AMPLIFIED EGO MOTION DRIFT INDICATION FOR HELICOPTER LANDING

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Abstract

Helicopter flight in degraded visual environment (DVE) can pose a serious safety hazard especially during low-level operations. One cause for rapidly losing the visual cues is introduced by surface properties such as sand or snow. They are prone to stir up particles due to the helicopters downwash and encase the helicopter in a non-transparent cloud. This effect is referred to as brownout or whiteout. Under such conditions lateral speeds introduce a high risk that when touching the ground may cause the helicopter to rollover. Therefore helicopter operators could benefit from some type of “drift indication” that mitigates the influence of degraded visual environment. To enhance the perception of ego motion in a conformal HMD symbol set the measured own ship movement was used to generate a “pattern motion” in the forward field of view close or on the landing pad [4]. As a next step the part task study presented here takes a closer look at the mechanism of subconscious drift indication. It is believed that providing this type of constant subliminal information can enhance the reaction time to unforeseen movements like from gusts. The study focused on none-professional participants. 31 candidates took part in this study. The main task was to steer the lateral position to the center of the presented landing pad. A second task forced the participant to react as fast as possible to a frequent presentation of two different characters on the display. The experiment was displayed on an Oculus Rift DK2™ virtual reality glass. The added “pattern motion” significantly supported participants in assessing drift, which reflected in lower lateral speeds during touchdown compared to the static presentation. Two of the three visualization concepts did not show a change in reaction time of the secondary task. Only marginally fewer correct responses to the secondary task were found. 24 candidates favoured the moving presentation rather than the static one. Few but some participants experienced pilot induced oscillation revealing that the chosen gain might have been too large. A follow-up experiment will try to optimize the gain.

1. INTRODUCTION

Helicopter flight in degraded visual environment (DVE) can pose a serious safety hazard especially during low level operations. Pilots need an adequate situational awareness in order to land the helicopter safely. Especially a good spatial orientation and speeds in reference to the ground are needed to keep the helicopter stabilized. Pilots derive their relative motion by the perceived environmental optical flow. Shortly before ground contact they mainly gather this information by looking sideways or down through suitable windows. The visual cues perceived are located close to the helicopter, therefore even small movements can be recognized. The loss of these visual references may result in poor situational awareness, spatial disorientation and high workload. One imminent risk factor is introduced by lateral speeds that when touching the ground may cause the helicopter to rollover. Therefore pilots could benefit from some type of “drift indication” that mitigates the influence of DVE.

One cause for rapidly losing the visual cues is introduced by surface properties such as sand or snow. They are prone to stir up particles due to the helicopters downwash and encase the helicopter in a non-transparent cloud. This effect is referred to as brownout or whiteout. Although severe brown- and whiteout induced accidents recently also occurred in the civil field [1] brownout became particularly a major problem in military rotary-wing aviation since NATO started operations in desert areas such as Afghanistan. According to the NATO Rotary-Wing Brownout Mitigation report [3] around 75% of coalition helicopter mishaps are attributed to brownout, making it the overall largest cause of US Services airframe loss. In the report three common misperceptions to cause spatial disorientation during brownout were identified. Firstly the pilot’s unawareness of sub-threshold lateral drifts prior to touchdown, which is referred to as Type I (unrecognized) spatial disorientation in flight. Secondly the visually induced illusion of self-motion (vection) due to the movement of the dust particles provokes the impression of banking or turning when actually in a level hover. Finally the loss of visual references is prone to evoke somatogravic illusions, giving the impression of pitching down when decelerating from forward flight.

Therefore, the rather high incident and accident rates certainly demand to counteract the occurrence of spatial disorientation during landing. One way to achieve this could be the introduction of three-dimensional and visual conformal symbol sets. Previous literature suggests that those are certainly more suitable when operating with a superimposed display. Visual conformal refers to the depiction of symbols on the display that are perfectly aligned (linked) to actual objects or virtual properties in the outside scene, sharing both a common position and a common motion. Visual conformal symbol sets were repeatedly found to mitigate prominent costs associated with head-up and helmet-mounted displays such as attentional tunneling and clutter costs. Moreover benefits were found with regard to flight path tracking and event detection performance, overall facilitating divided attention tasks [2][5].

With continuous technology advancement helmet-mounted displays (HMD) will soon become a spreading technology. At the present state HMDs are still expensive and are mostly reserved for military operations. Investigating some of those symbol sets revealed that lateral drift indication doesn’t live for what it promises. With practice these symbol sets assist well during the approach but lack of proper cues once the helicopter hovers.

A three-dimensional landing zone symbol set was also developed at the DLR Institute of Flight Guidance. It focused on the implementation of more visual conformal elements as well as a de-cluttered presentation. Two variations have been implemented and tested in a simulator study – with and without a new approach for drift indication. To enhance the perception of ego motion in a conformal HMD symbol set the measured own ship movement was used to generate a pattern motion in the forward field of view close or on the landing pad (Schmerwitz, Knabl, Lueken, & Doehler, 2015). As a next step the part task study presented here takes a closer look at the mechanism of subconscious drift indication. It is believed that providing this type of constant subliminal information can enhance the reaction time on unforeseen movements like from gusts.

2. METHOD

2.1. Participants

The study focused on none-professional. 31 candidates took part in this study (three female and 28 male). They split in 23 employees and eight students. Three participants hold a helicopter licence and eight a fixed wing licence. Their average age was 38.0 years (SD = 11.1). Experience was measured by PC gaming hours either with flight simulation or virtual reality glasses. Two candidates had no experience with flight simulation, nine less than 100 hours, and 20 more than 100 hours. Only five participants had experience with virtual reality glasses and all except one of them less than ten hours.

2.2. Experimental design

The trials contained 24 individual runs with an average runtime of 17.7 seconds. The complete experiment roughly lasted 35-40 minutes. Three display concepts for drift indication were tested with two different wind profiles while presenting a virtual background or none with and without drift indication (3x2x2x2 = 24 runs). All factors were counterbalanced except for the background texture. It was shown on block in a split group. One group started with twelve runs with the texture turned on and the other group with no background.

The main task was to steer the lateral position to the center of the presented landing pad from a randomized start-up position which was set from 7 to 15 meter left or right from the center. Thereafter the candidates had to hold position while reacting to the wind profile until a minimum trial time of 14 seconds before they could end the run as soon as they found the lateral speed to be acceptably small while close to the center of the pad. The 14 seconds were advised by an acoustic feedback during the runs. The forward position and altitude were static and only the lateral axis had to be controlled. The user input directly incremented the velocity which also influenced the banking. A damping was added to reduce lateral speed and bank over time to ensure that it was impossible to command an exact zero lateral speed. The two wind profiles were constant wind and changing wind. The initial direction (from left or right) was randomized but static for each run. It ensured that the bank angle for zero lateral speed was changing at least between the runs and for the changing wind profile within one run. The changing wind profile was generated from three different wind magnitudes, which were selected randomly in strength and time. The variation in time was set between 1 and 3 seconds. From one magnitude to the other a fading of 0.4 seconds was applied.

A second task required the participants to react as fast as possible to the presentation of two different characters (O and Q) which were randomized in type and position. The timing was constant at one character every 2.5 seconds. The character was presented for a maximum time of 1.5 seconds and cleared early if acknowledged. The positioning of the characters ensured that they had at least a minimum distance to the center position of the landing pad.

The briefing consisted of explaining the roots of the concept (conformal helicopter brownout symbol set, Figure 3), the three different display concepts, the modes of operation of the different drift indications, the general controller functions and trial tasks. The participant was told to solve the second task as good and fast as possible and secondly the lateral speed to be as small as possible. He was told to roughly catch the center of the pad but not try to exactly steer to it. He was advised to finish fast but not necessarily with the minimum runtime of 14 seconds.

During training the candidate was shown how to steer and solve the different tasks by the examiner first before he tried out under supervision of the examiner using the LCD monitor. Thereafter the Oculus was adjusted to the candidate and twelve training runs were conducted with no interventions during the runs.

Immediately after the training the 24 trials followed under the control of the participant. After one trial finished he was shown the results of this run concerning lateral deviation and speed as well as the trial time. He then could choose when to start the next run.

During the debriefing the candidate had to fill in two online questionnaires – a biographical and a debriefing one.

2.3. Apparatus

The experiment was displayed on an Oculus Rift DK2™ virtual reality glass. See Table 1 for some technical specifications and Figure 1 for a depiction of the Oculus. Additionally the display was shown on a standard LCD monitor for demonstration, training, and questionnaire.

A self-build digital button unit was used as controller (see Figure 2). The two tasks are separated between thumb (lateral control) and forefinger (character acknowledgement).

Table 1: Technical specification of Oculus Rift DK2

Field-of-view	100° circular
Resolution	2 x 960 x 1080 pixel
Framerate	75 Hz, 72 Hz and 60 Hz
Persistence	2-3 ms
Interface	HDMI / DVI
Tracker	External CMOS (60 Hz), internal accelerometer, gyroscope and magnetometer (1000 Hz)
Weight	440 g

Figure 1: Oculus Rift DK2™ [arstechnica.com]

Figure 2: Controller unit

2.4. Display concept

The display tested in this study is derived from a more complete symbol set of an approach and landing display for helicopter. It is dedicated to prevent spatial disorientation in case of a brownout or whiteout (see Figure 3). This concept depicts as many elements as possible in a visual conformal way like the landing pad with relative position markers and all angles (heading, pitch and roll). Besides those symbols the aircraft state information like speed, groundspeed, altitude, radar altitude, torque and some more are provided.

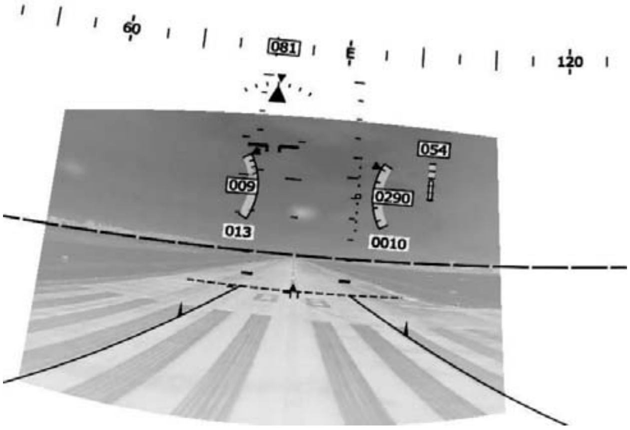

Figure 3: Conformal helicopter brownout symbol set

Since this study was conducted by none-professional candidates, the derived display consisted of only the absolute necessary elements to provide spatial orientation. All other symbols would only distract the novice. All symbols are drawn in green alike the target system on a helmet mounted display. The landing pad dimension was 15 by 60 meter.

The drift indication was implemented by moving the gaps of the dashed line to the left or right – the edges of it remained fixed relative to the landing pad symbol (see Figure 5). As input for this motion the relative speed between helicopter and landing pad was used. In case the helicopter was moving to the left the gaps of the line were moving to the right. The intended impression for the user is that this line appears to be very close to the helicopter. Modelling the mode of operation into the real world one could draw a dashed line onto a window looking outside. If moving left to right the background will move slowly and the dashed line will move faster. This way a slow motion can be perceived much earlier while still looking forward instead of sideways or down. These pattern motions can be realized in many different ways. The second and third concept tested within this study is shown in Figure 6 and Figure 7. Alike the real world example of a dashed line on a window these concepts give the impression of a virtual plane being closer to the helicopter. This plane is dotted with a regular (Figure 6) or a randomized grid (Figure 7).

During half of the experiment a checkerboard background was presented to improve spatial orientation by additional vanishing points (see Figure 4). Additionally it provides further motion cues. The checkerboard is coloured in grey and white. Towards the horizon haze is added in order to improve the degree of realism.

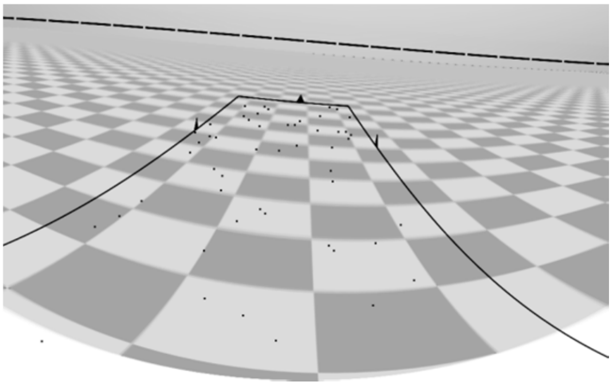

Figure 4: Checkerboard background reference texture

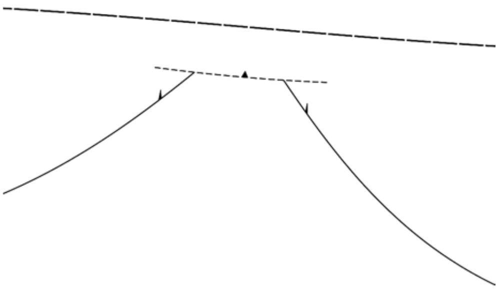

Figure 5: Drift indication: animated line

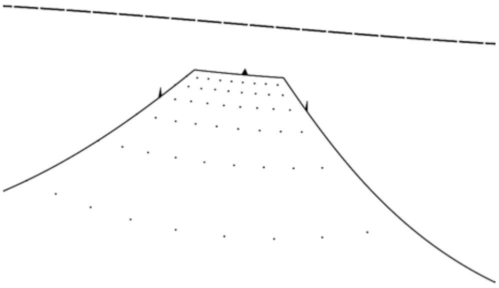

Figure 6: Drift indication: regular grid

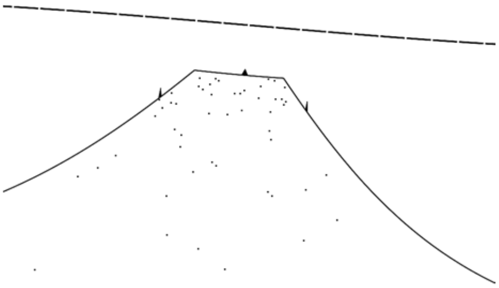

Figure 7: Drift indication: randomized grid

3. RESULTS

3.1. Objective measures

To assess performance differences, a 3 (*display*) x 2 (*gain*) x 2 (*texture*) x 2 (*wind*) repeated measures analysis of variance (ANOVA) was calculated for each dependent variable. Results are presented subsequently.

Lateral deviation

A significantly larger lateral deviation was obtained without proper textural cues (M = 0.43, SD = 0.20) compared to when ground texture was presented (M = 0.28, SD = 0.13), F(1,30) = 23.0, p = .000, $\eta^2 p = .434$ (see Figure 8).

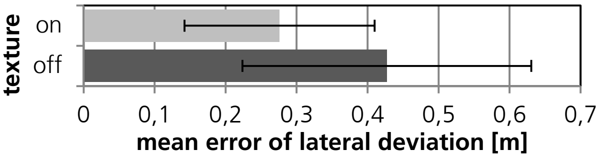

Figure 8: Influence of texture on lateral deviation

Lateral speed

Lateral speed during touchdown was significantly lower with the added motion (M = 0.22, SD = 0.11) than with the static presentation (M = 0.30, SD = 0.10), F(1,30) = 12.8, p = .001, η²p = .298 (see Figure 9).

Figure 9: Influence of gain on lateral speed

Lateral speed at touchdown was also by trend higher when no ground texture was presented (M = 0.28, SD = 0.11) compared to when the terrain featured textural cues (M = 0.24, SD = 0.09), F(1,30) = 3.4, p = .074, η²p = .103) (see Figure 10).

Figure 10: Influence of texture on lateral speed

Moreover, significant results were obtained for display, wind, and their interaction [display: F(2,60) = 3.2, p = .046, η²p = .097; wind: F(1,30) = 5.3, p = .028, η²p = .150; interaction: F(2,60) = 3.7, p = .030, η²p = .110]. Post-hoc t-tests with Bonferroni Holm corrections revealed that wind particularly affected the grid design. Thereby, lateral speed was significantly higher in variable compared to constant wind, t(30) = -2.6, p = .013. Moreover, the grid design produced the overall highest lateral speed during variable wind conditions among all display types. Thereby, it was significantly higher compared to the random design, t(30) = 2.6, p = -.013 (see Figure 11).

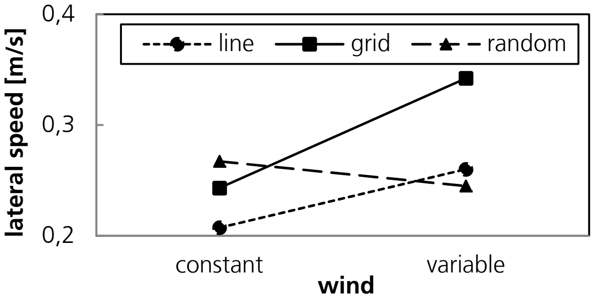

Figure 11: Influence of wind x display on lateral speed

Scenario time

The main effect display type did show significant, F(1.6,48.3) = 4.2, p = .029, η²p = .122. However, post-hoc Bonferroni comparisons only revealed a very small trend indicating that it took participants marginally longer to complete the scenario with the grid design (M = 18.18, SD = 3.12) compared to the line (M = 17.27, SD = 2.11) (see Figure 12).

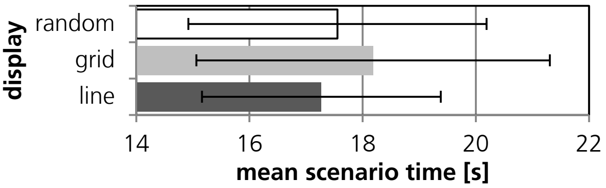

Figure 12: Influence of display on scenario time

In addition, significant results were obtained for the main effects gain, texture, and their interaction [gain: F(1,30) = 17.7, p = .000, η²p = .370; texture: F(1,30) = 4.4, p = .044, η²p = .129; interaction: F(1,30) = 8.3, p = .007, η²p = .216). Scenarios were completed faster without the added gain (M = 17.76, SD = 1.87) compared to when the gain was presented (M = 18.58, SD = 3.37). Moreover, texture type did not influence scenario duration with no gain (p = .701). However, with added gain, it took participants significantly longer to complete the scenario when no texture was presented, t(30) = -3.0, p = .006 (see Figure 13).

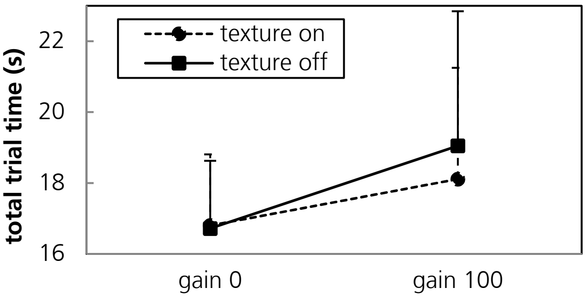

Figure 13: Influence of gain x texture on lateral speed

Reaction time to secondary tasks

Reaction time to secondary tasks was shorter with the static presentation (M = 0.79, SD = 0.08) compared to when the motion was amplified (M = 0.81, SD = 0.09), F(1,30) = 19.7, p = .000, η²p = .397 (see Figure 14). However, the interaction indicates that this only applies to the grid display, t(30) = -4.6, p = .000 but not to line and random. Moreover, reaction time with the grid display was also significantly longer compared to line (p = .002) and random (p = .018) in the added gain condition (see Figure 15).

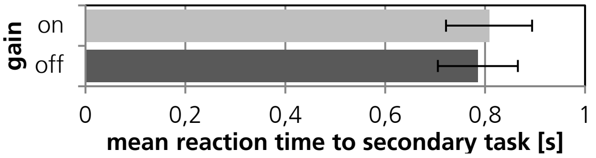

Figure 14: Influence of gain on reaction time

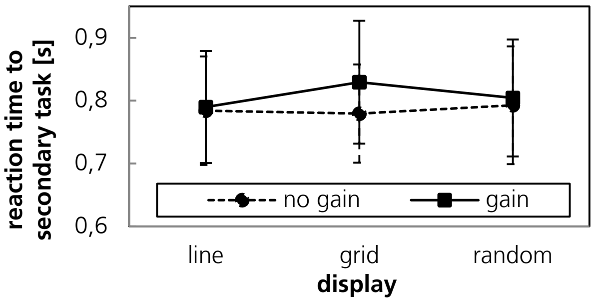

Figure 15: Influence of display x gain on reaction time

Correct answers to secondary tasks

Display type affected the relative frequency of correct answers given, F(2,60) = 3.6, p = .033, η²p = .108. Post-hoc Bonferroni comparisons indicated that the random display produced by trend more correct responses (M = 0.95, SD = 0.05) than the grid display (M = 0.93, SD = 0.07) (see Figure 16). Moreover, the gain x wind interaction was significant [F(1,30) = 4.9, p = .035, η²p = .140], showing that fewer correct responses were given with the added gain compared to no gain in variable wind conditions, t(30) = 2.1, p = .046, whereas gain did not affect performance during constant wind (see Figure 17).

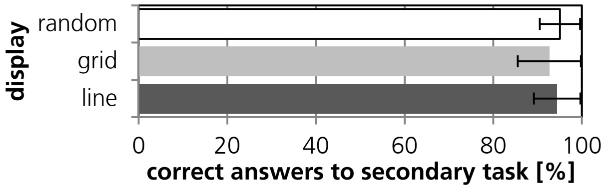

Figure 16: Influence of display on correct answers

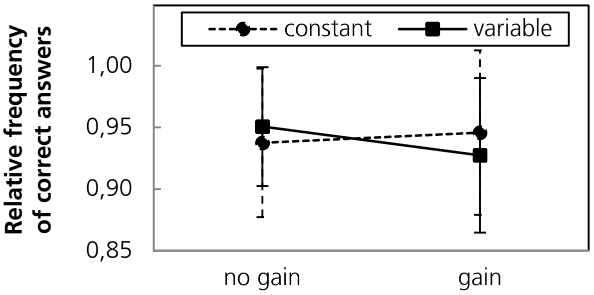

Figure 17: Influence of gain x wind on correct answers

Wrong or missed answers to secondary tasks

No significant results were found.

Total Task Score

Making use of none-professionals for a specialized task might not reflect the abilities alike the group of professionals would have. A total task score was built to provide a closer look into the speed accuracy trade-off found related to hidden effects like training, perception, dexterity and other superiority for the tasks. The participants were sorted along a total precision value summed up from four values – the second task precision (a combination of reaction time and correct answer rate), lateral deviation, lateral speed and scenario time and split into two groups gain ON versus gain OFF. It was taken care of that the terms provide close to equal weight (lowest score = 0 perfect score = 0.25). Figure 18 depicts the result. One can find the total score of gain ON vs. OFF as the topmost line pair since all terms are stacked. The total score for the group of all participants is on the left showing a slight advantage in favour for gain OFF (gain OFF score = 57.8%; gain ON score = 56.3%).

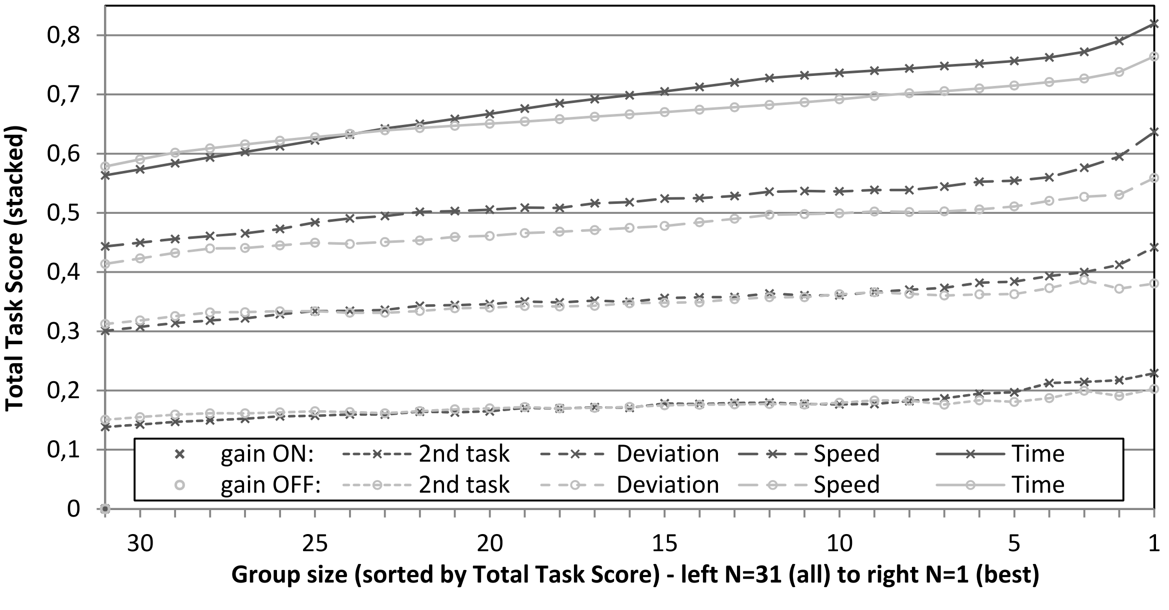

Figure 18: Total Task Score: Stacked normalized precision values for each task over the sorted group size.

On the right side one can find the score of the candidates that performed best. The second task as well as the lateral deviation doesn't vary much over the group size until N=7. Looking at lateral speed it can be stated that it is enhanced with the gain present over all group sizes and only raises in magnitude. Besides a step-up at N=25 the difference in lateral speed performance is rather constant. Looking at the scenario time or the total score it gets visible that the group with gain OFF differs much from the one with gain ON. At N=26 the total score for gain ON rises above the one with gain OFF and can built up a good advantage while reducing the group size until N=12. The group with gain ON is obviously not normal distributed within the factor trial time. The reason for this is not finally evaluated, but evidence has been found for pilot induced oscillation (see Figure 19).

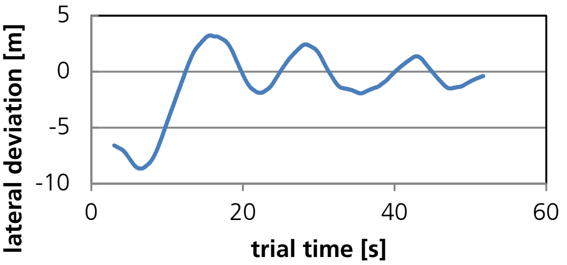

Figure 19: Example for evidence found towards pilot induced oscillation.

Results summary

The added motion (gain ON) significantly supported participants in assessing drift, which reflected in lower lateral speeds during touchdown compared to the static presentation. Nevertheless, it took participants longer to complete the trial when the landing zone was animated, indicating a speed accuracy trade-off. This became particularly evident when no ground texture was presented. Also, gain ON led to fewer correct responses to secondary tasks during variable wind conditions, whereas gain did not affect performance during constant wind. Gain ON also revealed a reaction time cost to secondary tasks for the grid display. Thereby, it has to be stated that the grid display was generally associated with inferior outcomes. In addition to the reaction time cost, the grid display also resulted in by trend fewer correct responses and longer trial times compared to the line display. Moreover, the grid design showed the overall highest lateral speeds, being significantly higher compared to the random design. Grid was also affected by wind condition, producing higher lateral speeds during variable compared to constant wind.

Finally, the lack of ground texture produced both higher lateral deviations as well as by trend higher lateral speeds during touchdown compared to when texture was presented.

The group of participants was inhomogeneous concerning the time needed to finish the task for the factor gain. This might be at least partially due to oscillation occurrences at some runs with gain ON. Individual performance differences are considerably large in all factors but believed to be homogeneous.

3.2. Subjective ratings

24 favoured the moving presentation (gain ON) rather than the static one (gain OFF). Five participants chose the line presentation to be the best, 15 picked the regular grid, and eleven favoured the randomized grid. Some reasoned to prefer the random grid because it appeared to be most realistic compared to the other designs. Others noted the regular and/or the random grid was too dominant respectively distracting. Some suggested using less gain in order to get useful. Nevertheless, the majority felt support in lateral speed perception due to the introduced motion.

Concerning motion sickness no relevant evidence has been found that might have influenced the trials. The candidates stated higher possibilities for motion sickness than actually experienced (see Figure 20 and Figure 21).

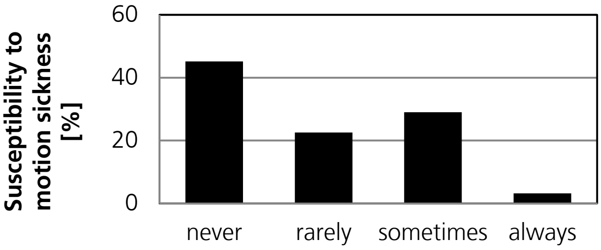

Figure 20: Subjects susceptibility to motion sickness.

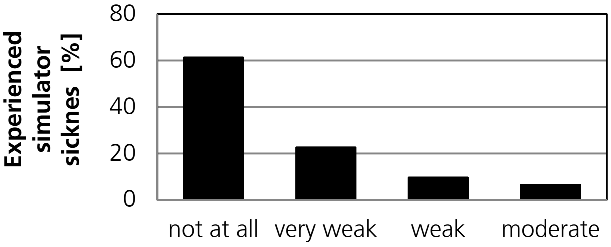

Figure 21: Experienced motion sickness.

4. CONCLUSION AND OUTLOOK

If the experimental design could support the subliminal perception of amplified motion as intended cannot be answered. However, it can be stated that this motion has been beneficial for most of the participants considering the lateral speed parameter. At the same time their correct answer rate didn't drop much which might support the thesis of subliminal perception, but only proofs the amplified motion to just marginally increase cognitive effort. It became obvious that participants needed longer with the amplified motion to finish a trial. That is somehow true by nature of the task but is also driven by hidden effects like training, understanding, dexterity and more. Since the mode of operation is not intuitive, all participants need to understand the roots of the animation first before they can effectively train with the system. If they lack of training and/or understanding they will most likely need longer to fulfill the task and/or cannot benefit from the motion adequately. In both cases it can be foreseen that the motion will not be perceived subconsciously. This fact could be mitigated by training. Another reason for participants to need longer for the task is that the gain to the motion might have been too large. Few but some participants experienced pilot induced oscillation which at all costs needs to be prevented. It got reasonable to repeat this experiment with different gains for the motion in order to reveal the best amplification for this experiment. With the follow-up experiments the concept of the regular grid will be dropped since it became clear to be inferior to the other concepts.

It was expected that presenting an amplified motion pattern on top of the real motion might not work as good as intended. This could be dispelled for this experiment. The results show lower lateral deviation, lateral speed and trial time when additionally to the amplified motion the texture was presented. At the same time it underlines the need of visual cues to build up a proper spatial orientation. This leads to the conclusion that the presentation of the landing pad doesn’t provide enough cues to equally well estimate the relative position to the centreline when no texture is shown.

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