present.

Acknowledgments

This research was supported through funding from the Canadian Foundation for Innovation (CFI) to Dr. C. M. Herdman. Additional infrastructure for this research was provided by the Canadian Department of National Defence. Special thanks to Dr. M. Brown for his assistance.

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