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HOW NOISE IMPACTS DECISION-MAKING IN TRIADIC CONVERSATIONS

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ABSTRACT

Hearing loss is associated with depression and is one of the top risk factors for developing dementia. This might be caused by increased difficulty with communication, which can lead to social isolation. Current paradigms of diagnosing hearing loss rely heavily on passive listening tests, where no conversational partner is present. Such tests do not provide information about whether a given person has challenges with speech communication. In this exploratory study, we investigated the potential of using task-oriented dialogues to evaluate how information exchange - a core aspect of communication - is affected by background noise. Ten triads of normal hearing participants were recruited. Each participant first individually answered a series of binary general-knowledge questions. Afterwards, they discussed the questions in groups of three, and finally, they answered the same questions individually again. We found a population-level effect that participants were more likely to adopt opposing views from other group members when background noise was present. The results show that noise impacts group decision-making processes in normal hearing individuals. The methods presented can potentially be used to study how other factors, such as hearing loss, cognitive ability or different acoustic conditions, affect the ability to communicate.

Keywords: *Ecological validity, interactive communication, triadic conversation, decision-making*

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1. INTRODUCTION

While people's ability to communicate relies strongly on their ability to hear, it is not solely determined by it. Current paradigms to test people's hearing status include measures of pure-tone sensitivity and speech intelligibility in stationary noise. These paradigms diagnose hearing loss in isolated, passive listening scenarios. These tests do not include conversational partners, meaning that the interactive aspect of communication is not reflected in these tests [1–3]. While passive listening tests have contributed to a better understanding of how to restore *hearing ability*, understanding *communication ability* requires other types of tests that acknowledge the fundamentally interactive nature of communication. To this date, no established methodology for gauging communication ability exists. A quantitative measure of communication ability would be a valuable tool for investigating communication-inhibiting factors that are not adequately captured by the outcomes of passive listening tests. A recent consensus paper by Carlile and Keidser noted that access to such a measure "seems of utmost importance" in hearing rehabilitation [1].

In this study, we investigated how interacting group members influence each other's opinions in a collaborative task. Sharing information and opinions is a fundamental and ubiquitous goal of human communication. Understanding these dynamics could potentially be relevant for diagnosing communication disability. To modulate the difficulty of the communication scenario, we used two different levels of interfering background noise. The aim was to investigate if the difficulty of the communication scenario would be reflected in the dynamics of how group members influenced each other's decision-making.

2. TASK AND EXPERIMENTAL SETUP

The study involved 30 participants divided into groups of ten triads. All were between 20 and 35 years old, normal hearing by self-report, and, with the exception of two pairs of individuals, unacquainted prior to the experiment. The experiment was conducted in Danish and took approximately 2.5 hours. Participants were compensated for their time and provided informed consent. All experiments were approved by the Science-Ethics Committee for the Capital Region of Denmark (reference H-16036391).

During the experiment, the participants were seated in an equilateral triangle facing the other two group members, as shown in figure 1b. The group was surrounded by eight loudspeakers playing separate Danish monologues, resulting in a spatially distributed multi-talker masker. The masker was played at two levels, namely 50 and 78 dB SPL, corresponding to a quiet and a noisy condition. The number of simultaneous maskers made them individually unintelligible in both conditions. The first task of the participants was to individually answer a series of general-knowledge questions divided into three topics: Hollywood movies (*Which movie is oldest?*), Copenhagen landmarks (*Which place is closest to the city center?*), and European countries (*Which country has the larger population?*). For each topic, there were two lists of 28 questions, one for each condition. Each list thus consisted of 28 trials, created by using all unique binary questions from the eight items related to that topic (e.g., eight Hollywood movies). The questions were presented one at a time with a visual illustration of the two options and accompanying labels on a touch-screen tablet. The participants were asked to choose either option along with a confidence level, expressed as a percentage between 50% and 100% (Figure 1a). They were instructed to interpret the scale as indicating their estimated probability of having answered the question correctly. After the first list of 28 questions, a discussion round followed, where the participants discussed their answers with the other group members. They were instructed to approach the task collaboratively, such that it was equally important to improve the performance of other group members as it was to improve their own. During the conversation, each participant was given a sheet showing the eight items that had appeared in the preceding round of questions (Figure 1b). After a time limit of ten minutes was reached, or once the discussion had come to its natural conclusion, the participants answered the same 28 questions again individually (Figure 1c). This process was repeated six times, once for each of the three topics in each noise condition.

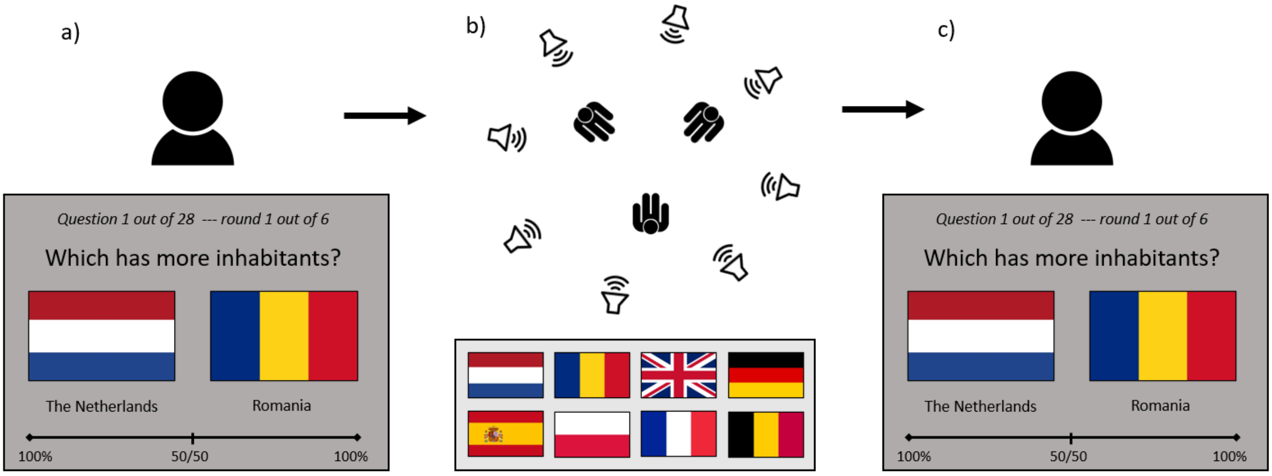

Figure 1. Overview of the experimental procedure and task. a) Each participant started by individually answering 28 questions from one of the three topics. b) Afterwards, the participants were allowed to discuss the questions, with the aim of improving their own answers as well as assisting their peers. The conversation took place in one of two conditions: loud background noise (78 dB SPL) or in almost quiet (50 dB SPL). To aid the discussion, each participant was given a sheet with the eight items that had appeared in the questions. c) After the conversation, the participants repeated the questions from the first step, again answering individually.

3. RESULTS

3.1 Pairwise and group-level decisions

In order to quantify how group members influenced each other, their pre- and post-conversation answers were analyzed in terms of their rate of *convergence*, i.e., how often they would reach agreement. The convergence rate was calculated both on a pairwise level and on a group level. *Pairwise convergence* trials were defined as those where a pair went from disagreeing prior to the conversation to agreeing afterwards, i.e. if one of them had "convinced" the other. On rare occasions, pairs would "convince each other", so that they still disagreed, but each taking on the other's prior view. This type of behavior was not counted as convergence and will instead be referred to as *swapping*. Trials with swapping were treated as a sub-category of non-convergent trials. Non-convergent trials where participants did not change their decisions will be referred to as *stay* trials. *Group convergence* was defined as trials where both options were chosen by at least one group member prior to the conversation, and the group members all chose the same option after the conversation. Swapping is not defined on the group level.

Table 1. Contingency table of pairwise and group-level decisions in prior disagreement trials.

		Convergent	Non-convergent	
		-	Swap	Stay
Pairs	Noise	548	6	63
	Quiet	539	27	102
Groups	Noise	272	-	60
	Quiet	268	-	95

The number of convergent and non-convergent trials in each condition is shown in Table 1, both for pairwise and group-level convergence. The difference between conditions was tested using Fisher's exact test. Both at the pair and the group level, the fraction of trials that were convergent was significantly higher in the noise condition (pairs: $p = 5.50e{-5}$, odds ratio (OR) = 1.90, groups: $p = 0.0108$, OR = 1.61). Pairs converged in 88.8% of the trials in noise against 80.7% in quiet, and groups converged in 81.9% of the trials in noise against 73.8% in quiet. These results indicate that groups were more likely to reach agreement on their post-conversation decisions when the noise was present. This conclusion was not affected by omitting the swap trials from the non-convergent category.

3.2 Individual decisions and effect of confidence

Participant responses in disagreement trials were also analyzed on the individual level, i.e. for each participant. For a given pairwise disagreement trial, participants could choose to either *stay* with their previous decision, or *switch* to the disagreeing member's view. These decisions were analyzed with respect to the noise/quiet conditions, and by controlling for whether the participant making the decision was the most or the least confident member. As shown in Table 2, individuals were much more likely to stay with their initial decision in trials where they were more confident than the other member. Background noise did not seem to impact how likely participants were to stay with their own prior decision. A two-sided binomial test showed a small, but significant overall bias of participants, with 54.2% of trials resulting in staying.

Table 2. Contingency table of individual-level decisions in prior disagreement trials.

	Stay	Switch	p	OR
Most confident	871	456	1e-32	2.55
Least confident	568	759		
Noise	687	597	0.508	0.95
Quiet	758	624		
All	1445	1221	1.55e-5	-

To investigate the interaction between confidence level and background noise, individual responses were grouped into stay/switch trials and noise/quiet conditions. The top panel of Figure 2 shows these four categories of trials as jittered point clouds. On the x-axis, the absolute difference in confidence between the two members in that trial is shown. Positive values indicate that the first-person member - "me", the one making the decision whether to switch or stay - is more confident. The solid lines show logistic regressions performed separately in each condition. The regressions predict the probability of a trial being a stay trial as a function of confidence difference. In both conditions, the slope is positive. The overall bias towards staying is reflected in the x-axis intercept, which is above the 50% mark in both conditions.

The interaction effect between condition and confidence level was investigated using a two-sided permutation test of the difference in the slope. Permuted slopes were obtained by randomizing the noise/quiet labels of each data point and fitting a logistic regression. Two test statistics were used for the slope difference between conditions, namely the absolute difference in the slope parameter, and the difference in slope angle at the x-axis intercept. Histograms of the test statistics are shown in the lower panels of Figure 2, along with the observed values marked by dash-dotted lines. For both test statistics, the noise condition was found to have a significantly steeper slope (absolute difference: $p = 0.0257$, angular difference: $p = 0.0252$). Thus, there was an interaction between condition and confidence level, such that the most confident member's prior answer was more likely to be chosen in the noise condition. Note that the slope parameters shown in the legend of the top panel of Figure 2 refer to the logit domain regression. In the linear domain, the slope at the origin is 1.05 for the noise condition, and 0.77 for the quiet condition. This means that going from equal confidence $c_{me} - c_{you} = 0$ to a difference of one percentage point $c_{me} - c_{you} = 1$ leads to 1.05 percentage points of change in terms of the stay/switch decision in noise, against only 0.77 percentage points in quiet.

4. DISCUSSION AND CONCLUSION

Background noise was found to impact information exchange in two different ways. In noise, the probability of the group reaching an agreement increased, and the more confident group member was more likely to determine the posterior decision in disagreement trials. While the psychosocial and/or perceptual processes involved in this change in behavior would be highly interesting to investigate, they have not been the focus of this study. The results demonstrate that background noise impacts group decision-making and information exchange, and that the proposed task and analysis framework provide a quantitative, behavioral measure of these changes in high-level communication behavior. The task framework used in this study represents a step towards an evaluation tool targeting communication ability. Such a tool could eventually be used to gauge communication ability in different environments, or to evaluate the benefit of interventions in terms of restored communication ability. Furthermore, the results might have implications for the study of group interaction processes, as they show that a challenging acoustic environment can affect decision-making during collaborative work.

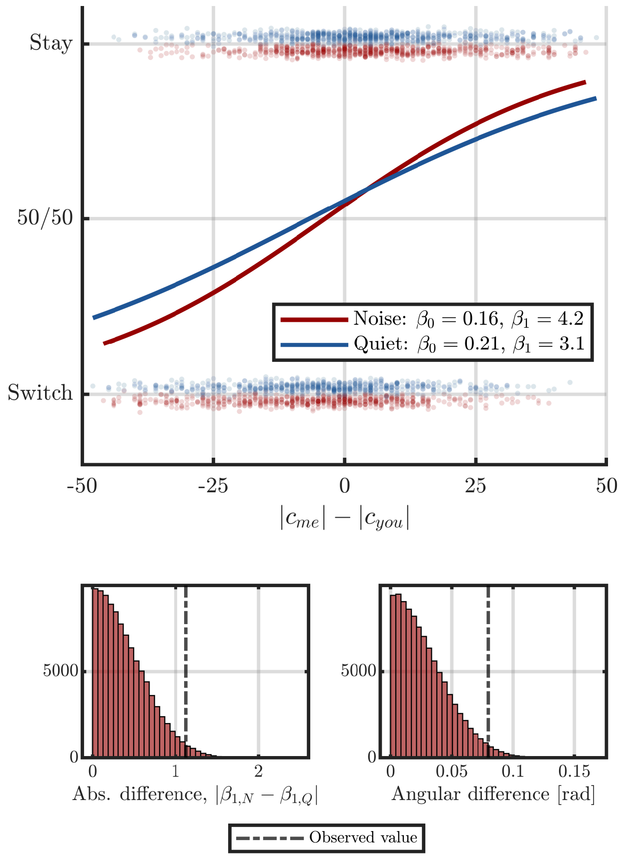

Figure 2. *Top:* Disagreement trials grouped by condition and by final decision (stay/switch). Trials are distributed on the x-axis according to members' relative confidence. *Bottom:* Permutation test of the difference in the slope parameter of the regression.

5. REFERENCES

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