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3D AUDIO SUPPORT FOR HELICOPTER PILOTS DURING CONFINED AREA LANDINGS

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Abstract

A major challenge in aviation and cockpit design is data overload, especially in the visual channel and associated breakdowns in monitoring systems. These problems are expected to worsen with new and increasingly complex missions, which will require pilots to manage higher volumes of data and undertake new responsibilities. Multimodal approaches, especially newly developed 3D audio systems, have the potential to become a major part of operating systems in the future. Current cockpits convey audio only as warning-or information-sound. This paper documents a helicopter simulator study to test the recently developed 3D audio system which is accurate enough for real-time applications to support pilots in future cockpits. The system is named SPAACE - Spatial Pilot Audio Assistance. Sixteen professional helicopter pilots (from law enforcement, search and rescue service and VIP transportation) flew approaches, hovered and performed vertical landings in confined areas during brown-out conditions. The 3D audio played over the pre-calculated landing spot so that the pilot's task was to fly towards the direction of the audio.

Results show that pilots can better maintain a hover during brown-out conditions with the support of spatial audio. The longitudinal and lateral movement during the hover improves significantly. The distance from the desired landing position improves. Results of questionnaires and interviews with the pilots confirm that the system is easy to use and requires only minimal training. Pilots reported longer head-up time and better situational awareness during the missions with 3D audio assistance.

1 Introduction

The study documented in this paper was conducted at the German Aerospace Center (DLR) in Braunschweig, Germany at the Institute of Flight Guidance. The research task was to investigate whether pilots could be supported by 3D audio during landing under brown-out conditions on confined landing pads. The particular system developed by the author and tested in this study is called Spatial Pilot Audio Assistance (SPAACE).

1.1 Background

According to the European Helicopter Safety Team, 78% of helicopter accidents are attributable to at least one human factor. Pilots' judgments and actions are the most frequently reported causes of accidents [1]. Most helicopter flights are professional operations, such as emergency medical services, commercial training or aerial work. These tasks are predominantly involved in accidents [2]

Results from accident analyses reflect the major challenges inherent in helicopter missions: operating in low visibility, operating close to the ground, flying with pilots under time pressure with unpredictable tasks. The helicopter itself is a highly dynamic platform. Flying a helicopter under these conditions places high demands on both human and machine. The workload in the helicopter raise and accidents are expected to increase with complex new missions, which will require pilots to manage increased amounts of data and fulfill new responsibilities [3]. Additionally, pilots' workload associated with head-down-displays is so high, that it is often difficult for them to pay sufficient attention to visual displays. [4]. Beyond that, pilots have to look out of the cockpit during landing to correct and control the helicopter's movement and identify possible threats during the critical flight phase. This becomes vital during operations in confined areas or during brown- and white-out conditions.

Research therefore needs to address two topics. The first is decreasing the visual workload to create free capacity in the human visual channel, which increases the information flow and lowers the stress of the flight crews. The second is improving the performance of flight crews during challenging flight phases or critical missions. To reach these goals, multimodal cockpits are conceivable. Multiple resource theories suggest that displaying information on different perceptual channels has the potential to free up pilots' mental resources for other tasks [5, 6]. Hearing and the natural ability to localize sounds are essential human senses, especially for actions happening outside the field of view or under conditions of stress or heavy workload [7, 8].

Currently, audio is only used as a warning or information signal in cockpits. Besides that, inter-crew and crew-to-ATC communication is present. Audio warnings are only used to bring the pilots' attention to a specific issue inside the aircraft or to the immediate environment. Spatial audio, meaning the direction or position of an audio source, is rarely used as supplementary information tool in civil commercial airplanes and helicopters [8, 9]. Thus, a substantial part of human sound processing capability remains unexploited. However, few hands-on studies have been conducted into continuous dynamic tasks, so insights into how audio-visual information affects workload and visual attention in various domains have, up to now, been relatively sparse. Different research approaches have examined audio support in the cockpit. Most of these results presented spatial audio by means of a loudspeaker array. These arrays are not suitable to install inside present or future cockpits. However, they describe various possible advantages for the aviation domain [9–15]. As it is not possible to install a loudspeaker array in the limited space of a cockpit, the scope of action of humans is also limited by their cognitive abilities. [16]. This creates new operational burdens and new failure in the overall human-machine system [13, 17]. Real-time 3D audio in a dynamic aviation environment with the presentation of sound by stereo headphones and state-of-the-art software has, up to now, not been extensively evaluated. To close this research gap, the author developed and tested a 3D audio system to support pilots in future cockpits, accurate enough for real-time applications. The system is named SPAACE - Spatial Pilot Audio Assistance. To test the performance of SPAACE and the its support of pilots during various flight phases and missions, the author conducted a helicopter simulator study in the Air Vehicle Simulator (AVES) as shown in figure 1, at DLR Braunschweig, Germany. This study aims to reduce helicopter pilots' visual workload to contribute to safer helicopter operations during challenging missions.

1.2 Present Study

The present study investigates a potential system to support helicopter pilots while landing under brown-out conditions in a confined area with limited maneuvering space. Under these circumstances, visibility from the cockpit is impaired because of dust or sand stirred up due to the downwash from the helicopter, then recirculated by the rotor blades during hover or take-off and landing. These conditions cause pilots to rely on cockpit instrumentation, support by other crew-members and training to perform a reduced-visibility hover or landing successfully. Flying without outside visual references is always a challenge for pilots. Referring to current publications and reports, the loss of situational awareness has caused around three-quarters of all helicopter accidents in the last decade [2, 18, 19].

Fig. 1 Air Vehicle Simulator with pilot using SPAACE during flight.

The tested system is designed as a flight aid to improve situational awareness and flight safety when carrying out approach and landing maneuvers near obstacles under reduced visibility conditions. SPAACE calculates the distance and direction to a safe target landing spot. The target landing spot in this study was visible during the initial approach. Pilots had to fly towards the 3D audio signals, and different sounds presented information about distance to the target position and final approach to the desired position. The detailed description of the study follows in the next chapter.

2 Method

The experiment took place at the Institute of Flight Guidance with the support of the Institute of Flight Systems at DLR, Braunschweig, Germany.

2.1 Simulator

The DLR simulation platform AVES, shown in figure 1, was used for the study. AVES is a helicopter simulator based on the Airbus Helicopter H135 in level D quality, not certified due to its research modifications. For this study, the cockpit instrumentation and flight characteristics were configured similar to the Airbus Helicopter's H135 model. Within the AVES, participants sat in the right-hand pilot seat. The experiment supervisor and the operator of the SPAACE 3D audio software sat directly behind the participant-pilot. The simulator speaker, which presents immersive flight and system sounds in the cockpit, was not used. The background noise level caused by air-condition measured in the center of the cockpit was around 65 dB(a) during the experiment. All sounds were at a comfortable level but at the same time audible to all participants. The sounds in the experiment were played using an off-the-shelf over-ear Beyerdynamic DT 880 stereo headphone. This semi-open headphone has a frequency range from 5 Hz to 35 000 Hz and has no built-in 3D audio technical possibilities. A Carl Zeiss Cinemizer head tracker was attached to the headphone to transmit head movements. The head tracker sends head rotating information to the experiment software SPAACE. This combination allows participants natural head movement, essential to localize virtual sound sources [15, 20] and provides realistic adjustment of the sound according to the pilots' head movements.

2.2 Sound Design

At the beginning of the approach towards the landing area, a *beep* sound and a synthetic voice are played in the pilots' headphones to inform the pilot that SPAACE is activated and the assistance system is available. The concept of the hover and landing assistance for confined area operations is to inform pilots about the helicopter's position offset by spatial audio. The current position, the relevant heading and distance to the desired hover and landing area are calculated in real-time by the system. The objective of the assistance design is to make this target area always audibly recognizable with minimal mental work or interpretation needed. If the pilot hears the sound from the 10 o'clock position, the target area is in front of the helicopter on the left side. If the sound moves from a forward to a backward position, for example, from the 1:00 o'clock over 3:00 o'clock to 5:00 o'clock position, the pilot knows that the hover and landing are just passed lateral on the right side.

The distance to the hover and landing area is, as demonstrated in figure 2, represented by vary-

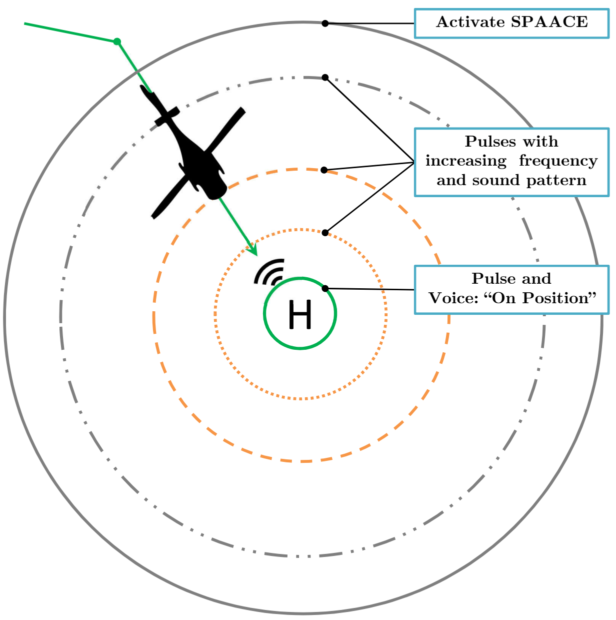

Fig. 2 SPAACE plays different sounds, depending on distance to the landing area. The 3D audio is always played at the landing position.

ing breaks and frequency in the sound design. As the pilot flies closer towards the landing position, the breaks in the sound design decrease. Right over the targeted position a synthetic voice announces: "on position". The sounds used are all friendly and positive. They are now described in detail.

All sounds used are a combination of two individual sound signals. Information is displayed acoustically using two parameters: on the one hand by the musical interval, on the other hand by the duration of the break between the individual signals. These signals are created from a sine tone. The short, hard transient responses, as well as the clearly audible release time are crucial for the characteristic of the signals. For better acoustic performance, overtones were added to the sine tone. In these sounds the musical interval of the two signals is a fourth (five semitones). This musical interval felt pleasant and indicates that the pilot should continue the approach, as the target position is still relatively far away.

For sound 1, the break between the two individual signals is the longest. This informs the pilot to approach the target position even further, the pilot is far from the target. The pause between the two signals for sound 2 and sound 3 is respectively shorter. Sound 4 signals that the helicopter has reached the target position by SPAACE playing the same signal twice. The musical interval is a prime (zero semitones). The pilots are instructed to hover when hearing this sound. To clarify, a synthetic voice announces: "on position". If the pilot leaves the correct position, the sound changes back to the representative sound as described before.

All sounds were played at the participant's eye level, with a fixed elevation angle at 0-degrees for the horizontal plane. Participants were informed about the characteristics and meaning of the sound design during the briefing and training. In this study, pilots received no further audio or visual warnings about additional obstacles in the vicinity of the helicopter. They need to rely on their out-the-cockpit visual references to avoid other hazards.

2.3 Participants

To reduce the effect of training and familiarization, the study targeted only professional helicopter pilots. As already described, the simulator platform was the AVES, based on the Airbus Helicopter's H135 model, thus participants with a valid type rating on this model were preferred.

Sixteen male helicopter pilots took part in the study. Due to the time concerns relating to one participant, the complete data-sets of fifteen participants are usable. The pilots ranged in age from 23 to 59 years ($M = 44.2, SD = 10.1$) with flight experience from 100 to 8 100 hours ($M = 3361, SD = 2527$). Fourteen participants were professional pilots with a current commercial pilot's license (CPL-H or ATPL-H). One pilot held a current private pilot license (PPL-H) and one was a former ATPL-H pilot but was not current during the period of the study. Three pilots had flown mainly military missions within the last 12 months, while all the other pilots had flown mainly civilian missions in the fields of emergency medical services, law enforcement and VIP transportation. As ilustrated in figure

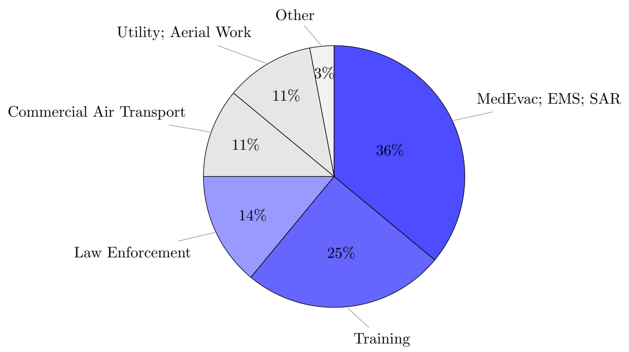

Fig. 3 Participants' flight experience in this study, gathering the most flight experience during Helicopter Emergency Medical Service and training flights.

Fig. 4 Approaching the landing area. The center spot of the field is the requested landing point. At that time, all obstacles were clearly visible.

3, participants gathered the most flight experience during Helicopter Emergency Medical Service (HEMS) and training flights. Twelve pilots held a current rating for light/medium turbine helicopters equivalent to the helicopter model in the simulator.

A medical certificate *Class I* was requested to ensure that all participants fulfilled the minimum hearing requirements for professional flying and, therefore, also for this 3D audio study. Fourteen participants met this requirement. Two pilots without a current medical certificate reported no problems with previous hearing disorders and demonstrated no abnormal results in the study. Their results are included unmarked in the evaluation. No participant was exposed to loud music within 48 hours prior to the study. Only two pilots had prior experience with 3D audio in computer games. The participants did not receive any financial compensation for their participation.

2.4 Flying Task

Participants had to fly into the landing area, perform a stable hover and land at the landing pad. Each pilot flew eight approaches with different setups, resulting in a minimum flight time of 40 minutes for this task. In the beginning, pilots trained on the simulator and the 3D audio system during two training flights. During the training, the pilots approached a different landing area as during the experiment session, so no prior area knowledge could be reused. The training flights were later excluded from the evaluation. Following the training session, two different experiment sessions were conducted. Between the sessions, pilots took a short break, discussed the setup with the experiment supervisor and filled out a questionnaire. The baseline condition was flown only visually without 3D audio support. The visual- and 3D-conditions were counterbalanced to minimize the effect of experience. There were three repetitions of each condition, which always started at the same point and targeted the same landing area. The flying task complied with the Aeronautical Design Standard ADS-33E [21].

The weather was constant for all flights. With simulated daylight conditions and a flight visibility of 1 500 meter (0.81 NM), the natural horizon was not clearly discernible, but pilots could always maintain visual ground contact (see fig. 4). No wind influenced the flights. Medium brown-out occurred during the landing in the training. The brown-out conditions worsened in the experiment session as demonstrated in figure 5.

Pilots were instructed to fly all tasks as they would fly in a real flight environment in line with their company regulations. All pilots were instructed to fly a straight approach into a soccer field, identifying the landing spot and all obstacles in the area. After reaching the field, participants needed to perform a stable hover over

Fig. 5 Brown-out during approach. The floodlight pool as a reference point starts to disappear in the dust. The soccer field markings on the ground are not visible at this moment.

the center spot at an altitude of around six meters (20 ft). At this altitude, heavy brown-outs critically reduce the out-of-the-cockpit visual reference. Pilots were asked to choose a hover-altitude as low as possible, close to the six meters, but within safe personal visual limits. This hover needed to be held over the center spot for two minutes. The countdown started after the pilot confirmed a stable hover position and simultaneously pressed a designated button on the center stick. After two minutes, the pilots were instructed to land vertically on the center spot. The task finished with the landing on the ground, collective-control in a full down position.

The soccer field included four floodlight poles at each corner of the field and two goals as additional obstacles. As illustrated in figure 4, all obstacles could be visually identified by the pilot during the approach. In the visual-only condition and during assistance with SPAACE, the cockpit instrumentation gave no reference about position offset over the target landing point. Participants had to rely on their visual perception. In the 3D audio condition, the SPAACE system helped to maintain position and guided the pilot back to the optimal position if the helicopter drifted unnoticed.

2.5 Quantitative Measures

The flight performance was evaluated by the pilots' ability to keep a stable hover position and altitude at a predefined position. The movements performed over the ground as well as the final landing position were considered. All position data and calculations are based on simulated GPS without offset error or noise.

2.6 Qualitative Measures

Each participant completed a biographical questionnaire, which collected information about age, gender, flying background, hearing disorders and prior experience with 3D audio. A custom-made questionnaire about subjective task difficulty, task-performance, and confidence was filled out by the participants after each setup had been flown. In a post-study questionnaire and during an open interview, the participants were asked about their professional views on the simulation experience, the realism of simulated weather conditions, simulator handling characteristics and available training time.

3 Results

Multiple results with different emphasis were calculated in the context of this study. This paper focuses on the ability of the pilots to maintain a stable hover in brown-out conditions and conduct a safe landing. The following sub-chapters describe the results in detail

3.1 Accuracy during hover

The main research question of this study was to evaluate if 3D audio can assist pilots in landing on confined landing pads under brown-out conditions. Previous research explains that maintaining position during the hover before the actual touchdown in brown-out conditions is challenging. In the briefing, participants were instructed to perform a stable hover over the target position for two minutes prior touchdown. To evaluate if the developed assistance system SPAACE can help pilots during this critical flight phase, the movement over the landing pad was analyzed.

For grading, three movement areas were defined. The desired area was 0-5 meters around the center of the landing pad. In this area, the assistance system played the synthetic voice announcement: “on position.” The adequate area reached from 5-20 meters around the center. Moving more than 20 meters from the center of the landing pad was ranked as loss of position.

Results indicate that during the two-minute hover, pilots held their position in the desired area by visual reference without an additional assistance system for only 27% of the hover time. A further 65% were in the adequate area, and 9% were graded as having lost their position. In comparison, with the support of 3D audio, these results improved to 54% with hover time in the desired area and 42% in the adequate area. Only 4% of the hover time was ranked as a loss of position. The improvement with SPAACE becomes even more visible when calculating the number of flights which spent 50% or more of the time in the desired area. As illustrated in table 1, 24 flights (out of 45 flights total) spent half of the hover time in the desired area of under 5 meters around the landing pad compared with only 6 flights in the visual only condition.

	Visual	3D audio
	time	time
0-5 meters	27%	54%
5-20 meters	65%	42%
>20 meters	9%	4%
	flights >50% time	flights >50% time
0-5 meters	6	24
5-20 meters	30	18
>20 meters	3	0

Table 1 Time and flights during the hover in the desired and adequate areas over the landing pad.

A deeper analysis of the flight with 3D audio support by SPAACE reveals that 30 flights (2% flight time) reached an offset 0 to 1 meters around the landing pad. All 45 flights reach an offset between 1 and 3 meters with a total hover time of 20%.

3.2 Altitude during hover

The altitude during the hover was the second variable of interest in this study. Pilots were instructed to hover as low as possible into the brown-out while still being safe and able to hold position. During the briefing, an altitude of 6 meters (20 ft.) above the ground was suggested. Participants had to press a designated button on the cyclic control when they were satisfied with the stable hover to start the two minute countdown. In the visual only condition, participants started the hover at an average altitude of 10.71 meters ($SD = 2.79$). With 3D audio support, they start the hover on average slightly higher at 11.39 meters ($SD = 3.70$). During the two-minute hover, the mean altitude increased in the visual only condition to 11.91 meter ($SD = 3.88$), and with 3D audio support to 12.91 meters ($SD = 2.80$). These results demonstrate that independent of the presence of the assistance system, the chosen altitude was twice as high as expected and, therefor, in medium brown-out conditions as scheduled. As the chosen altitude is not a significant difference, no negative effects occurred.

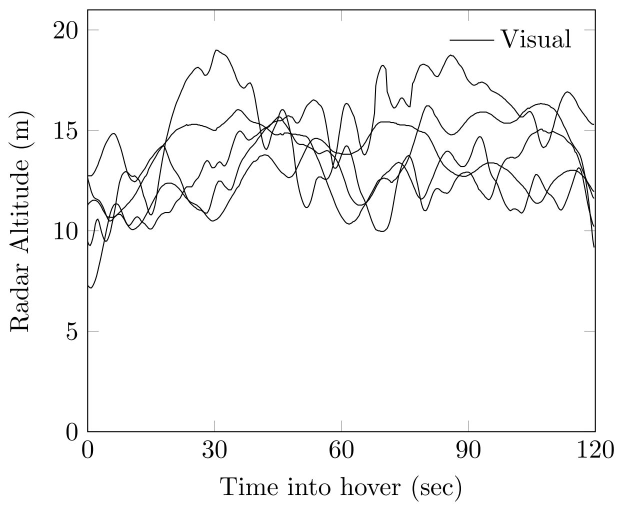

Fig. 6 Five representative flights for the visual condition. Graph shows altitudes during two minute hover before landing.

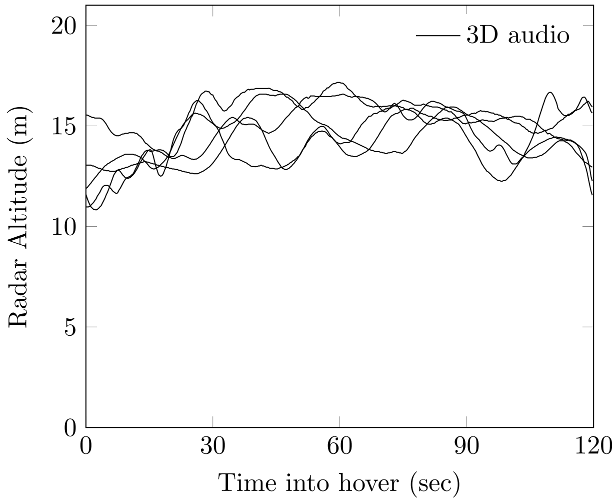

Fig. 7 Five representative flights for the 3D audio condition. Graph shows altitudes during two minute hover before landing.

For further evaluation, a hover height +/- 1 meter from the average altitude for each individual flight was calculated as desired altitude and +/- 2 meters as adequate altitude. Results indicate that without SPAACE all participants flew 41% of the hover time inside the desired altitude area. This increased slightly to 43% with SPAACE. Comparable results can be found for the adequate area. Without further assistance, pilots flew 29% in the adequate area, compared to 31% with 3D audio. Detailed results are presented in table 2.

Altitude during hover	Visual	3D audio
to high	16%	12%
adequate high	20%	16%
desired	41%	43%
adequate low	9%	15%
to low	14%	13%

Table 2 Percent of time during two-minute hover at the desired and adequate altitudes.

3.3 Groundspeed during touchdown

After completing the stable hover, the task was to maintain a steady descent to the defined landing point. It was acceptable to adapt the sink rate to make last-minute corrections before touchdown. For a safe landing, the pilots had to eliminate perceptible drift right before touchdown.

As indication for a stable and controlled approach, the last one meter before touchdown was analyzed. Results illustrate that the average helicopter longitudinal movement was -0.34 m/s ($SD = 1.35$) in the visual condition. This movement reduced to -0.16 m/s ($SD = 0.71$) with 3D audio support. Negative values indicate that, on average, the helicopter approached the last one meter with backwards movement. A deeper analysis of each individual flight results that 47 out of 90 flights (24 without, 23 with SPAACE) were conducted with longitudinal backward movement during the last one meter. The tendency to drift backwards close to the ground in this kind of helicopter simulator is apparent in other studies as well.

Beside longitudinal movement, lateral drift is an important safety factor for helicopter landings. As a result of the high center of gravity, helicopters roll over easily during touchdowns with lateral movement. In this study, the lateral drift reduced from 0.86 m/s ($SD = 0.81$) to 0.62 m/s ($SD = 0.60$) with the support of SPAACE.

The helicopter movement during the actual contact of the landing skids with the ground was calculated as total of the longitudinal and lateral vectors. Results indicate that in the visual only condition, the average movement was at 0.16 m/s ($SD = 0.20$) compared to an average movement with SPAACE assistance of 0.13 m/s ($SD = 0.09$).

3.4 Unsafe landings

All participants were urge in the briefing and again in the simulator to fly as in a real flight environment within safe limits. Nevertheless, throughout the study, out of 90 approaches, there were six unsafe landings resulting in a rapid abort of the landing or in a dynamic rollover. These hazardous maneuvers were perform by three participants as illustrated in detail in table 3. In total, these participants crashed five times in the visual only condition. In the 3D audio condition, one participant crashed one time; the same participant also crashed in the visual only condition two times.

Participant	Visual	3D audio
1	X	
1	X	
2	X	X
2	X	
9	X	

Table 3 The symbol *X* represents one unsafe landing during the study.

3.5 Distance to landing position

Participants were asked to perform a vertical landing at the center of the field after a stable hover. In the visual only condition, they had to assess the position and the lateral offset without additional assistance. In the 3D audio condition, they had the audio support by SPAACE until touchdown. In total, 90 approaches down to touchdown were flown; six of them were removed because they exceed safety limits. In the visual condition, participants landed on average of 8.22 meters offset of the landing spot ($SD = 8.45$). With the support of 3D audio this improved to an average offset of 8.03 meter of the landing spot ($SD = 6.79$). Figure 8 shows the improvement for each participant in detail.

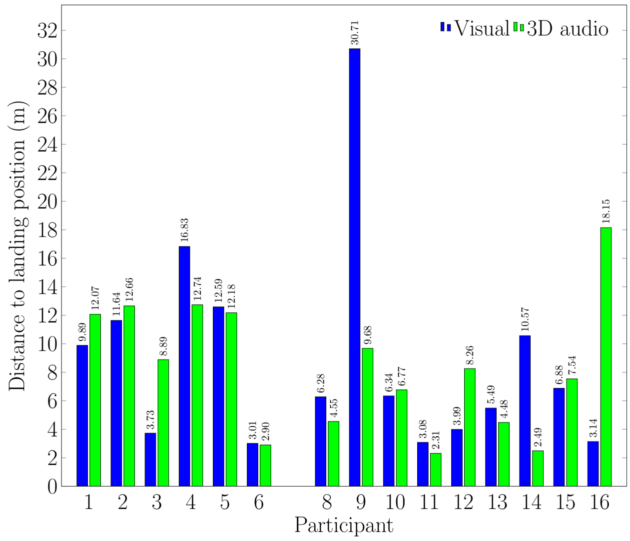

Fig. 8 Participants' landing distance from the desired landing position. P 7 was removed due to incomplete data.

3.6 Questionnaires

After both the visual and the 3D audio session, participants filled out a questionnaire on the recently completed task. Comparing responses from these demonstrates that participants felt very confident during the landing task (visual = 9 participants, 3D audio = 11 participants). All pilots rated the tasks in both conditions as "difficult" to "extremely difficult" but achievable with tolerable workload. Surprisingly the pilots' felt they did better in the visual only condition and judged their own performances higher (visual = 9, 3D audio = 7).

The focus during a helicopter landing is on outside reference points to maintain a stable approach. In the visual condition, eight participants stated that the primary instruments within the cockpit had only low priority. Nine participants in the 3D audio condition said the same.

The next question was whether a good landing was achieved within a manageable workload. A total of ten participants agreed to this statement in both conditions. This is particularly interesting because the actual landing performance differed strongly between the two conditions.

Six landings were not included in the evaluation due to unsafe flights. This fact is also evident in the questionnaire results. In the visual condition, eight participants stated that the flights were not always inside safety limits. The same statement can be found by only six participants during the 3D audio condition.

A main goal of the study was to research whether the pilots were able to perform a stable hover and landing during brown-out and whether they could land on confined landing pads with assistance from 3D audio. In total eight pilots agreed that the 3D audio assistance helped to maintain a stable hover position. Further, 11 participants agreed that the 3D audio helped during the low-visibility flight phases.

At the end of the study, participants were asked about their overall experience with the 3D audio system SPAACE, the sound design and the simulator. They were then asked for their opinion based on their professional helicopter background.

The environmental conditions as presented in the simulator were rated as realistic by thirteen participants. However, only three participants had flown a helicopter in similar weather conditions to those presented in the simulator session more than five times within the last twelve months, and seven participants had never flown in comparable weather conditions at all.

The question of which condition participants felt more comfortable with and which condition was more difficult was balanced.

The new SPAACE system was designed to use human capabilities to locate sounds and keep possible training times short. Except for one pilot, all participants agreed that the time allocated for training during the study was sufficient to become familiar with the 3D audio system. Overall, the need for training on the system was rated as low, and all participants expected a steep learning curve.

All participants agreed that they would like to use the system regularly during their missions. The system's complexity was rated as neutral, even though all participants (strongly) agreed that it was intuitive to use. As a result, the overall system rating in the standardized System Usability Survey was good to excellent.

3.7 Discussion of Results

The results of this study demonstrate the potential of 3D audio to improve performance for helicopter pilots during landings under brown-out conditions on confined landing pads. The highest positive impact on flight precision was found during hovering. The results of the questionnaires and feedback by the pilots during simulator breaks were not as positive as the results of the quantitative measures. The 3D audio system demonstrated its capability as a flight aid to improve situational awareness and flight safety. As expected, pilots only needed minimal training time to understand the system and to use it for their mission during the flight. Overall, participants rated themselves as satisfied with the system and recommended further developments.

4 Conclusions

In conclusion, a new method of providing information in the cockpit was evaluated to help pilots maintain a stable position during approach, hover and land under brown-out conditions in confined areas. A 3D audio signal was played at the position of the landing spot. Pilots could use the direction of the audio signal as a guidance command. Overall, the level of acceptance for the 3D audio system SPAACE was very high and all pilots referred to a subjective feeling of increased situational awareness with a decreasing workload. The overall performance was markedly improved. The most important results are summarized as follows:

- All pilots could locate the spatial audio presented by SPAACE with high precision. Location performance was high and robust enough for aviation tasks.
- Only minimal training was necessary to use the 3D audio system during flight.
- The system improved the accuracy during the hover significantly.
- The longitudinal and lateral offset for the touchdown did not improve as much as expected.
- Results show that 3D audio SPAACE has the potential to become a robust safety feature in present and future helicopter cockpits.
- All pilots requested further development of the system so it will become available in future helicopters.

As research till now has been primarily limited to simulator studies, it remains an open question whether real aircraft noise and the dynamic flight environment will have any negative effect on the developed SPAACE system. Real flight trials with SPAACE are planned for the end of 2018.

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