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Exposure to Disturbance Motion During Practice in an Analog of a Flight Task Influences Flight Control of Naive Participants

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ABSTRACT

Objective: This article examines whether strategies and performance differed depending on whether naive participants were exposed to motion disturbance during practice of a tracking task.

Background: Despite several decades of research, there is still debate regarding whether physical motion during flight simulation training improves later performance. Evidence suggests that presence of disturbance affects the utility of motion on transfer of training studies. Therefore, an important question is whether performance with disturbance motion (e.g., wind gusts) at test depends on whether participants practice with disturbance motion.

Method: Naïve participants flew through a series of suspended rings in a motion-based simulator. Practice was with or without correlated (joystick control) and random motion (disturbance). The task was an analog of a flight task, modified to accommodate nonpilots. A quasi-transfer design included two practice blocks followed by two test blocks that incorporated both correlated and random motion.

Results: No differences were detected in accuracy, but groups who practiced without disturbance made smaller joystick movements during both practice and test phases compared to those who practiced with disturbance.

Conclusion: Practice without disturbance resulted in adoption of a different (possibly more efficient) joystick control strategy compared to practice with disturbance. The results suggest that during training, some control elements should be learned under relatively easy conditions, subsequently increasing in difficulty (e.g., add disturbance) at an optimal point in training.

Experimental research on the effectiveness of flight simulators for pilot training has found few instances in which training with a motion-based simulator substantially and objectively improves performance over training with stationary simulators (Bürki-Cohen & Go, 2005; Bürki-Cohen, Go, & Longbridge, 2001; Go, Bürki-Cohen, & Soja, 2000; Jacobs & Roscoe, 1975; Koonce, 1979; McCauley, 2006; Woodruff, Smith, Fuller, & Weyer, 1976). However, there are some experimental reports that have found a benefit of platform motion on performance (Ince, Williges, & Roscoe, 1975; Jacobs, Williges, & Roscoe, 1973; Lee & Bussolari, 1989; McDaniel, Scott, & Browning, 1983; Pool, Harder, & van Paassen, 2016; Proctor, Bauer, & Lucario, 2007; Van der Pal, 1999; Zaal, Schroeder, & Chung, 2015) and subjective reports have consistently found that motion-based simulators are preferred by pilots (Boldovici, 1992; Bürki-Cohen et al., 2001; Pool, Mulder, Van Paassen, & Van der Vaart, 2008; Reid & Nahon, 1988).

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There is a large literature on motion in flight simulation, both from the perspective of the importance of motion fidelity to achieve realism, and from the perspective of whether motion cues provide valuable context for learning (reviews can be found in Bürki-Cohen, Sparko, & Bellman, 2011; Cohen, 1970; de Winter, Dodou, & Mulder, 2012; Hopkins, 1975; McCauley, 2006; Schroeder & Grant, 2010). The benefit of platform motion on performance is sensitive to a number of different factors, including but not limited to type of task, flight conditions, quality of visual display, temporal synchronization of visual and motion cues, type of aircraft, experience of pilot, and difficulty of the control task (Grant & Lee, 2007; Hosman, Grant, & Schroeder, 2005; Reid & Nahon, 1988; Schroeder & Grant, 2010; Showalter & Parris, 1980). Even though knowledge about these factors is accumulating, understanding the contribution of motion cues to transfer of training has received much less attention than research aimed at improving the fidelity of the motion cues (Bürki-Cohen et al., 2011). Thus, it is still not well understood how motion interacts with these factors in the context of transfer of training (de Winter et al., 2012; Grant, Yam, Hosman, & Schroeder, 2006). In this article, we used an analog of a flight task to assess whether specific motion cues might be valuable to improve transfer of training for novices in a quasi-transfer design. We focused on the presence or absence of disturbance, which has received attention in the past as a potentially important factor.

Disturbance cues are continuous or random movements that are the result of environmental effects such as turbulence, sudden wind shears, and engine failures. Flight simulators can mimic disturbance by visually displacing the participant on the screen, and by vibrations and unpredictable movements of the simulator platform. Previous research indicates that pilots are better able to respond to disturbances (faster and with more accuracy) when motion cues are present (Bowen, Oakley, & Barnett, 2006; Bürki-Cohen & Go, 2005; Grant et al., 2006; Showalter & Parris, 1980; see Caro, 1979, for a review). For example, motion cueing benefits performance on disturbance management tasks to a greater extent than on tracking tasks (Grant et al., 2006; Hosman, Advani, & Haeck, 2002), and responses to engine failure are faster when motion is present than when it is not (Bürki-Cohen & Go, 2005). Although results from two meta-analyses indicate that the presence of disturbance affects the utility of motion on transfer of training (Caro, 1979; de Winter et al., 2012), there is only one study that we know of that has directly examined the influence of disturbance versus no disturbance motion on transfer effects (Grundy, Nazar, O'Malley, Mohrenshildt, & Shedden, 2016).

Grundy et al. (2016) directly manipulated the presence of physical motion and disturbance in a quasi-transfer design. Participants used a joystick to perform a simple lateral-motion compensatory tracking task, in which motion direction was sway only and performance was measured within short, discrete trials. During training, platform motion and disturbances (e.g., wind gusts) were either present or not. At test, groups trained without disturbance made fewer joystick movements than those trained with disturbance. This simple task gave us some indication that training with disturbance can affect later behavior on discrete trials, but we could not infer that fewer joystick movements reflected a better strategy, nor whether the effect would be maintained on a continuous task in a more complex environment.

The experiment presented here used a pseudo-transfer design with the same training conditions as Grundy et al. (2016), but with a more realistic task and environment that better captured the continuous control needed to maneuver a vehicle through space. We used an analog of a flight tracking task in which participants flew through a series of rings suspended in a virtual sky. This task was situated in a three-dimensional environment, and motion dynamics were tuned to give the impression of a small aircraft. We examined effects of practice with and without platform motion, comparing motion correlated with joystick control and motion due to random disturbance (i.e., wind gusts). Note that our simulation was an analog of a flight task because it involved simplified dynamics and decoupled control axes (see the Methods section), and fixed velocity of movement through space (e.g., participants did not control speed).

We considered three hypotheses. First, participants trained with physical motion and disturbance are able to better learn the dynamics of the simulated environment. This is in line with previous studies reporting that the benefit of platform motion over stationary stimulators is larger when a disturbance task is used (de Winter et al., 2012; Grant et al., 2006). Thus, this hypothesis predicted an interaction in the test phase between the training groups such that individuals trained with disturbance would perform better than those trained without disturbance.

An alternative hypothesis was that the presence of disturbance during training would hinder learning of the simulated environment (see Wulf & Shea, 2002). When no disturbance is presented during practice, all the motion is directly correlated with the joystick movements. This might allow participants to learn exactly how responsive the simulator is to their actions such that, when disturbances are presented in the test phase, they are able to isolate what movements are due to disturbance and to compensate for them effectively. In contrast, participants trained with disturbance might not be able to effectively isolate what movements are due to the joystick and what movements are due to disturbance, reducing their ability to compensate for the disturbances. This hypothesis predicted improved performance at test for all participants trained without disturbance relative to those trained with disturbance.

A third hypothesis involved a training condition in which disturbances were presented in the visual display only (i.e., there was no platform motion). Joystick movements controlled altitude and heading visually and occasional wind gusts pushed the vehicle off course visually. This condition was driven by a curiosity about whether physical motion is necessary when learning to compensate for random noise. Information about joystick control is available between wind gusts so that participants can learn control; they might also develop strategies to compensate for the wind gusts. This hypothesis predicted similar performance at test for all participants trained with disturbance regardless of whether there was platform motion during training.

Methods

Design

Independent variables were block (two practice blocks followed by two test blocks) and type of motion presented in the first two exposure blocks (five learning conditions described later). Dependent measures included two measures of accuracy (missed rings; distance from ring center on completed rings), and two measures of joystick control (joystick movements; joystick switches). The study employed a mixed design with exposure condition as a between-subject variable and blocks as a within-subjects variable.

Participants

Eighty undergraduate students from McMaster University volunteered to participate in this experiment. Data from five participants were excluded; three quit due to motion sickness, and two did not complete enough trials during practice blocks. The remaining 75 individuals (30 female; M age = 20.3 years, range = 16–33) were distributed across the five conditions (15 participants per condition). All participants reported normal or corrected-to-normal vision. The procedures for this experiment fulfilled the requirements of the Canadian tri-council policy on ethics and were approved by the Hamilton Integrated Research Ethics Board.

Apparatus

The simulator pod was supported by a MOOG platform with 6 *df* (Moog series 6DOF2000E; maximal displacement = 20 cm; maximal acceleration = .6 g). All stimuli were controlled by a program coded in C++ using the VegaPrime (Presagis) library. The program was hard real-time loop synchronized to a 60 Hz signal. Target stimuli were presented on three 42" (diagonal) LCD panels with a resolution of 1920 × 1080 pixels and refresh rate of 60 Hz. Participants sat inside the enclosed pod in an automobile-style bucket seat bolted to the floor at the center of the Moog platform; this position maintained an approximate distance of 120 cm between the participants' eyes and the LCD display screens. Participant responses were registered with a USB-connected Logitech joystick. The joystick was mounted on a T-shaped apparatus that rested on the participants' lap so that the joystick was stable without having to hang on to it with the noncontrolling hand. Participants wore earplugs rated to reduce noise, and white audio noise (an untuned radio station) was played inside the simulator; this effectively masked the sound of the simulator motors and mechanics. The only source of light in the simulator came from the LCD display screens, resulting in a dimly lit environment. Two cameras mounted inside the simulator pod (one facing the screen and one facing the participant) allowed the experimenter to monitor the participant throughout the experiment to detect and correct any problems that might occur during data collection.

Stimulus Presentation

The visual display created a virtual environment that emulated the windows of an aircraft through which the participant viewed a blue sky with clouds and a mountain terrain with trees and buildings below, rendered using VegaPrim. Ten rings were equally spaced along one of four curved paths (Figure 1), which curved either right or left forming half a 200 m radius circle, and angled either up or down by 50 m between rings. The angle between two rings, and the angle between the start and end of a segment, was 18°.

We started with a FlightSim model of a stick-controlled airplane, comparable to the Piper A28, and simplified the flight model by decoupling the joystick inputs, so that joystick movement in the X-axis (orthogonal to forward momentum) controlled yaw rate, which affected heading, and joystick movement in the Y-axis controlled pitch angle, which affected rate of change of altitude. This adjustment achieved a manageable level of difficulty for nonpilot participants.

The control input to the model was position of the joystick (Jx, Jy). Jx was low-pass filtered and caused the vehicle to roll and yaw (the roll was computed and not controlled by the pilot) producing a change in heading; participants experienced yaw and roll accelerations and a resulting sway acceleration. Jy was low-pass filtered and caused the vehicle to pitch, producing a rate of change in altitude (vertical velocity); participants experienced pitch and heave accelerations. The low-pass filters were implemented as $F^2/(s2 + 2D\ Fs + F^2)$, where the cutoff frequency F was 4 rad/s and the damping factor D was .9. There was no surge in our model as we did not change speed. The motion cues were computed using a classical algorithm (Reid & Nahon, 1986) using high-pass filters implemented as $s2/(s2 + 2D\ Fs + F^2)$, where the cutoff frequency F was .2 rad/s and the damping

Figure 1. The visual display as seen by the participant.

factor D was 2. A false-cue eliminator applied a nonlinear gain that smoothed the filter response on the falling edge of a pulse, so that the washout effect was less noticeable.

Vibration noise was present whenever the simulator platform was active. The vibration was a 1 to 5 Hz Gaussian noise that simulated vibration of the aircraft. This had the benefit of masking the motion platform movements, and increased the realism by mimicking the vibrations of a real vehicle. The Gaussian noise did not affect the overall position of the vehicle.

Disturbance simulated wind gusts that affected the position of the airplane. An angle was selected from a random uniform distribution in a circle around the flightpath vector (speed was not affected), a maximal force F_m was selected from a random uniform distribution ranging from 0 to 0.2 m/s^2, and a duration D ranging from 1 to 2 s was used to compute the resulting force: F_m *cos*(2□□/*Dt*). The result was applied as horizontal and lateral accelerations projected at the selected angle. The wind gust disturbance at its maximum was at most 40% of the force generated by moving the joystick to oppose it.

Training Conditions

Five training conditions controlled exposure to correlated motion and disturbance during the practice phase. Instructions were given on the task and how to use the joystick at the start of the experiment. We use the term *training* to describe exposure to and practice with specific types of motion in the practice phase. The conditions summarized in Table 1 are described next.

- V (visual navigation only): The effect of joystick movements was represented on screen only. Both platform motion and disturbance were turned off (the motion platform was parked).
- V-CM (visual navigation with correlated platform motion): The effect of joystick movements was represented on screen and by motion platform (correlated motion); disturbance was turned off.
- V-DV (visual navigation with disturbance represented visually; no platform motion): The effect of joystick movements and occasional disturbance was represented on screen only. The motion platform was parked.
- V-CDM (visual navigation task with disturbance and correlated platform motion): The effect of joystick movements was represented on screen and by motion platform (correlated motion); occasional disturbance was represented on screen and by motion platform. This training condition was also the test condition for all five groups.
- V-DM (visual navigation task with disturbance platform motion but no joystick-input-correlated platform motion): The effect of joystick movements was represented on screen only; occasional disturbance was represented on screen and by motion platform.

Procedure

Participants were randomly assigned to one of the five training conditions (V, V-CM, V-DV, V-CDM, or V-DM). There were two training blocks followed by two test blocks, each consisting

Table 1. The five training conditions summarized with respect to type of motion.

Training Condition	Visual Correlated Motion	Physical Correlated Motion	Visual Disturbance Motion	Physical Disturbance Motion
V	✓			
V-CM	✓	✓		
V-CDM	✓	✓	✓	✓
V-DM	✓		✓	✓
V-DV	✓		✓	

of 20 trials of 10 rings. This resulted in a 75-min experimental session, which allowed optimal data collection without excessive fatigue. Test blocks were identical to the V-CDM condition. Participants used a button on the joystick to start each block. Participants were able to exit the simulator during breaks between blocks.

Instructions were to fly through the center of each ring as accurately as possible using the joystick to control the vehicle (Figure 1). Although joystick movements resulted in changes in altitude and heading, they did not affect speed; therefore, there was little variance in time to complete each segment (ring-to-ring), which was approximately 3.5 s for all participants. The system was reset to reposition the aircraft at the start of a new track at the beginning of each trial, which began immediately following the previous trial. If participants deviated too far off course (specifically, if their heading would not allow them to reach the next ring) the trial ended and was reset to the start of the next track. The number of rings missed due to this reset function is analyzed as rings not reached.

Results

Four dependent measures (rings not reached, distance from center of ring, joystick movements, and joystick switches) were examined separately by 5 × 4 mixed-model analyses of variance (ANOVAs) with five levels of training condition (between subject) and four levels of block (within-subjects). The Greenhouse–Geisser correction for violations of sphericity was applied; we reported epsilon and adjusted p values along with original degrees of freedom. For significant interactions we examined linear trends for each condition to establish which conditions led to improvement across blocks. In the figures and analyses, training blocks are referred to as practice blocks P1 and P2, and test blocks are referred to as test blocks T1 and T2. The first and last rings on each trial were excluded from all dependent measures (with the exception of the error measure calculated as rings not reached) to exclude irrelevant variance.

Error (Rings Not Reached)

Our first measure of accuracy was the percentage of rings that were missed due to the reset function (i.e., when participants deviated too far off course) within each block for each subject (see Figure 2). In each block there were 200 rings possible (20 trials with 10 rings each).

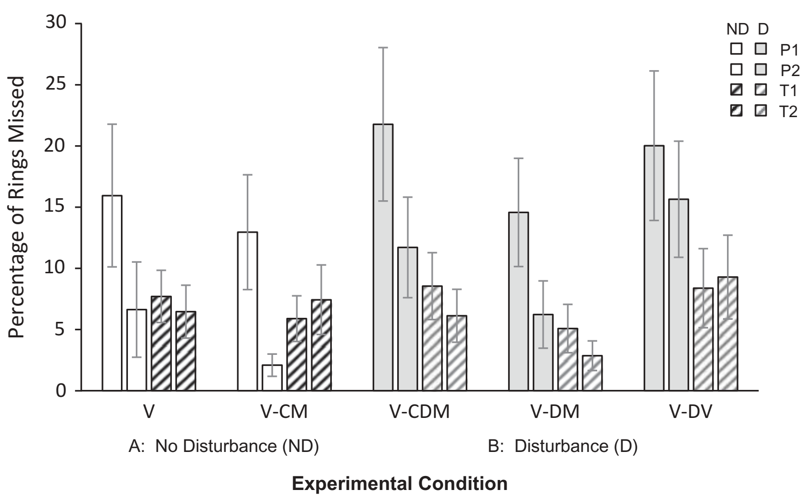

Figure 2. Number of rings missed as a function of the training condition across practice and test blocks. Error bars represent standard error.

Error decreased across blocks, $F(3, 210) = 24.5$, $p < .001$, $\varepsilon = 0.58$, $\eta p^2 = 0.26$. Training condition was not significant ($F < 1$), nor was the interaction between block and training condition, $F(12, 70) = 1.2$, $p = .3$, $\eta^2 = 0.06$. Given that there was no interaction between training condition and block, we did not run any further analyses. Visual examination of the graph shows that the number of rings missed decreased rapidly for all training conditions over the practice blocks and stabilized over the test blocks. Even though our participants were not pilots and were initially naive to the task, improvement over trials shows they were motivated and able to learn.

Accuracy (Distance from Center of Ring)

Our second measure of accuracy was based on how close the participant got to the center of the ring (see Figure 3). This average excluded any rings that were not reached, such that on a given trial if a participant successfully passed 5 of the 10 rings, 4 rings were included from that trial (the first ring was removed as outlined earlier).

Accuracy improved across blocks, $F(3, 210) = 35.1$, $p < .001$, $\varepsilon = 0.46$, $\eta p^2 = 0.33$. Although there was no significant main effect of training condition, $F(4, 70) = 1.8$, $p > .1$, $\eta p^2 = 0.09$, this was moderated by a significant interaction, $F(12, 210) = 7.8$, $p < .001$, $\eta p^2 = 0.31$. For groups that trained without disturbance, accuracy improved during practice, and then decreased during test, likely due to the disturbance. As such, there were no significant linear trends: V, $F(1, 14) = 1.3$, $p > .2$; V-CM, $F(1, 14) = 1.4$, $p > .2$. Pairwise comparisons within each group across successive blocks (P1–P2, P2–T1, T1–T2) support this analysis: V, P1–P2: $t(14) = 4.6$, $p < .001$; P2–T1: $t(14) = -6.1$, $p = .001$; V-CM, P1–P2: $t(14) = 4.6$, $p < .001$; P2–T1: $t(14) = -15.5$, $p < .001$.

For groups who trained with disturbance, accuracy improved across all four blocks, which is reflected by the significant linear trends across blocks: V-CDM, $F(1, 14) = 13.7$, $p < .003$; V-DM, $F(1, 14) = 25.7$, $p < .01$; V-T, $F(1, 14) = 16.4$, $p < .02$. Pairwise comparisons within each of these three groups across successive blocks (P1–P2, P2–T1, T1–T2) produced supporting results: V-DV, P1–P2: $t(14) = 4.1$, $p < .001$; P2–T1: $t(14) = 2.4$, $p = .033$; T1–T2: $t(14) = 2.8$, $p = .014$; V-CDM, P1–P2: $t(14) = 3.5$, $p = .004$; V-DM, P1–P2: $t(14) = 4.9$, $p < .001$; T1–T2: $t(14) = 2.2$, $p = .043$.

When we compare the training conditions within each test block we find no significant differences on accuracy among the five training conditions on either test block (T1 and T2; all ps > 0.1). In other words, participants trained without disturbance motion show a decrease in accuracy when they

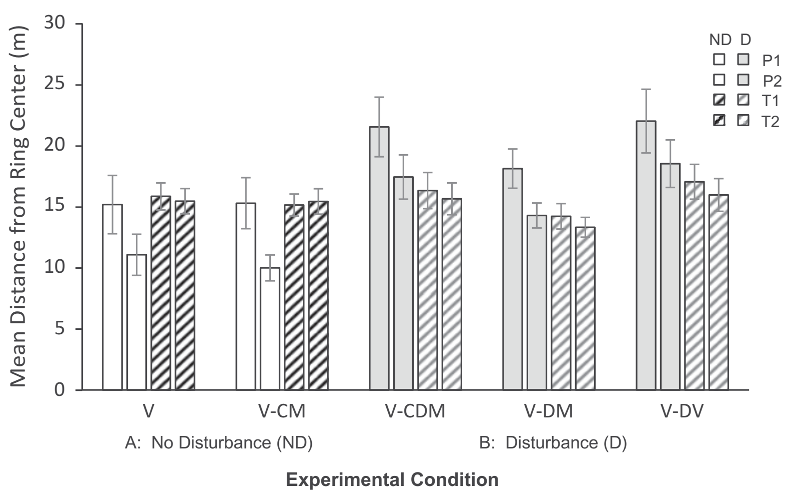

Figure 3. Distance from the center of the ring as a function of the training condition across practice (P1, P2) and test (T1, T2) blocks. Error bars represent standard error.

encounter disturbance motion at test (T1 and T2), but we found no significant difference in their accuracy at test relative to the groups who trained with disturbance motion. This is consistent with the hypothesis that disturbance at training does not affect later performance. A different story emerges, however, when looking at joystick control.

Joystick Movements

One measure of joystick control was evaluated as the mean absolute difference (MAD), calculated as the area under the curve of the joystick position relative to the participant's average (i.e., the integral of the joystick movements). MAD is related to root mean square error (RMSE) but uses linear weights so that large deviations are not weighted more heavily than small errors. This is the same measure used by Grundy et al. (2016). We collapsed over the direction variable (up or down, left or right) to analyze performance averaged across all four tracks. Each trial was cut into "segments" from ring to ring such that on ring N, the segment started just after ring N – 1 and ended just after ring N. This resulted in a single average value per segment for all rings that were successfully tracked; smaller values reflected smaller joystick movements. This provided a performance measure that might index differences in strategy (see Figure 4) and is not explained by number of joystick switches (see later).

Analysis of joystick movements revealed a significant effect of block, $F(3, 210) = 12.6$, $p < .001$, $\varepsilon = 0.57$, $\eta p^2 = 0.15$; a significant effect of training condition, $F(4, 70) = 3.7$, $p < .01$, $\eta p^2 = 0.17$; and a significant interaction, $F(12, 210) = 2.4$, $p = .02$, $\eta p^2 = 0.123$.

For groups that trained without disturbance (V and V-CM), there was a reduction in the size of joystick movements across practice (from Blocks 1–2), followed by an increase from the second practice block to the first test block (Blocks 2–3; note that disturbance was turned on in Block 3), and a decrease across the test blocks (Blocks 3–4). As such, there were no significant linear trends for these two conditions: V, $F(1, 14) = .25$, $p > .5$; V-CM, $F(1, 14) = .18$, $p > .5$. Pairwise comparisons within each group across successive blocks (P1–P2, P2–T1, T1–T2) support this analysis: V, P1–P2: $t(14) = 3.0$, $p = .01$; P2–T1, $t(14) = -3.8$, $p = .002$; V-CM, P1–P2: $t(14) = 4.7$, $p < .001$; P2–T1: $t(14) = -6.1$, $p < .001$.

For the group that trained with disturbance in the visual display only (V-DV; no platform motion), joystick movements were reduced in size across the four blocks, which was reflected by the significant linear trend, $F(1, 14) = 8.9$, $p < .02$. In contrast, for the other two disturbance conditions (V-DM and V-CDM), there was no change across blocks, resulting in no significant

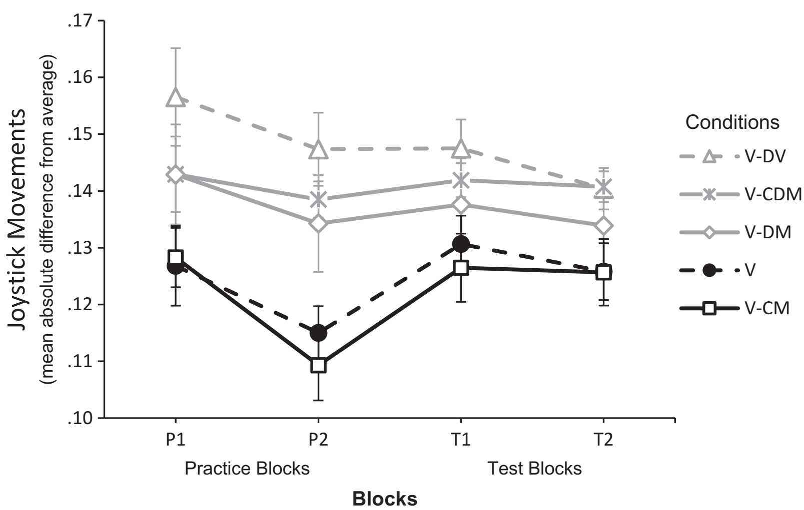

Figure 4. Joystick movement as a function of the training condition across practice (P1, P2) and test (T1, T2) blocks. Error bars represent standard error.

linear trends: V-CDM, $F(1, 14) = .1$, $p > .5$; V-DM, $F(1, 14) = 2.7$, $p > .1$. Pairwise comparisons within each of these three groups across successive blocks (P1–P2, P2–T1, T1–T2) produced supporting results: V-DV, P1–P2: $t(14) = 2.1$, $p = .047$; T1–T2: $t(14) = 2.6$, $p = .02$; V–DM, P1–P2: $t(14) = 2.6$, $p = .02$.

To further examine the interaction, we collapsed across conditions in a 2 (disturbance vs. no disturbance) × 4 (block) mixed ANOVA. We observed significant effects of block, $F(3, 219) = 14.4$, $p < .001$, $\varepsilon = 0.58$, $\eta p^2 = 0.16$; and disturbance, $F(1, 73) = 13.3$, $p < .001$, $\eta p^2 = .15$. Joystick movements were larger overall for participants who trained with disturbance. A significant interaction, $F(3, 219) = 7.1$, $p < .001$, $\eta p^2 = .09$, further supported the distinction between groups as illustrated in Figure 4. Those who practiced without disturbance showed much smaller movements during practice, and critically, even though joystick movements increased in size at test, the movements were still smaller compared to groups who practiced with disturbance: T1, $t(73) = -2.6$, $p < .01$; T2, $t(73) = -2.7$, $p < .01$.

The overall pattern of results indicates that participants trained without disturbance made smaller joystick movements during practice and test than those trained with disturbance.

Joystick Switches

The number of joystick switches is another measure of joystick control (Table 2). For each ring segment, we used the mean of the joystick position in the X and Y directions within that segment as an analog of a zero crossing. We then counted the number of times the direction of the joystick switched across this mean. As the number did not differ between X and Y, we analyzed the average across X and Y. Analysis of the number of joystick switches revealed a significant effect of block, $F(3, 210) = 22.9$, $p < .001$, $\varepsilon = 0.71$, $\eta p^2 = 0.25$, representing a decrease in the number of switches with practice. There was no effect of training condition, $F(4, 70) = .6$, $p = .6$, $\eta p^2 = 0.03$, and there was no interaction, $F(12, 210) = 1.3$, $p < .2$, $\eta p^2 = 0.07$. These results help to interpret the joystick movement observations in which size of the movements depends on training condition, supporting the hypothesis that smaller movements might reflect more control.

Discussion

We compared five conditions that contrasted training with and without correlated motion and disturbance motion. The task was not difficult but provided enough challenge to novice participants to observe learning over the session. During the test phase, all groups experienced both correlated platform motion and disturbance; we did not detect significant differences in accuracy or in the number of joystick switches made across groups. However, participants who trained without disturbance made smaller joystick movements relative to those who were trained with disturbance.

Our findings are similar to those of Grundy et al. (2016), who also showed that participants trained without disturbance made smaller joystick movements. In the compensatory tracking task used by Grundy et al., smaller joystick movements could have been seen as a negative: Those participants were not as sensitive to the disturbance. In contrast, here it seems more likely to be a

Table 2. Joystick switches: Mean count and standard error averaged across X and Y switches.

	P1 Block		P2 Block		T1 Block		T2 Block	
Training Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
V	3.23	0.100	3.26	0.086	3.18	0.064	3.09	0.049
V-CM	3.27	0.061	3.28	0.050	3.14	0.053	3.04	0.046
V-CDM	3.34	0.086	3.27	0.053	3.17	0.069	3.14	0.060
V-DM	3.25	0.052	3.18	0.050	3.18	0.054	3.12	0.055
V-DV	3.18	0.078	3.09	0.072	3.07	0.081	3.06	0.073

positive: Accuracy at test did not differ across groups, but those trained without disturbance used smaller movements to accomplish the same task, which might reflect more efficient performance.

The results support the second hypothesis outlined in the introduction; training with disturbance might have impaired learning relative to training without disturbance. Practice without disturbance might have produced better knowledge of the consequence of joystick movements, leading to increased sensitivity to disturbance in the test phase. This could have improved ability to counteract the disturbance at the appropriate magnitude without overcompensating. In contrast, participants who trained with disturbance might have experienced more trouble learning the consequences of their joystick movements. They achieved the same accuracy as those trained without disturbance, but not by making a greater number of joystick movements. Rather, they adopted a strategy of making larger movements, overshooting, and then overcompensating to get back on course.

Participants in the V-CDM condition practiced with the same conditions presented at test (rather than a quasi-transfer experiment, this group experienced continuous training). Although they showed improvement across blocks, joystick movements were still larger at test than those of participants who trained without disturbance, who made smaller and arguably more efficient movements at test. This indicates that practicing without disturbance might be more beneficial than practice in the more challenging condition (V-CDM) throughout the whole experiment.

From a learning perspective, our results are comparable to a finding reported by Bürki-Cohen and Go (2005) in which they found steadier control (either in pedal or wheel control) throughout the experiment by participants trained without motion relative to those trained with motion. Their participants were also novices: newly hired pilots who had completed ground school, but had not yet been in the simulator. Our experiment is an analog of a flight task and our differences were due to disturbance and not motion per se, but both sets of results can be taken to suggest that for novices, learning key aspects of the task in the simulator (e.g., joystick control) before applying learning in more complicated conditions might yield the best training (Wulf & Shea, 2002).

Critically, the presence of platform motion that was controlled by joystick movements did not influence accuracy or efficiency, nor did it interact with disturbance. It is possible that in our analog of a flight task, visual cues were dominant and motion cues provided redundant information about controlling the vehicle's movement. Alternatively, motion cues might be ignored if the task is too easy, the vehicle is easy to operate, or the motion cues provide poor accuracy (Bürki-Cohen et al., 2011). Vision affords richer and more compelling information about self-motion than do mechanoreceptors of the vestibular system (Berthoz, Pavard, & Young, 1975; Lishman & Lee, 1973) and humans rely more heavily on their visual system to detect motion. Thus, if we had reduced the resolution or perceptual salience of the visual stimuli (e.g., obscure with clouds), or increased task difficulty, motion might have had a greater benefit.

Limitations and Future Directions

In this experiment, we used an analog of a flight task with simplified flight dynamics. This work builds on and extends a previous study by Grundy et al. (2016) that used a discrete-trial tracking task with left-to-right movement (sway) only. The overall pattern of results between the two studies was consistent, indicating that this pattern holds across at least two tasks with different motion parameters. However, this is still just a small step forward in a systematic investigation of the role of motion and disturbance on training. We expect that changing the flight dynamics, changing the task, testing over multiple sessions, or providing more extensive feedback on performance would change the observed results (cf. de Winter et al., 2012; Grant & Lee, 2007; Hosman et al., 2005; Schroeder & Grant, 2010), and future work will be needed to explore such differences. Moreover, it is known that performance depends heavily on specific vehicle dynamics and software and hardware control, so generalizations must be made with caution. In future work, it would also be informative to examine individual differences.

We also chose to use novice undergraduate participants rather than skilled pilots. This was done in part for practical reasons and in part because we were interested in how these factors affect novices. Experienced pilots would likely have performed at ceiling on our simplified task. Nevertheless, our novice participants were motivated to learn and showed improved performance over trials. The purpose of this experiment was to examine whether motion or disturbance would affect training in novices; future research is needed to extend findings to pilots.

Conclusion

This study investigated whether training with disturbance and motion produced better performance than motion alone during an analog of a flight task. We found that motion does not provide better training relative to no motion, regardless of whether disturbance is present. Critically, practice without disturbance resulted in increased efficiency and smoothness of flight at test compared to practice with disturbance. This addresses a more basic question regarding how learning progresses (Schroeder & Grant, 2010; Wulf & Shea, 2002), suggesting that critical elements of the task (e.g., joystick control) should first be learned under relatively easy conditions, subsequently increasing in difficulty (e.g., adding disturbance) at an optimal point in training.

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