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Enabling effective communication for human space exploration beyond Low Earth Orbit

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Executive summary report

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EUROPEAN SPACE AGENCY CONTRACT REPORT

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Executive Summary

Context

Communication between crew and ground on future deep space missions will be impacted by communication delay (signal latency), caused by the finite speed of light and radio waves across great distances.

The one-way latency caused by the distance between the Earth and the Moon is about 1.3 seconds. The actual latency at lunar distances during the forthcoming Artemis missions is expected to be even higher due to the various signal processing steps associated with the digital communication protocols. Estimates currently vary up to 10 seconds one way. The Apollo missions, which used analog communication techniques instead of digital, were not subject to this additional delay.

For future missions to Mars, the situation will be much more challenging. During transit, the crew will experience continually varying latencies starting at zero on departure and growing as they travel to Mars. On the surface latency will still vary continuously as the Earth and Mars follow their separate orbits around the sun. The shortest possible latency to the Martian surface is about 3½ minutes one-way, the maximum is over 22 minutes.

To date, there has been little research into the consequences of communication delay on future crewed missions. However, like other challenges such as microgravity and radiation, it is unavoidable and will continuously impact the crew. It is expected to have significant operational impacts. Additionally, with the crew potentially unable to maintain meaningful connections with their loved ones on Earth, the consequences for crew health of prolonged isolation could impact the mission to some extent.

Study

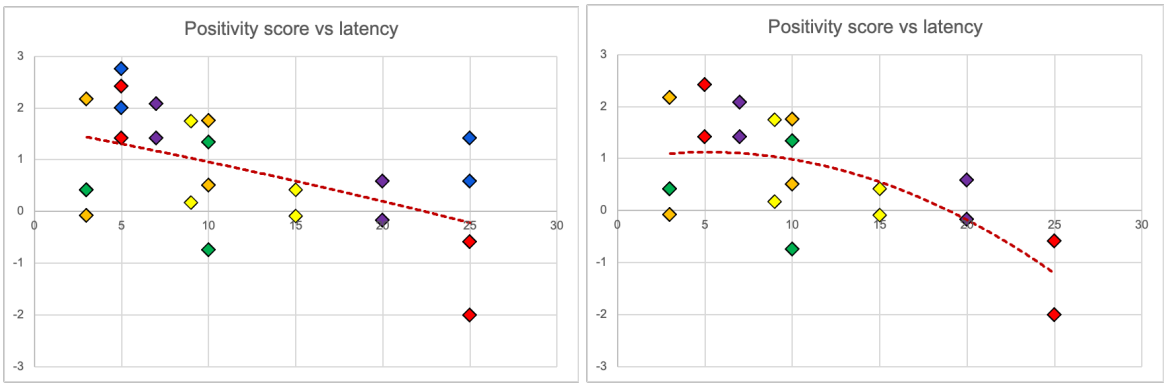
This investigation has been funded by ESA through its OSIP programme. Braided Communications Limited, a UK-based SME, has developed the first known mitigator for communication latency, a tool called Space Braiding. Braided is the lead investigator and sole organisation providing deliverables to ESA under this research contract.

This study has two components that were completed in a twelve-month timeframe. Component A is an investigation into the impact of communication delay on the effectiveness of voice communication between crew and ground at the latencies that will be experienced on future lunar missions and in the near Earth stages of transit for future Martian missions. Essentially we are trying to create preliminary data to answer the question “how far can humans travel from Earth before communication delay renders normal voice communication ineffective?” Component B is an investigation into the feasibility of a therapist on the ground using Space Braiding to deliver synchronous sessions of psychological therapy to a crew member on or near Mars.

Findings

All findings are articulated in the context of a limited sample size. Component A compared the reported effectiveness of collaborative problem-solving in voice communications subjected to varying levels of signal latency in the 3-25 second one-way range. This showed two key results.

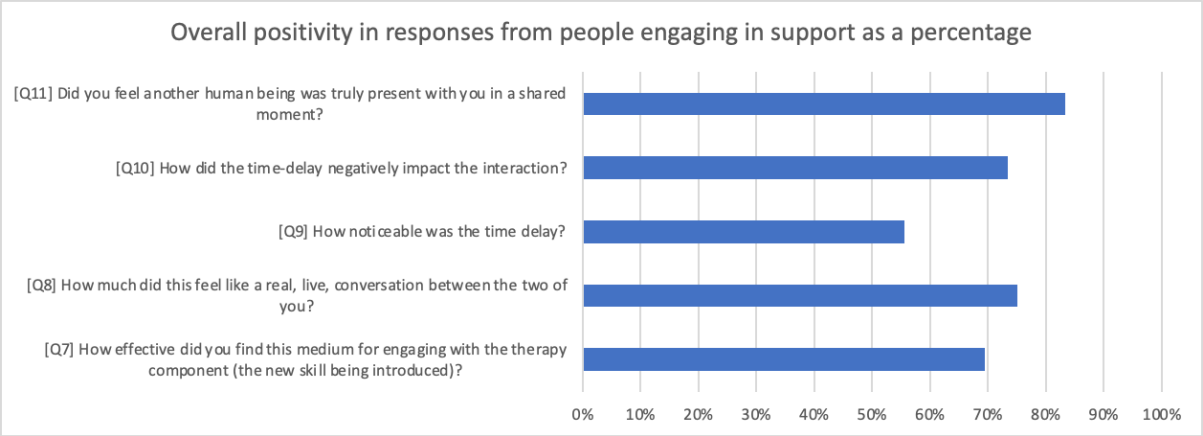
First, as was hypothesised, in general terms the effectiveness of voice communication decreases as latency rises, with some indication (once an outlier had been excluded from the analysis) that a 'drop off' may occur between 20-25 seconds, as illustrated in these summary graphs:

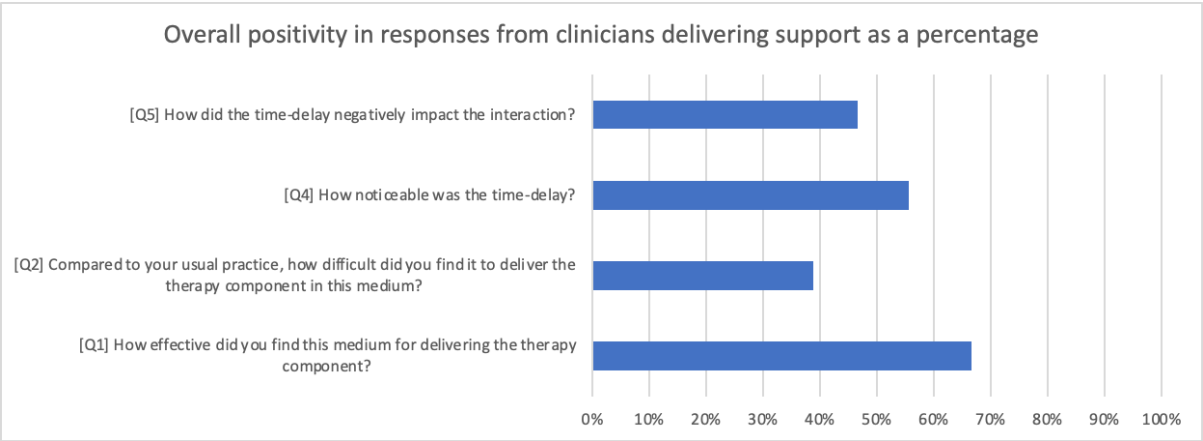


Secondly, and unexpectedly, there were some indications that communication at low levels of latency, less than 10 seconds, was less effective than at higher latencies of ~15 seconds. This was most evident in participant commentary.

We hypothesise that at these lower latencies the participants are more likely to adopt the conversational behaviours they would under normal zero latency conditions, but that those behaviours then create difficulties such as step-ons and crossovers due to the latency. As these low latencies are exactly the range that is anticipated for Artemis it indicates a need for further urgent research.

Component B investigated the reported feasibility of delivering synchronous sessions of evidence-based psychological therapy under high-latency (5-minute one-way) from the perspective of expert psychological therapists engaging in clinical simulations. It showed a clear result that expert clinicians consider it feasible to deliver live sessions of evidence-based psychological support under conditions of major signal latency using a communication tool designed to cope with latency (Space Braiding, see Appendix). From the perspective of the person engaging with support, the experience reported was resoundingly positive across all domains.





This was also the case for the clinicians delivering support indicating they could deliver evidence-based therapy but it was more difficult under these conditions compared to their day-to-day clinical practice. In contrast to their session partners, participants in the role of the clinician delivering support described the signal latency to be more noticeable and impactful. Taken together, the participants reported that it is feasible to deliver synchronous, sessions of psychological therapies under conditions of major signal latency when Space Braiding is the communication medium.

Recommendations

This study has illuminated some of the inevitable challenges of high latency in future deep space missions, both to the Moon and onwards towards Mars. It has highlighted some areas in which further research is certainly required.

Most urgent of these, in view of the advanced plans to return humans to the Moon within the Artemis programme, is further research into the potential challenges of voice communication at lunar distances with the anticipated Artemis latencies. Future studies should more thoroughly investigate the unexpected difficulties at relatively low latencies and the potential drop off at higher latencies in a variety of use cases (medical, personal and operational conversations, for instance). This would require larger populations of participants and the involvement of participants with relevant mission

or analogue experience. Consideration should also be given to comparison with Space Braiding, Latency Governed Messaging and other tools as possible better alternatives in some situations.

The use of Space Braiding to facilitate effective connection with friends and family on future missions in order to maintain relationships and as a preventative mechanism protecting the crew's psychological well-being should be explored. Additionally, in order to optimise the health support available under conditions of high-latency, future research should explore the efficacy of a range of synchronous, high-intensity, evidence-based psychological therapies enabled by Space Braiding in the human spaceflight context. It would be important to understand the key factors that make some contextual-behavioural and cognitive-behavioural approaches more amenable to effective use through Space Braiding while others will be less congruent. Follow-on research from this preliminary study can adopt a controlled-trial methodology that also enables comparison of synchronous and asynchronous psychological support for deep space exploration.

Appendix

Space Braiding: A tool for synchronous human communication under high-latency

Braiding divides a conversation into several threads, or Braids, and presents these to participants on a revolving carousel. At any one point in time the participant at one end of the latency, say on Mars or in transit to Mars, is reading and typing in one Braid whilst the other participant, on Earth, is reading and typing in the Braid on the opposite side of the carousel. Meanwhile content from the other, currently inactive, Braids is making its way across the void. By carefully controlling the number of Braids and the rotational speed, each participant will receive content from the other just as the carousel rotates so they are never exposed to the latency

The Braiding tool is designed for use in Earth based experiments, such as this one, and therefore the latency can be varied from session to session as can the number of Braids and other parameters. In this study those variables were all fixed across the entire experiment. Braiding maintains the sequence and theme of related utterances under time delay, removing the need for the participants to separately identify the linkages and untangle the themes.

Additionally, because braiding orchestrates both users' attention and behaviour to the same rhythm, it achieves interpersonal synchrony that is detectable by the users (they can tell they are in a shared moment of live conversation). Although not the subject of this study it is anticipated that this synchrony will be beneficial in maintaining the psychological health of future crew by enabling meaningful communication with their loved ones on Earth. Interpersonal synchrony may also prove to aid more effective operational communication in specific use cases.

A US patent has been awarded for Space Braiding. Number 11,397,521.