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Anecdotal evidence suggests that a thumb and index finger grip might facilitate recovery from the manifestation of spatial disorientation known as the giant hand phenomenon. Sixteen pilots volunteered as subjects in an experiment that compared the effectiveness of the thumb and index finger versus the whole hand technique to overcome a visually induced analogue of the giant hand phenomenon. Thumb and index finger control produced greater stability overall, but did not overcome the specific tracking bias induced by a background visual roll stimulus. Various hypotheses are discussed as to why the thumb and index finger technique was ineffective in the present instance.

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22a. NAME OF RESPONSIBLE INDIVIDUAL
Lisa F. Weinstein, PhD

22b. TELEPHONE *(Include Area Code)*
(512) 536-3521

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A Test of Thumb and Index Finger Control in Overcoming a Visual Analogue of the Giant Hand Illusion

LISA F. WEINSTEIN, M.A., Ph.D., FRED H. PREVIC, M.A., Ph.D., CARL G. SIMPSON, M.D., M.P.H., TERENCE J. LYONS, M.D., M.P.H., and KENT K. GILLINGHAM, M.D. Ph.D.

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Anecdotal evidence suggests that a thumb and index finger grip might facilitate recovery from the manifestation of spatial disorientation known as the giant hand phenomenon. Sixteen pilots volunteered as subjects in an experiment that compared the effectiveness of the thumb and index finger versus the whole hand technique to overcome a visually-induced analogue of the giant hand phenomenon. Thumb and index finger control produced greater stability overall, but did not overcome the specific tracking bias induced by a background visual roll stimulus. Various hypotheses are discussed as to why the thumb and index finger technique was ineffective in the present instance.

A POWERFUL MANIFESTATION of spatial disorientation experienced by pilots is the giant hand (GH) phenomenon. According to U.S. Air Force Manual 51-37 (Instrument Flying), the GH illusion is "the feeling that the aircraft control system is malfunctioning, as though a giant hand were pressing down on the nose or wing of the aircraft when in reality the aircraft is responding to the erroneous control inputs of the disoriented pilot, who is trying to make appropriate corrections, but must fight his or her own unconscious reflex responses to execute the conscious corrections necessary to make the instruments give the desired indication (10)." The preconscious orientational percept that pilots must overcome is ordinarily created by vestibular inputs (e.g., a sustained, nonvertical gravitoinertial force), but visual factors may also play a role. The incidence of the GH illusion among fighter pilots has been estimated at between 7% and 16% according to two recent surveys (7,8).

Anecdotal evidence suggests that grasping the stick with only the thumb and index finger (TI) during the GH phenomenon may enable a pilot to overcome the illusion. King (5) was the first pilot to report the use of this technique to recover from a spatial disorientation episode that is now understood as the GH illusion. His anecdotal report of improved aircraft control using the thumb and index finger during the GH phenomenon prompted a neurophysiological explanation to account for why the TI technique could improve a pilot's ability to cope with this illusion (8). The neurophysiological explanation is based on the different neural pathways involved in TI versus whole-hand (WH) stick control. From the work of Kuypers and others, we know that control of the fingers is mediated by the lateral corticospinal (pyramidal) pathway in primates, whereas the proximal musculature (i.e., shoulder and upper arm) is controlled largely via the ventromedial system (6). Since the ventromedial system also includes the neuronal pathways involved in the vestibulospinal reflexes, the use of a pyramidal motor strategy would essentially "bypass" the influence of the more primitive motor system.

Attempts to recreate the GH phenomenon by employing vestibular stimulation generated by motion-based simulations have met with variable degrees of success (3,9). Presently no empirical literature exists concerning the visually generated reproduction of the GH phenomenon or the effect of different motor strategies in overcoming this illusion. In this experiment, we attempted to simulate the GH phenomenon by using a rotating visual background field to induce the illusion. During a

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From the United States Air Force School of Aerospace Medicine, Brooks Air Force Base, TX.

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Address reprint requests to: Lisa F. Weinstein, Ph.D., who is currently a research scientist with KRUG Life Sciences, Det. 4, AL/VNB, Brooks AFB, TX 78235-5300.

tracking task involving alignment of an "attitude indicator" with one's perceived horizontal, background visual roll stimulation is known to result in a manual control bias in the direction of scene rotation (Kenyon RV. Personal communication). The bias is accompanied by the compelling impression that the attitude display is being "pulled" by the background scene, and one typically experiences difficulty restoring the attitude display to a horizontal position. Some subjects may apply an inordinate amount of physical force on the control stick in an attempt to achieve a horizontal attitude. When, however, the attitude display is not perturbed but passively viewed against the background scene rotation, it is perceived to move opposite to the rotation, in keeping with the well-known "induced motion" illusion (2). Thus, the subjects apparently move the display in the direction of scene rotation to overcome the falsely perceived opposite motion, leading to the percept of a countervailing force acting against their conscious motor efforts.

It is not clear whether the above phenomenon is a valid analogue of the GH phenomenon. On the one hand, there apparently exists a "war" between subconscious and conscious motor systems, similar to that found in the actual illusion. On the other hand, the subconscious motor response in the visual analogue situation is driven by a visual, rather than a vestibular, stimulus and may be more dependent on higher-order (presumably cortically mediated) perceptual inferences. For example, the "induced motion" appears to be more powerful when the attitude display appears in front of the rotating scene, as is also true of vection and other orientational responses (1).

If the TI strategy is effective in overcoming the visual analogue of the GH phenomenon, then the results would indicate that the rotating peripheral scene adequately simulates the subcortical vestibular input that normally creates this illusion. If not, the results would point to the inadequacy of this visual analogue, and/or the dynamics of the laboratory tracking control system for replicating and understanding the actual GH illusion, or alternatively, the inadequacy of the pyramidally mediated control strategy in overcoming this illusion.

METHODS

Subjects

Sixteen military and civilian pilots volunteered as participants in the experiment. These subjects had a mean total flight time of 3,200 hours and ranged in age from 32 to 52 years. All subjects met either USAF or FAA visual acuity requirements for pilots.

Apparatus

The experiment was conducted in a darkened booth in the USAF School of Aerospace Medicine's Visual Orientation Laboratory. The laboratory includes a) a Silicon Graphics IRIS 3130 computer workstation, b) a Sony 1030Q CRT video projector; c) a subject booth containing a Draper Cine-15 viewing screen and Fresnel lens assemblage on which the enlarged computer-generated image is projected at optical infinity; and d) a simulated F-16 aircraft seat with a side-arm force-stick controller. An elliptical shroud was attached to the lens assemblage to prevent subjects from viewing the edge of the screen or receiving visual orientation information from sources other than the display. The height of both the video projector and the viewing ensemble is adjustable, thus allowing the center of the projected image to be set at eye level for each subject sitting in the simulated aircraft seat.

Procedure

The flight task consisted of a compensatory roll-tracking task. Subjects were asked to maintain an unstable attitude display at a perceived wings-level orientation. The position of the attitude display on the screen was determined by the subject's control stick input, the dynamics of the display-control system, and a perturbing function consisting of the sum of 13 sinusoids. The display-control system was a first-order divergent (positive-feedback) plant with Lambda set at 2.56. (For a complete description of the plant dynamics see Jex *et al.* (4).) Therefore, to maintain the display at a constant biased position, the subject had to provide a continuous force to the stick. Subjects controlled the display using the right hand.

The visual scene viewed by the subjects subtended a visual angle of 115° horizontally by 105° vertically and is pictured in Fig. 1. The attitude display consisted of five horizontal red lines whose luminance was set at 7.2 cd/m^2; it was presented using an inside-out frame of reference (i.e., the display simulated the motion of the horizon during aircraft roll). The attitude display at its maximum subtended approximately 24° of visual angle both horizontally and vertically. The background scene consisted of 100 blue dots of varying sizes (the average-sized dot subtended slightly less than 2° of visual angle) with a luminance of 2.9 cd/m^2. Due to the effect of chromostereopsis (11) the red attitude display appeared at a considerable distance in front of the background dots.

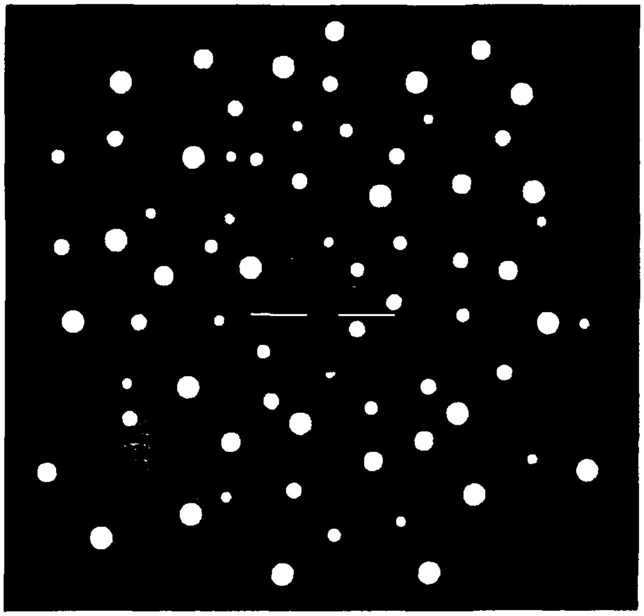

Fig. 1. The attitude display and background visual scene viewed by the subjects.

During half of the trials (*congruent* condition), the background scene moved with the attitude display. On the remaining trials (*incongruent* condition), the background scene rotated independently of the attitude display at a constant velocity (30°/s). The direction of rotation (i.e., clockwise vs. counter-clockwise) was alternated between trials.

Subjects were instructed to use two different techniques for holding the control stick. In the WH condition, the subjects grasped the lower part of the stick with the entire hand and were free to use whole arm and shoulder motion to control the attitude display. During the TI trials, the subjects performed the task while lightly applying the thumb and index finger to the top of the stick. Subjects were instructed to refrain from all arm and shoulder motion when using the TI technique.

A within-subjects design was used such that all subjects experienced all experimental conditions. There were four possible trial types: WH congruent, TI congruent, WH incongruent, and TI incongruent. Subjects completed two trial blocks (each consisting of four trials) for each condition for a total of 32, 70-s trials. The first blocks of each condition were presented in a pseudo-random order, and then the remaining four blocks were repeated in the reverse order. Subjects were able to pace themselves through the trials and were given a break for as long as they desired after completing half of the trials. Each experimental session lasted 1.5 h. Two measures of tracking performance were obtained: bias and stability. "Bias" was defined as the mean deviation of the attitude display from the horizontal (i.e., wings-level) position, while "stability" was defined as the standard deviation of the attitude display around the mean bias position.

At the conclusion of the experiment each subject was asked a series of questions to determine how disorienting the visual stimulus was, as well as which control method was preferred in the congruent and incongruent visual conditions.

RESULTS

The incongruent visual scene produced a powerful effect on all subjects' tracking behavior. Their mean biases ranged from 7.7 to 25.0 degrees. An example of the tracking performance of a representative subject in the congruent and incongruent visual conditions is shown in Fig. 2. A repeated-measures analysis of variance (ANOVA) was used to determine inferentially the effects of visual background condition and motor strategy on the bias and stability measures.

The bias results are shown in Fig. 3. The mean biases in the congruent, incongruent-clockwise and incongruent-counterclockwise conditions were −0.56°, 12.16°, and −15.52°, respectively. After reversing the sign of the counterclockwise bias values for each subject, an ANOVA was performed which revealed a significant main effect of visual background ($F(2,30) = 47.14$, $p < 0.01$), but a nonsignificant effect of motor strategy ($F(1,15) = 1.42$, $p > 0.05$) and a nonsignificant visual background × motor strategy interaction effect ($F(2,30) = 1.50$, $p > 0.05$). A *post hoc* comparison of means using the Duncan Range test revealed that the main effect of visual background was due to the difference between the congruent and incongruent (clockwise and counterclockwise) conditions, whereas the two incongruent conditions did not differ significantly from one another.

The stability results are shown in Fig. 4. The sum-of-sines forcing function created a considerable amount of instability in all conditions, but this instability was present especially in the incongruent conditions. The ANOVA revealed a significant main effect of visual background condition ($F(2,30) = 46.26$, $p < 0.01$), with *post hoc* comparisons again pointing to a significant difference between the congruent and incongruent conditions, but no difference between the clockwise and counterclockwise conditions. The ANOVA also revealed a significant main effect of motor strategy ($F(1,15) = 5.72$, $p < 0.05$), but no significant interaction between motor strategy and visual background ($F(2,30) = 1.75$, $p > 0.05$). The motor strategy difference reflected the lower standard deviation overall using the TI technique.

Although the stability results indicated that subjects did in fact use different motor strategies in the TI and WH conditions, it was possible that even more significant differences between the TI and WH techniques in the incongruent conditions could have occurred had subjects not been required to exert so much upper-body force on the stick when the attitude display deviated substantially from the baseline position as a result of the illusory relative motion of the display. Hence, a correlational analysis was performed to determine if the differences between the TI and WH techniques varied as a function of the overall magnitude of visually induced bias for each subject (i.e., did those subjects who showed a larger TI bias also exhibit less of an overall difference between the two techniques?). The Pearson's r value (0.10) proved nonsignificant, indicating that the effectiveness of the TI strategy in overcoming the visually induced bias was not affected by the magnitude of the induced bias.

Finally, the subjective data acquired during the post-experimental interviews revealed that, in general, a subject's preference for one control method over the other was not indicative of performance, especially in the incongruent conditions.

DISCUSSION

Given the findings of the current study, it is premature to either endorse or condemn the TI technique for overcoming the GH phenomenon in the aircraft. The TI technique was not effective in combatting the visually induced analogue of the GH phenomenon generated in our laboratory. Several possible explanations for this finding are discussed below.

First, we must explore the possibility that the subjects were not using the TI technique as instructed. Although subjects may have been incorrectly using the technique, stability differences between the TI and WH trials indicate that subjects were in fact using two different control techniques. Unfortunately, there is no way to determine definitively the degree to which subjects followed instructions. We initially considered restraining the subject's forearm in the TI condition to ensure that only the thumb and index finger would be

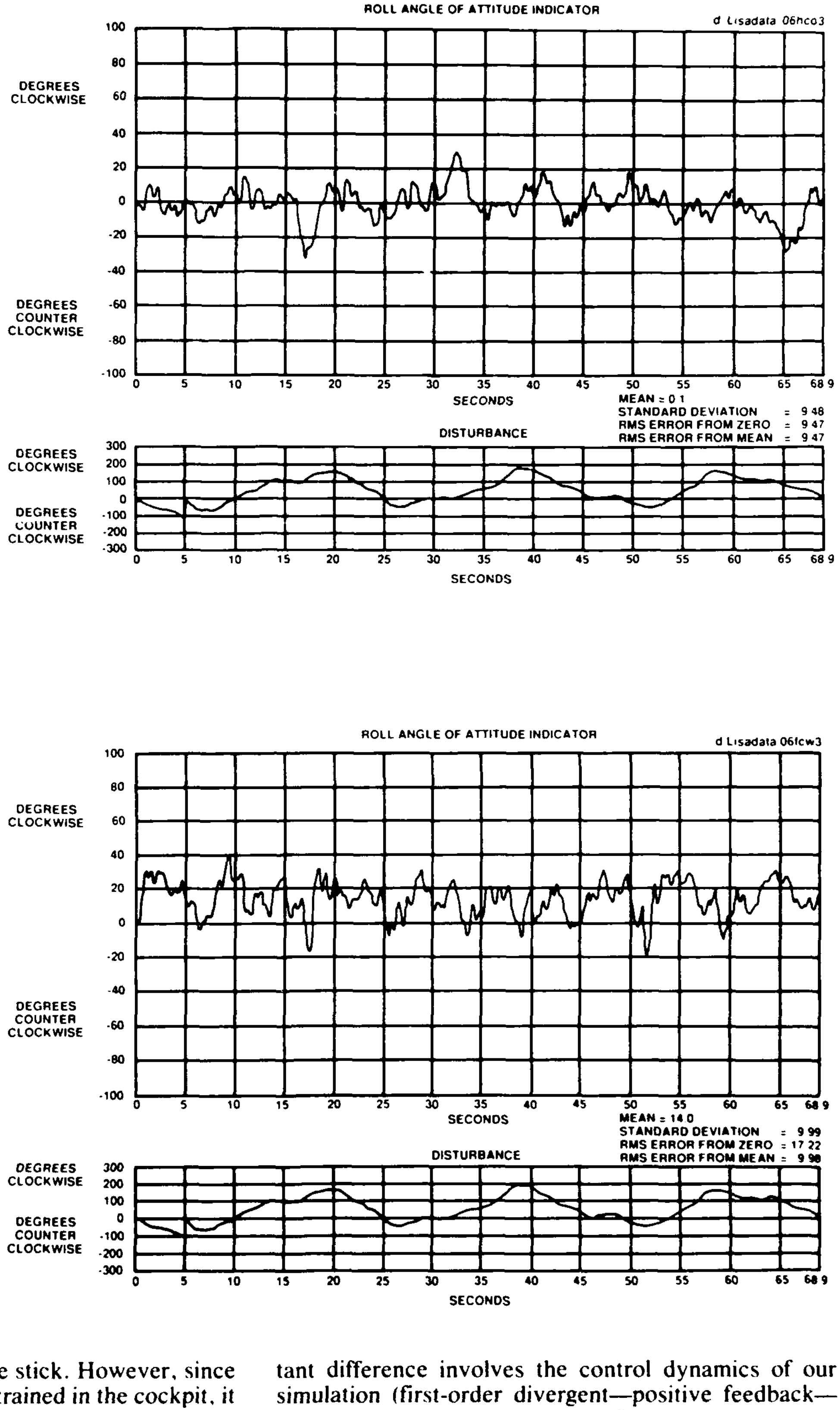

Fig. 2. An example of the tracking performance of a representative subject and the cumulative disturbance of the attitude display generated by the forcing function. The top illustration is from a WH-congruent trial, and the bottom is from a TI-incongruent clockwise trial.

used positioned on the top of the stick. However, since the pilot's arm would not be restrained in the cockpit, it seemed excessively artificial to restrain it during data collection.

A second and more likely explanation is that differences between our experimental conditions and the cockpit environment precluded an adequate simulation of the GH phenomenon, thus eliminating the possibility of effectively evaluating the TI technique. One important difference involves the control dynamics of our simulation (first-order divergent—positive feedback—control) vs. that of the aircraft (first-order stable control). The combination of positive feedback and the force-stick control in our experiment made it necessary for a constant actual force to be applied by the subject to maintain the attitude display in the biased position. Whenever a biased bank attitude is achieved in the aircraft, however, no actual force is required to maintain it

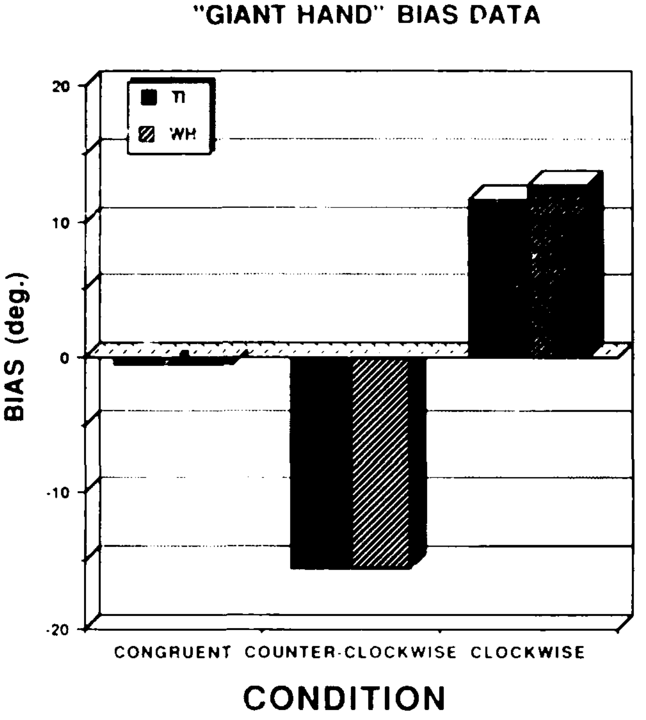

Fig. 3. Bias in degrees as a function of visual condition and control technique.

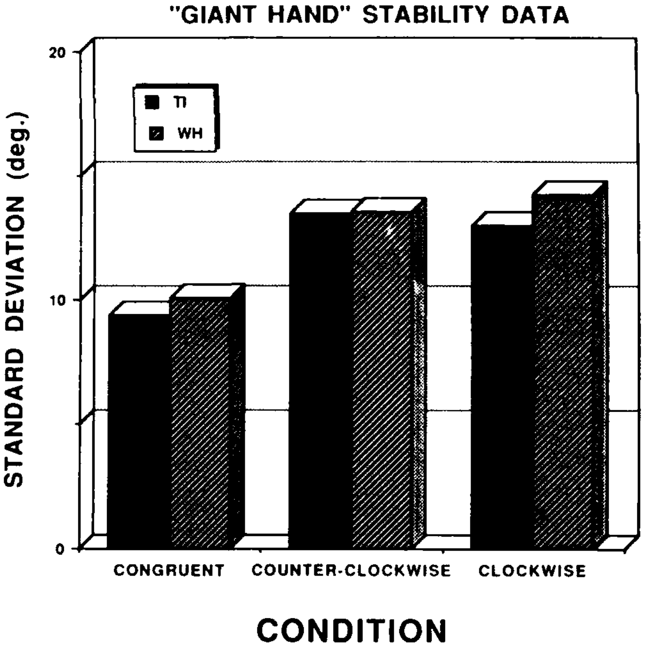

Fig. 4. Stability in degrees from the mean bias as a function of visual condition and control technique.

there: the only force felt comes from the pilot's own preconscious countercontrolling stick inputs when voluntary corrective control inputs are attempted. Thus, the reflex generating the GH phenomenon could possibly be more readily broken by the TI technique in the aircraft (where no actual force is being applied) than in the laboratory (where the expression of the visually-induced spatial disorientation obligates an actual force to be applied by the subject).

Several other differences between the aircraft and our simulation may have contributed to the failure to demonstrate a difference between TI and WH techniques in overcoming the bias. The TI control technique, as discussed by Lyons and Simpson (8), is mediated by the corticospinal pyramidal pathway and may not be effective in overcoming a presumably cortically-mediated visual illusion. In essence, the visual analogue may place both the perception of the orientational illusion and the TI control technique under cortical control, thereby nullifying the hypothesized benefit of the TI technique in bypassing the more primitive subcortical reflex response to the illusion. In addition, the laboratory environment does not reproduce the emotional stress that could precipitate the GH phenomenon in the aircraft when disorientation is experienced and threatens the pilot's life.

Third, in spite of the anecdotal evidence suggesting the utility of the TI technique, it may not be universally effective for overcoming the GH phenomenon. Individual differences in susceptibility to and control of spatial disorientation episodes may render the technique useful for a limited population. While these results do not show a specific benefit for the TI technique in overcoming the GH illusion, this technique did offer a more stable control method overall for subjects and should be suggested as an effective technique for pilots.

Although the current study failed to show an advantage for the TI technique under the visually disorienting conditions, it is difficult to determine which factors were responsible for the outcome of the study. Thus, further research should be conducted to explore the following alternative procedures before the use of the TI technique for overcoming the GH illusion can be evaluated definitively.

First, if the control dynamics were responsible for generating a situation (i.e., maintenance of a constant stick force) that could not be overcome by the TI technique, then the study should be replicated using first-order stable control dynamics. Second, if the ineffectiveness of the TI technique was due to the cortical mediation of the visual analogue, then vestibular input created by a motion-based simulation may be necessary to accurately reproduce the GH illusion and the subcortical reflexive actions that the TI technique is expected to overcome. Third, a displacement stick with less resistance would eliminate the possible need for recruitment of large muscle groups and should allow subjects to easily use the TI technique as instructed. It should be noted, however, that the amount of actual force applied by the subject may not be especially critical, as the TI technique proved no more effective for subjects who had a larger maintained bias (i.e., applied a larger force to the stick) than for those who exhibited a lesser bias to begin with. Fourth, some subjects reported control reversal due to the inside-out frame of reference; hence, an outside-in display might be used to eliminate the possibility of inadvertent control actions that could bias the results.

Once these factors are accounted for, a thorough exploration of the GH phenomenon, its physiological basis, and effective recovery techniques can be undertaken. A thorough understanding of the phenomenon will enable researchers to suggest improved training methods and display designs to prepare pilots to handle this and other manifestations of the spatial disorientation that they may encounter in flight.

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