Prosocial reward relates to speech reception thresholds and age relates to subjective ratings of speech perception in noise.

Ryan J Oakeson, Jesca Herbert, Simon Roper, Hongyi Zhang, Stuart Rosen, & Sophie K Scott

Abstract

This study explores how prosocial motivation and social reward relate to speech perception in noise (SPiN). We investigated SPiN performance and subjective listening experiences across different masker conditions: 1-speaker, 2-speaker, and steady-state noise (SSN). Results indicate that individuals who rated themselves higher in prosocial traits performed better in the condition that yielded the worst threshold out of the three conditions i.e., the 2-speaker condition. Age significantly influenced subjective ratings of listening effort across all conditions where older participants reported greater effort. These findings highlight prosocial motivation as a potential factor influencing SPiN abilities, particularly in complex listening scenarios, alongside the role of age in shaping subjective auditory experiences.

Introduction

Perceiving speech in noisy environments is a difficult task that requires a listener to accomplish several different goals simultaneously. Not only must the listener ignore or attenuate the irrelevant streams of auditory input, but they must also focus their auditory attention to the speaker they aim to listen to using effortful listening. This process leads to a complex state in which the listener is exerting substantial amounts of cognitive effort—putting the listener at an increased risk of mental fatigue and loss of motivation to listen, which ultimately results in diminished listening effort. This is the essence of the cocktail party problem i.e., needing to focus on a single auditory object in an ocean of background noise. By understanding how the brain is capable of such selectiveness, research may be a step closer to understanding the complexity of cocktail party effect. However, objectively measuring effort and fatigue can prove to be a difficult task of itself (McGarrigle et al., 2014). Following this notion, numerous researchers have been interested in the various components underlying the “cocktail party” problem and how to solve the mystery as to how the brain performs and overcomes such adversity.

Speech Perception in Noise

Speech is rarely processed in silence. Fundamentally, where selective attention is key process in the cocktail party effect, masking sounds are the key issue in the cocktail party problem. Whilst the power or salience of the masking sound varies from situation-to-situation, the type of maskers in the environment can play a significant role in outcomes related to speech perception in noise (SPiN). Maskers in this case can be classically divided into two types, energetic and informational (Cooke, 2006; Shinn-Cunningham, 2008). Energetic maskers suppress or distort

speech signals at the signal level whereas informational maskers are types of noise that encompass everything beyond the signal level (Kidd et al., 2008). For example, informational maskers are found to typically disrupt speech perception at higher-ordered perceptual and cognitive levels related to language and other implicated capacities e.g., attention and memory (Mattys et al., 2012; Rönnberg et al., 2013). These speech-masking noises result in listeners exerting effort due to increased demand for mental resource allocation, resulting in the listener to evaluate the costs and benefits related to this mental exertion (Pichora-Fuller et al., 2016). One way to combat these increasing demands is motivating the listener's effort.

Personality Traits and SPiN

As mentioned above, SPiN involves aspects that place demands are different orders of processing, typically cognitive and perceptual demands. However, it may also be that social factors are playing important roles in this processing as well. There are few studies addressing how individual differences and social factors affect SPiN performance. For example, neuroticism is the personality trait associated with negative emotions e.g., anxiety, frustration, jealousy, etc. Whereas extraversion is the trait associated with seeking and engaging in social interactions, as opposed to introversion which is related to being more concerned with oneself than others. Wöstmann and colleagues investigated how the Big-5 personality traits relates to subjective and objective performance on SPiN tasks and found evidence for key traits of higher neuroticism and lower extraversion (Wöstmann et al., 2021).

More specifically, there was evidence from this large-sample study that demonstrated trends for individuals who had higher neuroticism and lower extraversion to exhibit reduced subjective performance self-ratings. Higher neuroticism specifically had an association to the listening effort and objective performance of the in-noise task, albeit a small association. Audiometry was not conducted in this study making it difficult to discern whether neuroticism related to hearing thresholds or general hearing-in-noise performance. Additionally, there was only one noise condition used which was a constant steady-state noise; therefore, the findings may only be generalizable to conditions related to pure energetic masking. Overall, this study (Wöstmann et al., 2021) demonstrated individuals with higher neuroticism underrating their subjective performances while having small yet better objective performances in noise, and individuals with higher extraversion overestimated their subjective performances. Thus, there may be an important aspect of personality and the role of self-doubt, confidence, and modesty arising from these findings when thinking about a listener's ability to perform in SPiN.

Prosocial Motivation

Social interactions are often rewarding, therefore there may be several motivating factors motivating individuals to effortfully engage in these rewarding social exchanges (Krach et al., 2010). Individuals perform with greater effort given various tasks demands, both physically and mentally when motivated to do so and whether the task rewards them or others (Soutschek et al.,

2018). In one case, Lockwood et al., (2021) found that age played a determining factor in whether an individual would be motivated to grip harder on a device in order to either reward themselves or others. They found older individuals tended to exert more effort willingly for others in prosocial instances and showed less self-bias for effort that benefitted themselves. Motivation has also been shown to elicit self-reports of increased effort in participants however also increased reports of tiredness or fatigue (Picou & Ricketts, 2014). This may be because effortful behaviors often require more exertion—either physically or mentally, which can be costly metabolically.

Motivation is most classically defined as extrinsic or intrinsic. Extrinsic motivators, commonly referred to as incentives, are used in research tasks and real-world paradigms as they can be much more motivating for participants and employees e.g., money/bonuses, positive feedback, achievement, etc. However, both types of motivation can improve performance in a task. According to various theories, incentives may demonstrate an undermining effect leading to a decrease in intrinsic motivation (Deci, 1971; Deci et al., 1999). For example, incentives may displace the motivational salience to obtaining the task reward rather than on the task performance itself. Contrarily, incentives and intrinsic motivation may show an additive effect (Covington & Müeller, 2001) where when used together, incentives enhance intrinsic motivation, performance, and overall general motivation. A study by Hendijani and colleagues (2016) set out to explore the interaction between incentives and intrinsic motivation by testing several hypotheses relating to the potential undermining and additive effects on performance and motivation. These researchers used a unique approach to intrinsic motivation by recruiting participants based on their chosen college major—math and literature, respectively; they then administered math and literature problems with the assumption that math majors would be more motivated by math problems and less by literature problems and vice versa. Ultimately, the researchers found support for the additive effect hypothesis on performance and overall motivation (Hendijani et al., 2016).

Another study investigated whether for certain tasks, if more intrinsically motivated individuals demonstrate behavioral and physiological differences compared to less motivated counterparts. Herlambang and colleagues (2021) head-fixated participants in front of a computer to track and measure eye metrics whilst also recording heart rate variability; they then asked the participants to complete sudoku puzzles for 3 hours, continuously. The puzzles were divided into low motivation and high motivation puzzles, where low motivation puzzles were harder and less enjoyable than the easy-to-complete high motivation puzzles. Main findings from this study support a resource allocation theory (van der Meer et al., 2010, Hendijani et al., 2016; Herlambang et al., 2021) where participants, whilst becoming notably fatigued over time, were able to maintain performance throughout the high motivation tasks by investing more effort which was also evidenced using multiple physiological instruments.

Additionally, a demonstration of motivation on effort and physiology was conducted by Heitz et al. (2008) using pupillometry and a working memory task. The researchers found that when separating a group of participants by their working memory capacity (high vs. low) and introducing within these group different levels of incentives (no incentives, feedback, feedback

& money) they found that with more incentives, task performance was enhanced and evoked a larger pupil dilation response. However, even the highest incentivized low working memory group never performed better than the no-incentive high working memory group even though they seemed to demonstrate more effort based on physiological findings. Thus, this study suggests an important role of incentives on physiology and performance but only to a limit constrained by cognitive abilities. This finding demonstrates evidence for a cognitive efficiency theory related to effort and motivation rather than a resource allocation theory (Heitz et al., 2008, Ahern & Beatty, 1979; Hendijani et al., 2016).

Lastly, Amani (2022) was interested in the moderating effects of emotional intelligence on personality and its association to prosocial behavior. Amani's findings indicated emotional intelligence played a key role in prosocial outcomes. More specifically, the study found that the main personality traits of neuroticism, agreeableness, and openness were shown to have associations to prosocial behavior (Amani, 2022). Emotional intelligence showed a moderating effect that proved to have the largest effect on the prosocial behavioral outcomes as well as having significant interactions with the three specific personality traits.

Aims & Hypotheses

Clearly incentives play a role in effort and fatigue, but the role of prosocial motivation on listening effort and performance remains unclear. It also remains unclear what the best metric is to probe for motivation in this case. Therefore, the main purpose of this study was to make a novel approach to SPiN by relating performance and subject reports of effort to scales regarding social reward and prosociality. The logic behind using prosociality to probe motivation is due to the idea that listening to speech is a task that innately requires cooperation and turn-taking via the interlocution between a speaker and a listener, and that prosocially motivated individuals may tend to be individuals that find value in benefiting others through cooperation and empathy (Penner et al., 2005; Amani, 2022).

Thus, we hypothesized that individuals who self-score higher on social reward and prosocial items will also demonstrate better performance in SPiN. Moreover, we tested the hypothesis that demanding listening situations that may require more subjective listening effort will also reflect different levels of motivation or reward. Since task demands are increased in more adverse listening conditions, depending on how rewarding individuals rate various social interactions and the prosocial tendencies an individual expresses, these may relate to lower or higher relative listening effort. It may also be the case that there will be more effort or awareness from prosocially motivated individuals.

Methods

Participants

136 participants were recruited from London, UK using several recruitment channels including a university subject pool (SONA), word of mouth, and online advertisements. Of the 136

participants, 83 were female and 53 were male. Mean age was 29.6 years (SD = 10.6, range = 18-68).

Stimuli

Children's Coordinate Response Measure (CCRM)

The CCRM is a corpus of sentences used to assess speech perception—similar to the coordinate response measure (Bolia et al., 2000). Three speech masking conditions were used, 1) a steady-state speech-spectrum-shaped noise (SSN), 2) a 1-speaker condition, and 3) a 2-speaker condition. The SSN condition acts as a purely energetic masker whereas the two maskers with competing speakers are primarily informational maskers. The target speaker and competing speakers are different native British adult males. The target speaker was randomly one of three male potential speakers. Additionally, the competing speakers were never the same as the target speaker, nor the other masking speaker. The target speech in all conditions and trials directs the participant to "*Show the dog where the [color] [number] is*", requiring the participant to select the corresponding color-number pair. The color-number combinations are random and included any combination of six monosyllabic colors (red, white, blue, green, pink, black) and eight numbers (1-9, excluding 7). If a participant responded accurately by selecting the correct combination, a happy bear is presented as feedback; if incorrect, a sad bear.

This task adaptively determines where listeners will accurately respond to the target speech approximately 50% of the time when listening to speech-in-noise, i.e. the so-called speech reception threshold (SRT). This speech-in-noise task was administered with MATLAB R2022b, and all participants listened to the sounds at the same comfortable level through Sennheiser HD221 headphones, although participants were allowed to adjust the volume if they felt it necessary.

The initial signal-to-noise ratio (SNR) is set at +12 dB, resulting in easily intelligible speech. The task follows a stepwise adaptive process based on the listener's responses. For the first four reversals—defined by correct and incorrect responses—the SNR is adjusted by -9 dB, followed

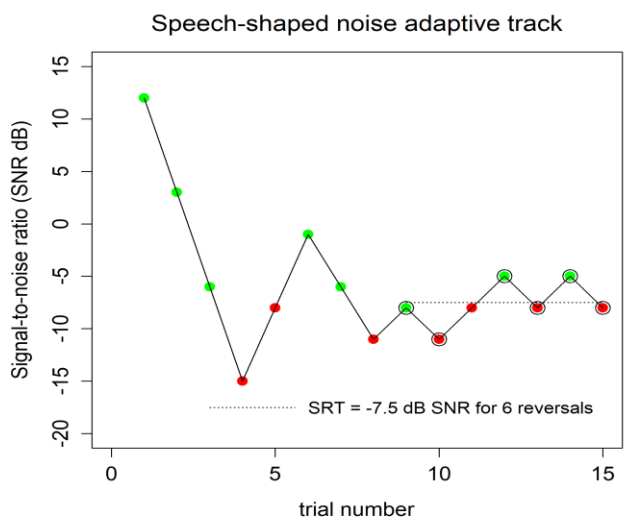

Figure 1: An example of a participant's performance in the SSN condition showing trials and corresponding SNR at each step. Circled steps represent the steps in which reversals occurred. The final SRT was -7.5 dB.

by +7 dB, -5 dB, and finally ±3 dB. Once the ±3 dB step is reached and speech becomes significantly less intelligible, a mean score from the last six reversals is calculated to determine the listener's SRT. Although the task allows for a maximum of 30 trials, the program terminates after the sixth reversal at ±3 dB, regardless of the trial number at that point (see Figure 1).

CCRM Questionnaire

This questionnaire was devised to inquire subjective reports of how the individual perceived the noise, their listening effort, and the awareness of their effort following each of the speech masking conditions in the CCRM. Each question was on a continuous scale from 0-10 (*Table 1)*.

1) How noisy was it during the listening situation? (0 = quiet, 10 = very noisy)
2) How much effort was required in order to understand what was being said? (0 = no effort, 10 = lots of effort)
3) How aware were you of your listening effort during your listening experience? (0 = completely unaware, 10 = very aware)

Table 1: Questions from the CCRM questionnaire

Item 1 relates to subjective perceptual ratings of SPiN, whereas items 2 and 3 inquire subjective ratings more closely related to cognitive processes underlying SPiN performance. Subjective ratings for listening effort and awareness of effort were combined into a single score to represent cognitive ratings of SPiN.

Reading Span Task

This cognitive task utilized an open-access, computerized version of the reading span task (RST; Daneman & Carpenter, 1980). This version was acquired from http://www.cognitivetools.uk/cognition/ and administered on a Dell laptop using Tatool via JAVA. The RST measures working memory capacity (WMC) or the ability to process new information whilst holding previous bits of information in mind for recall. The information stored and recalled in each trial was a random digit between 1-99. After the random number was presented in the center of the screen for 250 ms, a short sentence is presented and the participant processed and determined whether this sentence was sensical or not using the keyboard's arrow keys. Sentence response feedback is provided in the form of a green check for correct responses or a red 'x' for incorrect responses. The sensibility is strictly based on semantics e.g. "*you can hear with your ears*" (sensical) or "*boats like to eat crisps*" (non-sensical). Following the sentences was a screen that prompts the participant to input the digits previously presented before the sentences respectively. The same feedback system is used for correct or incorrect number inputs. After each trial there is a 2500 ms pause before the next trial begins. The span length starts with two digits, then a length of three, etc. to eventually a length six. There were three trials per span condition, six different span conditions, 15 total trials, and a total of 60 number and 60 sentence responses. A working memory score was derived by taking the total

number of correct digit responses out of 60. Sentence accuracy was also calculated by total number of correct responses out of 60.

Social Reward Questionnaire (SRQ)

The SRQ is a 20-item questionnaire that measures how rewarding or enjoyable individuals find various social interactions (Foulkes et al., 2014). The scale is divided into 5 subscales of social reward—Admiration, Negative Social Potency, Passivity, Prosocial Interactions, and Sociability. Items are scored using a 7-point Likert scale with points ranging from Strongly Disagree to Strongly Agree. Participants were instructed to report how much they imagine they would enjoy an item in the case they had never experienced that prompt.

According to Foulkes et al., (2014) each subscale—or factor, can be described as follows; admiration: "*being flattered, liked and gaining positive attention*";

negative social potency: "*being cruel, callous and using others for personal gains*";

passivity: "*giving others control and allowing them to make decisions*";

prosocial interactions: "*having kind, reciprocal relationships*";

and sociability: "*engaging in group interactions*".

The SRQ subscales are unidimensional and were subsequently collapsed into five individual aggregate score.

Prosocial Scale for Adults (PSA)

The PSA is a 16-item questionnaire that measures differences in prosocial tendencies (Caprara et al., 2005). The scale instructs participants to mark their first reaction to different, common intersocial scenarios. Self-rated items e.g., "*I easily help others*" get scored on a 5-point Likert scale where values represent Never/Almost Never, Rarely, Occasionally, Often, and Always/Almost Always. This scale is considered unidimensional; therefore, all item scores were collapsed into one aggregate score for prosociality.

Procedure

Participants were tested onsite at University College London, Institute of Cognitive Neuroscience (UCL ICN). Informed consent and demographic information were obtained from each participant following the approval from the UCL Research Ethics Committee. Participants first completed the Children's Coordinate Response Measure (CCRM)—after each condition, the participant would report their subjective listening experience on the CCRM questionnaire. The three masker conditions were pseudorandomized to eliminate any potential learning effects in performance and adaptations in subjective reports. Participants then completed the reading span

task (RST) and lastly, the paper-and-pen SRQ and PSA. After all tasks and scales were administered, participants were allowed to ask any questions and provided a debrief regarding the aims of the study. All participants were compensated 10 British Pound Sterling for their time and efforts.

Data was primarily analyzed with JASP and RStudio. All reported statistics have undergone assumption checks and if any assumptions were violated, corrected statistics are reported when applicable. There were few cases of missing data therefore linear mixed models (LMM) were utilized to address the issue of unequal sample sizes, particularly between masker conditions in the CCRM. There were also few instances of outlying data points. Data outside of three standard deviations from the mean were excluded from LMM. For regression, outliers were labelled as negatively influential according to a relatively conservative Cook's distance (Cook's d = 0.1). Any outliers with a Cook's d larger than .01 were subsequently removed from the analyses. Furthermore, backwards elimination stepwise regression was used to elucidate meaningful relationships between outcome and predictor variables. Backwards elimination stepwise regression considers all predictor variables and subsequently eliminates each variable from the model one-by-one starting with the least insignificant (highest p-value) variable until there only remains a model—or models, with significant p-value predictors (threshold of $p = 0.05$).

Prior to the regression analyses, a principal component analysis (PCA) was performed on the scores produced by the social reward and prosocial questionnaires (FactoMineR; Lê et al., 2008). PCA was used to reduce the dimensionality of these metrics in order to elucidate any underlying structure amongst these variables. To ensure contributions were equal, the variables underwent initial standardization prior to PCA.

PCA indicated there were two principal components that accounted for 60.59% of the total variance (40.26% and 20.33%, respectively). The first component was influenced by prosociality, prosocial interactions, sociability, admiration, and negative social potency; suggesting this dimension represents rewarding social interactions based primarily on prosociality. The second component was influenced by negative social potency, passivity, admiration, sociability; suggesting a component represented by rewarding social interactions without prosociality. Thus, although these two components are loaded by several of the same variables, we believe these two dimensions to represent a key difference in the data which pertains to the moderating role of prosocial motivation in social reward. Therefore, these two components are used as variables to explore relationships between prosociality and objective and subjective SPiN.

Results

SPiN Performance & Subjective Experiences

To address missing data, linear mixed-effects models (LMM) were used in JASP to explore the differences in performance between the masker conditions in the CCRM, subjective noise ratings, and the subjective cognitive rating of SPiN. Firstly, a model was fitted to explore the effect of masker type on SRTs, with participant as a random effect. Analysis discovered a significant masker type effect on SRT ($F[2,267.29] = 761.717$, $p < .001$; Figure 2). Using restricted maximum likelihood (REML), which provides less biased estimates of variance components for random effects. The deviance in the model was 2132.17 with Akaike information criterion (AIC) and Bayesian information criterion (BIC) values of 2142.170 and 2162.177, respectively.

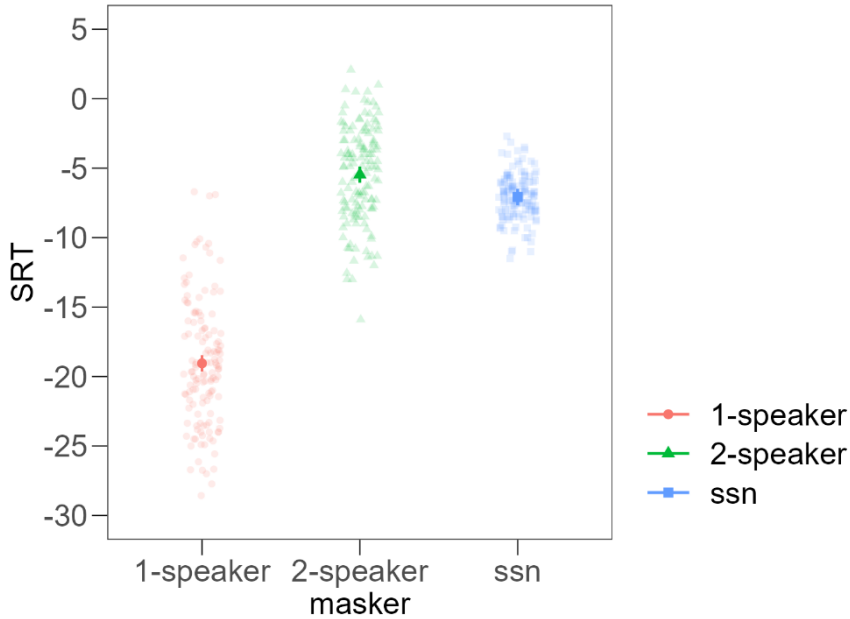

Figure 2: Plot of mean SRTs for each masker condition with confidence intervals

The estimated marginal means for SRTs in the masker conditions along with the respective 95% confidence intervals are presented in Table 2 below. In terms of fixed effects, the estimated intercept of the model was derived as a grand mean from SRTs from the three masker conditions. The estimated mean of this intercept was -10.531 ($p < .001$). The fixed effect for the 1-speaker ($masker_1$) represents its deviation from the grand mean (-8.520, $p < .001$) while the 2-speaker condition (masker2) deviates positively from the grand mean (5.063, $p < .001$). Moreover, the SSN condition serves as the reference level for the other masker conditions. The estimated mean for the SSN condition can be calculated by subtracting the sum of the other conditions from intercept (SSN_{mean} = intercept – [$masker_1$ + $masker_2$]). In other words, $masker_1$ compares the 1-speaker condition to the SSN condition, and $masker_2$ compares the 2-speaker condition to the SSN condition.

Table 2: Estimated Means and Confidence Intervals (SRTs)

		95% CI	
Masker	**Mean**	**Lower**	**Upper**
1-speaker	-19.051	-19.633	-18.468
2-speaker	-5.469	-6.047	-4.890
SSN	-7.074	-7.656	-6.492

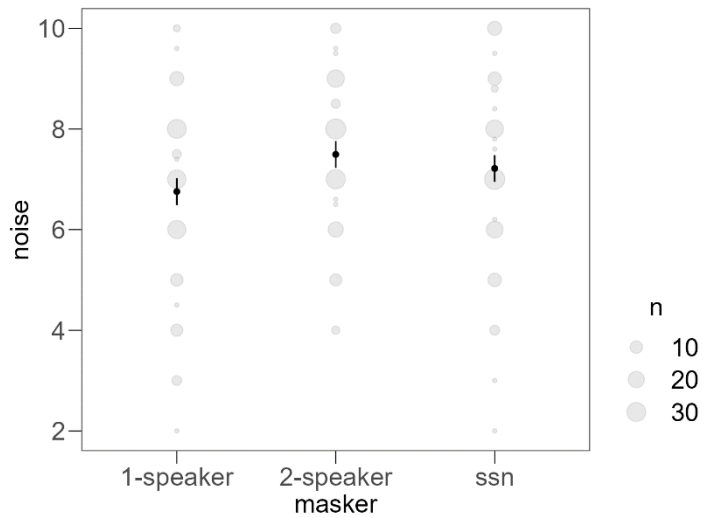

Figure 3: Plot of mean subjective ratings of noise with confidence intervals.

Another LMM was fitted to explore the effect of the three masker types on differences in subjective noise ratings in the CCRM. Masker type had a significant effect on listener's subjective noise ratings (F[2,265.57] = 12.078, p < .001, Figure 3). Deviance in this model according to the REML was 1457.398, and the model was fit with an AIC of 1467.398 and a BIC of 1487.381. As for fixed effects, the estimated intercept of this model was derived as a grand mean from the subjective noise ratings from the three masker conditions. In this model, the estimated mean of this intercept was 7.156 (p < .001). The fixed effect for the 1-speaker ($masker_1$) represents its deviation from the grand mean (-.399, p < .001) while the 2-speaker condition (masker2) deviates positively from the grand mean (.399, p < .001). Means and confidence intervals for noise ratings in each masker may be found in Table 3 below.

Table 3: Estimated Means and Confidence Intervals (Noise ratings)

		95% CI	
Masker	**Mean**	**Lower**	**Upper**
1-speaker	6.757	6.490	7.024
2-speaker	7.495	7.229	7.762
SSN	7.216	6.950	7.481

A final LMM analysis was run to determine the effect of masker type on the listener's subjective ratings of their cognitive experiences of SPiN in the CCRM. Masker type had a significant effect of the subjective cognitive experience listener's rated in each condition (F[2,265.05] = 11.372, p < .001; Figure 4). Deviance in this model according to the REML was 1299.097, and the model was fit with an AIC of 1309.097 and a BIC of 1329.104. The fixed effects in this analysis derived its estimated intercept of this model the combined subjective ratings of effort and awareness from the three masker conditions. The estimated mean of this intercept was 7.788 (p < .001). The fixed effect for the 1-speaker ($masker_1$) represents its deviation from the grand mean (-.185, p < .001) while the 2-speaker condition (masker2) deviates positively from the grand

mean (.306, $p < .001$). The means and confidence intervals for subjective cognitive ratings in each masker are presented in Table 4 below.

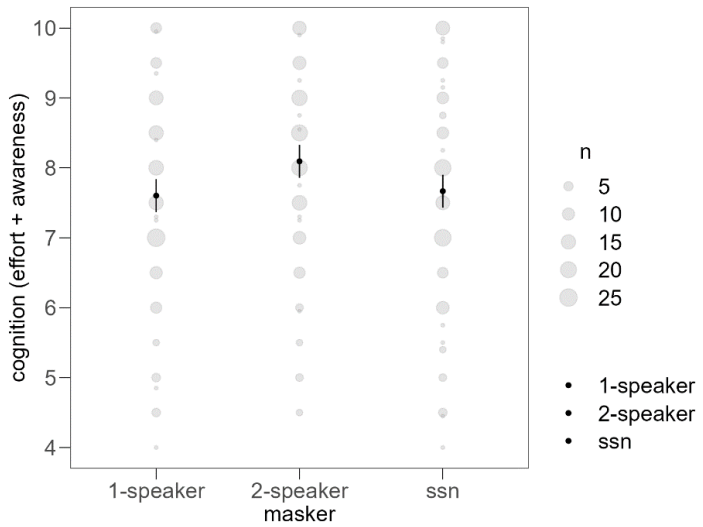

Figure 4: Plot of mean subjective ratings of cognitive aspects of SPiN with confidence intervals.

Table 4: Estimated Means and Confidence Intervals (Cognitive Ratings)

		95% CI	
Masker	**Mean**	**Lower**	**Upper**
1-speaker	7.603	7.367	7.839
2-speaker	8.093	7.858	8.329
SSN	7.667	7.431	7.902

SPiN & Prosocial/Social Reward

To explore any significant relationships between objective and subjective SPiN performance and other measures, backwards elimination stepwise regression was performed. For each dependent variable (SRTs, subjective noise, and subjective cognitive ratings), the regression model

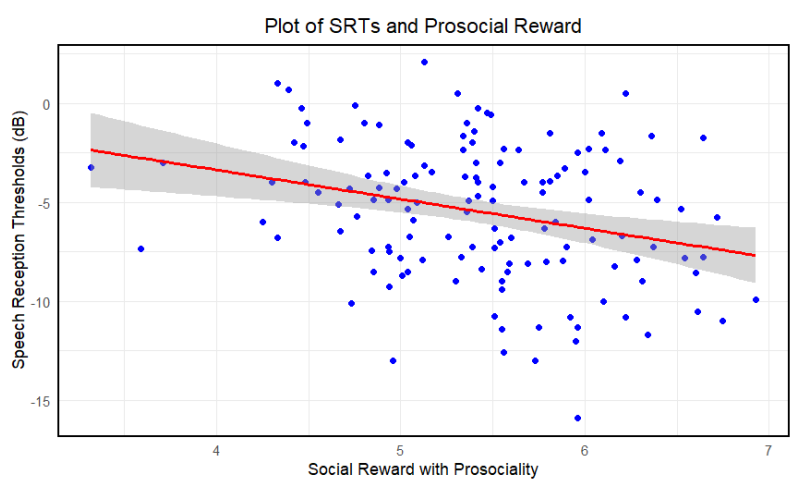

Figure 5: Scatter plot showing the relationship between SRTs in the 2-speaker noise condition and the self-rated social reward with prosociality ratings.

predictors of age, reading span, social reward with prosociality, and social reward without prosociality.

This initial analysis exploring the SRTs as the outcome measure resulted in a relationship between objective performance in the 2-speaker condition in which the model demonstrated SRTs were significantly predicted by higher ratings of social reward with prosociality ($\beta = -0.319$, $p < .001$, $R^2 = 10.2\%$). In this case, individuals who rated rewarding social interactions with prosociality as more rewarding, they also exhibited better thresholds in this informational masker condition. SRTs from the other masker conditions failed to create any significant regression models with the given covariates.

As for the subjective ratings related to the cognitive aspects (effort + awareness) of SPiN, age proved to be the only significant predictor in the 1-speaker masker ($\beta = 0.220$, $p = .012$, $R^2 = 4.8\%$), the SSN noise condition ($\beta = 0.183$, $p = .036$, $R^2 = 3.3\%$) and in the 2-speaker condition ($\beta = 0.258$, $p = .003$, $R^2 = 6.6\%$).

Discussion

General Discussion

When studying SPiN, existing literature has explored how intrinsic and extrinsic motivators affect a listener's effort when perceiving speech-in-noise (Picou & Ricketts, 2014; Carolan et al., 2022). This current study, to our knowledge, is the first that has explored how social interaction traits—as opposed to personality traits—specifically pertaining to social reward and prosociality, relate to SPiN performance and to self-rated listening experiences of SPiN.

Prior to analyses, several variables were found to be highly related to one another e.g., listening effort and awareness of effort, and were combined as a representation of the overall subjective cognitive aspect of SPiN performance. Additionally, we were concerned that several of the subscales in the SRQ were addressing the same or similar constructs, therefore principal component analysis was performed to reduce the dimensions of social interaction traits and prosociality measures. These procedures allowed for more focused data structures and analyses.

In this study, we tested the hypothesis that individuals who rate themselves higher in prosociality demonstrate better SRTs during a SPiN task. Findings from the study show that indeed, in certain masker conditions e.g., high-difficulty speech-on-speech (2-speaker condition), people who rated themselves higher in finding social interactions—with a principal component of prosociality, as more rewarding, they also demonstrated better SRTs. When testing the hypothesis that prosocially motivated individuals would differ in cognitive traits i.e., listening effort, age proved to be the most significant predictor of self-rated cognitive experience of SPiN in all masker conditions.

SPiN Performance & Subjective Experiences

First, the findings of this study demonstrate that the masker conditions in the CCRM elicited significantly different SRTs. Previous research has shown that informational maskers affect speech perception differently than energetic maskers (Shinn-Cunningham, 2008; Scott et al., 2004; Evans et al., 2016, Brungart, 2001) where informational maskers affect more top-down than bottom-up processes. Specifically, the informational masking condition in this study that had 2-speakers competing against target speech resulted in the worst thresholds out of the three conditions, whereas the informationally masking condition with only 1-speaker yielded the best out of the three conditions. This finding, it seems, reveals that with the mere addition of one additional speaker in the background, SPiN performance is severely affected.

Background noises that are amplitude modulated (e.g., a single speaker in the background) provide more chances for listeners to "glimpse" target speech i.e., time periods where the SNR is more favorable (Brungart, 2001; Mattys et al., 2009; Scott et al., 2004). This experience of glimpsing target speech is directly associated with the number of competing speakers, along with other features (Cooke et al., 2008; Zhang et al., 2021). Rosen and colleagues (2013) also demonstrated that a condition with 2-speaker babble proved the most difficult in terms in accuracy performance; and that, when incrementally increasing the number of competing speakers up to 16 or infinity, there was a small increase in performance. This may be due to the fact that with more speakers, the amount of information that can be accessed from each speaker diminishes as aperiodic speech streams overlap one another (Steinmetzgeter & Rosen, 2015). Therefore, when the number of speakers in the background is increased—if the amplitude modulations of the competing voices are not aligned i.e., there will be more overall energy uniformly distributed across time, there will be a reduced likelihood for glimpses to be experienced. All informational maskers also mask speech at a signal level meaning informational maskers also have attributes of energetic maskers; at an extreme level, if you can imagine walking into a sports stadium with tens of thousands of fanatics. When that number of competing speakers increases, there leads to masker signal misalignments. As a result of these misalignments, there is a subsequent transformation where the informational masker starts to reflect a masker profile more characteristic to that of an energetic type, particularly when there are larger numbers of competing speakers. In other words, if we assume the SSN condition reflects a masker with infinite number of speakers, i.e., where there is practically zero opportunity for the target speech to be glimpsed, we observe an increase in performance from the informational masker condition with two competing speakers.

The increase in performance Rosen and colleagues (2013) revealed may be recognized in our study's data. Performance in the energetic masker condition in this study was significantly different than both informational masker conditions. In this case, the SSN condition generated SRTs better than 2-speaker condition and significantly worse compared to the 1-speaker. Clearly there is an effect here where the number of speakers in the background plays an important role in a masker's effectiveness. Essentially, by increasing the amount speakers in the background, informational maskers can result in similar, yet different SRTs to steady state energetic noise. This notion can be exemplified in that informational maskers also contain elements that lead to various levels of energetic masking, ultimately depending on the number of speakers within the masker.

These behavioral findings reflect the natural effect of numerous speakers in the background i.e., multi-speaker babble, and when informational maskers start to transform and exhibit characteristics similar to energetic maskers. Additionally, the masker type effect observed between the different masker conditions had on performance allows each condition to be explored independently from one another, allowing the assumption that each condition may require different resources for processing, whether cognitive, perceptual, or motivational.

In summary, the current study found a large and robust effect of masker-type where listeners performed best in a 1-speaker informational masker, and worst in a 2-speaker masker. Moreover, listeners performed better in the SSN energetic masker than the 2-speaker informational masker but not better than the 1-speaker condition. It seems that as more speakers are added, there are less chances for glimpses to be had due to aperiodicity, and that the amplitude profile of an informational masker eventually affects performance similar to that of steady state energetic maskers. However, this effectiveness of an informational masker is highest where there are two-competing background speakers.

SPiN Performance & Prosocial/Social Reward

When looking at SRTs in the CCRM, using backward elimination regression, a significant correlation was elucidated between performance in the 2-speaker noise condition and social reward with prosociality. According to Foulkes et al. (2014), prosocial interactions was defined as "*having kind, reciprocal relationships*". Therefore, this finding demonstrates that individuals who self-rate themselves as more prosocial tended to perform with better SRTs in the 2-speaker condition in our study. Moreover, in the study by Wöstmann (2021) and of all the personality traits, higher neuroticism demonstrated the only relationship to better objective hearing in noise performance. According to Foulkes et al., (2014), prosociality is highly correlated with all five personality traits with agreeableness being the strongest (r = .44) and neuroticism towards the bottom of the list (r = .15). However, Wöstmann and colleagues failed to include an informational masker condition, only using SSN.

The finding in the current study may touch on the fact that individuals who tend to find kind and reciprocal interactions more rewarding may also have more experience i.e., time spent, in group settings where there are increased chances of several competing speakers. It may also be the case that this experience is helpful only when listeners are faced with the most adverse conditions. To our knowledge, this is a novel study that explored and found a significant connection between prosocial motivation and social reward on objective and subjective SPiN performance. Moreover, there was a study that investigated sociability in a group of cochlear implant users, this study found similar results although with subjective ratings of listening effort (Hughes et al., 2018). Other studies have been interested in size of social network and its relation to speech perception abilities (Lev-Ari, 2018; Lev-Ari, 2022), however have yielded mixed results.

Subjective Cognitive Components

As for the ratings of cognitive experience in our study—an aggregate of effort and awareness, the primary variable that predicted these subjective ratings was the listener's age. This finding seems consistent with previous listening effort literature (Peelle et al., 2010; Degeest et al., 2015; Kwak & Han, 2021). This age association was found in all three speech masking conditions. Moreover, prosocial interactions are often effortful interactions (Lockwood et al., 2017; Lockwood et al., 2022). In this case, individuals rating higher for social reward with an emphasis on prosociality were rating themselves as experiencing more cognitive demands.

Usually when cognitive tasks become more demanding, as in the case of increased background noise on listening effort, there are greater impositions on resource allocation and general processing. This notion has been demonstrated in previous studies using evoke pupil responses, which is often used as a physiological index for mental effort (Ahern & Beatty, 1979; Zekveld el al., 2011; Koelewijn et al., 2012). In our study, when older listeners had higher demands placed on their processing i.e., increased background noise, there tended to be a subsequent increase in their subjective accounts of cognitive effort in specific conditions. However, while there may be discernable differences in subjective experiences, as for our study and the Koelewijn et al. (2012) study, there was so significant relationship or difference between age and performance, respectively. Therefore, it may very much be the case that individuals exert differential levels of cognitive effort to achieve similar performances to other listeners, depending on task demands. Unfortunately, there is no reliable objective measure of effort, and we must often rely on subjective ratings or physiological measures that typical relate to several other cognitive processes beyond effort (Larsen & Waters, 2018; Mathôt & Vilotijević, 2022).

Awareness

To our knowledge, no study interested in SPiN and listening effort has been concerned with an individual's awareness of their effort exertion. More generally, awareness plays an important role in the "cocktail party" problem, especially in regard to knowing and attending to the auditory streams that are of interest. Awareness contributes major elements in metacognitive abilities and attention—in that, a listener must be aware of which stream of auditory signals they wish to attend to and are most relevant, whilst also being aware of the types of noises in the auditory scene needing to be ignored. Kahneman (1973) describes this association between perceptual effort and awareness as a conscious process. Kahneman furthers this notion by noting that even when auditory channels with lower relevance are segregated and are "unattended to", there is still minor awareness for these irrelevant auditory objects which may still lead to their perhaps unnecessary attention, selection, and perception. This has been a large question in the literature stemming back from the original ideas from Cherry (1953) and Broadbent (1958) regarding divided and selective attention. For example, Scott et al. (2004) demonstrated using positron emission tomography (PET) that unattended speech processing occurs within the same stream that attended speech is processed—including the bilateral later superior temporal gyri and sulcus (STG/STS), and the left anterior STG. Moreover, using electroencephalography (EEG), O'Sullivan and colleagues (2014) investigated divided attention using electroencephalography (EEG); using a similar diotic listening task as Cherry (1953), they found support that unattended

speech inputs demonstrate different neural representations, meaning unattended speech is perceived, however, perhaps lacking the perceptual awareness for the active perception of the input.

Furthermore, if certain listening environments require extensive listening effort, the demands for selective attention may have negative effects on a listener's awareness, leaving them unable to divide their attention when necessary (Shinn-Cunningham et al., 2019). Lastly, a study by Lewis et al., (2021) found when an individual increases their self-awareness, they subsequently increase their prosocial behaviors. Due to the nature of correlations, it is difficult to know in the current findings whether it is the more prosocial individuals rating more cognitive effort and awareness, or the more self-aware individuals who are rating higher prosocial tendencies. This is a finding worth deeper exploration in future studies.

Motivation

When developing the PSA, Capara and colleagues (2005) were interested in elucidating prosociality and mention that prosociality arises from complex processes, particularly related to processes related to attention and evaluation. These researchers also note that prosocial behaviors may be utilized to overcome or counteract difficulties often related with aging. Therefore, where prosociality was found to relate to the objective thresholds of the 2-speaker masker condition, the performance demonstrated by listeners may have been derived from prosocial motivation. However, due to the nature of correlational analysis, it is difficult to make claims about the causal relationship between prosociality and speech perception in noise performance.

It has been well established that motivation has a key role in the relationship to task demands and the amount of effort exerted (Pichora-Fuller et al., 2016; Heitz et al., 2008; Picou & Ricketts, 2014). Demanding tasks that require motivation and effort are often tasks with underlying neuroeconomics, i.e., tasks that require an individual to assess the metabolic and cognitive cost-benefit ratio of exerting effort to benefit performance at the risk of cognitive fatigue. The regions shown to support the process linked to determining self-benefiting or prosocial effort involves frontal regions, particularly in the anterior cingulate gyrus and anterior insula (Lockwood et al., 2022). It has also been demonstrated that when manipulating the frontopolar cortex using excitatory—as opposed to sham or inhibitory transcranial direct current stimulation (tDCS), participants were more likely to exert both physical and mental effort to gain respective rewards (Soutschek et al., 2018). This finding demonstrates an important piece of anatomy playing a causal role on an individual's motivation to exert effort for a reward or not i.e., a frontal region, implying the use of top-down control processes. Therefore, future studies interested in SPiN and motivation should seriously consider how these regions may be playing important roles in the maintenance and modulation of prosocial motivation on performance and the subsequent outcomes of effort, awareness, and fatigue.

Overall, motivation has been found to play a role in listening performance and subjective experiences (Carolan et al., 2022), as well as how individuals utilize their effort based on costs and rewards. This, to our understanding, is the first study to explore social rewards and prosocial

tendencies and how prosocial motivation may be instrumental to SPiN performance and subjective experiences.

Conclusion

This study provides novel insights into the relationship between social reward, prosociality, and speech perception in noise (SPiN) performance. We found that individuals who rated themselves higher in prosocial traits performed better in the most challenging masker condition (two competing speakers), suggesting that prosocial motivation may enhance SPiN abilities in difficult auditory environments. Additionally, age was a key predictor of subjective cognitive effort across all masker conditions. These findings highlight the importance of considering social interaction traits, alongside traditional factors such as age, in understanding both objective SPiN performance and subjective listening experiences. Further research is needed to explore the neurobiological mechanisms underlying prosocial motivation and its impact on cognitive processing in challenging auditory tasks.

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