Child-appropriate experiment on auditory selective attention in a virtual acoustic environment

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Introduction

Assessing noise effects in children‘s development has gained more and more importance in the last years. Noise not only affects cognitive processes of children, e.g. attention control [3], but can also lead to stress-related bodily reactions, such as increased heart rate [5]. Recent research has therefore brought correlating factors between physiological and psychological effects into focus. This leads to the integration of combined assessment of cognitive parameters and vital parameters in listening experiments with noisy conditions.

To meet higher ecological validity in these experiments, influences caused by the experimental setup should be minimized. It is therefore important to consider unobstrusive measurement methods which do not constrain participant movement during the experiment.

A method to assess vital parameters using an unobtrusive measurement method is proposed in combination with a child-appropriate experiment on auditory selective attention in virtual acoustic environments.

Participants

A pre-study was conducted with ten adults (age: 21-34 years; M = 23.5 year, SD = 4 years, 3 female). Inclusion criteria were German speaking and normal hearing abilities (within 25 dB[HL] - pure tone audiometry). All participants have never participated in a listening experiment on auditory selective attention before. Further, informed consent was obtained from all participating persons prior testing.

Binaural sound reproduction

The experiment was carried out in an acoustically optimized hearing booth. Binaural sound signals were provided via headphones using non-individualized head-related transfer functions [7]. Furthermore, individual headphone transfer function equalization was done according to Masiero and Fels [4]. A static reproduction without considering head movements was chosen for this pre-study. The acoustic virtual environment for the listening experiment was implemented using the Virtual Acoustics (VA) integration for MATLAB provided by the Institute of Technical Acoustics [2].

Stimuli

The speech material consisted of eight German animal names which could be categorized easily as “flying” or “not flying”. Each word contained two syllables, and all were all phonetically dissimilar words. The category ”flying” comprised ”Katze” (cat), ”Ratte” (rat), ”Schlange” (snake) and ”Robbe” (seal). The category ”not flying” comprised ”Biene” (bee), ”Ente” (duck), ”Taube” (pigeon) and ”Eule” (owl). The speech material was spoken by a female adult (24 years old) and by a male child (5 years old), both native German speakers.

Cognitive task and experimental design

A child-appropriate version of an established paradigm by Oberem et al. [6] to assess auditory selective attention processes was chosen. Hereby, two stimuli were presented simultaneously. The participant is asked to focus on the target (T), which is previously indicated using a visual cue, and to ignore the distractor (D). The task was to categorize the presented animal from the target to ”flying” or ”not flying” in combination with „big“ or „small“, so that there were four possible answers (cf. Figure 1).

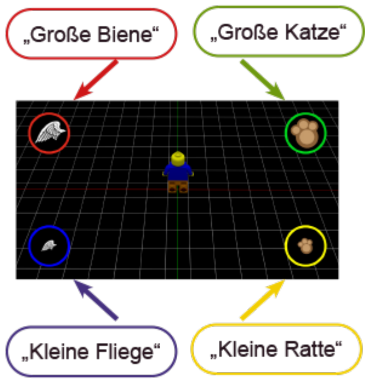

Figure 1: Examples of correct answer to the cognitive task according to all four kinds of combinations of ”big”/”small” with ”flying”/”not-flying” animal.

Colorful pictures with game elements were used to keep children’s motivation to a sufficient level throughout the experiment. Furthermore, a feedback system was added to reflect performance of a participant and to visualize progress. One representative trial including cue and feedback is shown in Figure 2.

This paradigm allows to measure reaction time and error rate as dependent variables. To reflect cognitive performance in a spatial hearing situation, the following independent variables are examined.

Transition of attention is represented in the switch or repetition of target’s position in two following trials (cf. Figure 3). In case of a switch, the participant must reori-

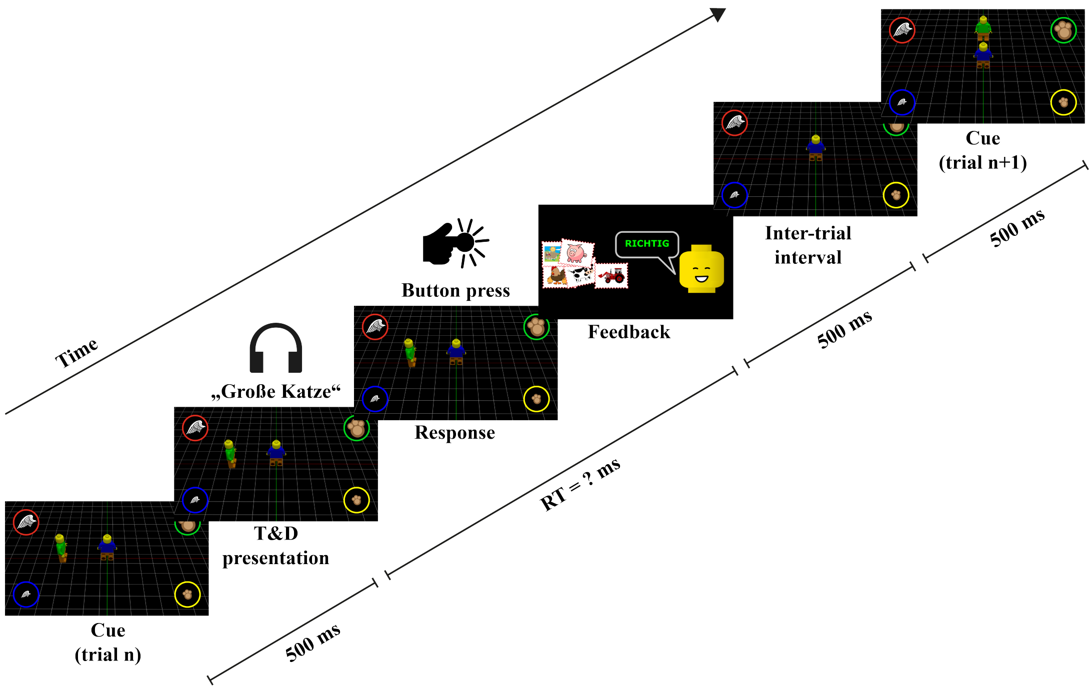

Figure 2: Structure of one representative experiment trial with all components and corresponding time intervals.

entate in space and therefore requires more time to react and might make more mistakes.

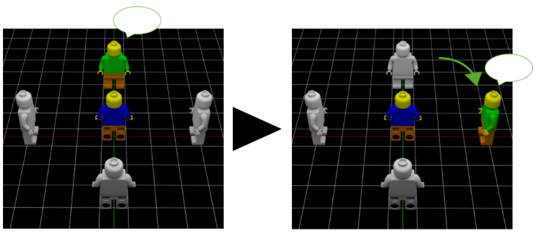

Figure 3: Attention switch in two following trials. Target's position changes from "front" to "right". Participant must reorientate and refocus attention to the new position in space.

Congruency is interpreted as the ability to suppress irrelevant information. Its effect can be assessed by the difference in responses to target and distractor of the same, or of different categories in one trial. Depending on the error rate it is possible to derive whether participants were able to suppress irrelevant information provided by the distractor. Since one stimulus consists of two words, there are three posibilities (cf. Figure 4):

- Congruent - all words from target and distractor are from the same category.
- Semi-Incongruent - either first or second part of stimuli are from different categories.
- Incongruent - all words from target and distractor are from different categories.

Complexity regarding irrelevant information suppression is increasing from congruent trials over semi-incongruent trials to incongruent trials where the highest error rate is expected.

T-D position combination describes the spatial distribution of target and distractor in one trial. They could be either presented in the position front (F), back (B), left (L) or right (R). Thus, possible position combinations were left-right (L-R), neighboring (Next) or front-back (F-B) (cf. Figure 5).

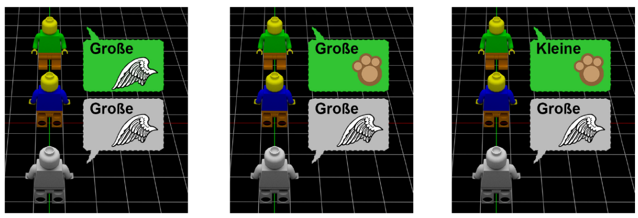

Figure 4: Examples for different complexity of congruency. From left to right: Congruent - all words from target (green) and distractor (grey) are from the same category; Semi-Incongruent - either the first or the second part of stimuli of target and distractor are from different categories; Incongruent - all words from target and distractor are from different categories.

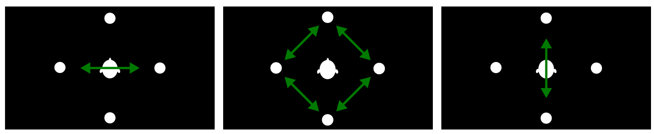

Figure 5: Possibilities to combine target and distractor positions (from left to right): left-right (L-R) combinations, neighboring (Next) combinations or front-back (F-B) combinations.

Noise was presented in half of the trials to examine the effect of background distraction. Stationary noise with children's speech frequency spectrum was chosen. Signal-to-noise ratio (SNR) was +6 dB.

Measurement of vital parameters

In this study, it was decided to evaluate cardiac signals to extract heart rate variability parameters. For this purpose, two measurement methods were chosen: Firstly, an "ElectroMechanical Film (EMFi) transducer" mat (L-Series by Emfit Ltd., Vaajakoski, Finland) was placed under the participant on the chair (cf. [1]). This mat is able to convert mechanical vibrations induced by pulses from the pelvic artery into electrical signals. Secondly, a Polar H7 chest strap, which is commonly used in athletic activities, was used. Internal sampling rate for EKG was $f_s = 1000$ Hz.

To obtain first insights, only data from the Polar H7 chest strap were evaluated in this pre-study. mechanical recorded signal using the EMFi transducer mat will be evaluated in the future. Parameters were calculated for each trial (between two responses) and treated as dependent variables in the analyses. NN hereby describes the interval between two peaks of normal heart beats.

- meanHR [bpm]: average heart rate (heart beats per examined interval).
- SDNN [ms]: standard deviation of NN intervals and represents the total variability in heart rate.
- RMSSD [ms]: root mean square of successive differences between adjacent NN intervals.
- pNN50: proportion of NN50 (successive NN intervals with more than 50 ms differences) divided by total number of NN intervals.

Results

Analyses of variances (ANOVA) were performed to analyze the cognitive performance using reaction time (RT), error rate (ER) and parameters regarding heart rate variability (HRV). To obtain first insights, only main effects are examined in this pre-study. Degrees of freedom were corrected using Greenhouse-Geisser estimates iff Mauchly's test indicated that the assumption of sphericity had been violated. Furthermore, multiple linear regressions were conducted to show the relationship between physiological (heart rate variability parameters) and cognitive parameters (reaction time and error rate).

Reaction time and error rates

As expected, a significant transition effect was found in RT, $F(1, 9) = 5.469$, $p < .05$, $\eta_p^2 = 0.378$, but not in ER, $F < 1$. Furthermore, a significant congruency effect was found in ER, $F(2, 18) = 184.771$, $p < .001$, $\eta_p^2 = 0.954$, but not in RT, $F < 1$. Significant main effect in target-distractor position combination was observed in RT, $F(1.25, 18) = 23.873$, $p < .001$, $\eta_p^2 = 0.726$ (G.G.c.), and in ER, $F(2, 18) = 269.886$, $p < .001$, $\eta_p^2 = 0.968$. Performance was best in L-R (RT: $M = 2443.347$ ms, $SD = 80.337$ ms, ER: $M = 2.5$ %, $SD = 0.6$ %) compared to Next (RT: $M = 2649.766$ ms, $SD = 141.439$ ms, ER: $M = 5.9$ %, $SD = 0.8$ %) and worst in F-B (RT: $M = 2991.083$ ms, $SD = 170.794$ ms, ER: $M = 31.8$ %, $SD = 1.5$ %). However, no significant main effect of noise was found, neither in RT nor in ER (both $F < 1$). More detailed results can be found in Figure 6.

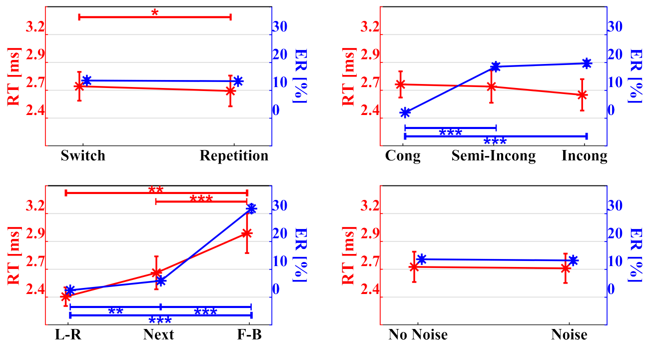

Figure 6: Results of independent variables considering reaction time (RT) and error rate (ER) are presented from top-left to bottom-right: transition, congruency, target-distractor position combination and noise. Number of stars indicates level of significance of main effect and corresponding t-tests.

Heart rate variablity

Results from RMSSD and pNN50 revealed no significant main effects, all $F < 1$.

Significant main effects were only found for meanHR and SDNN. SDNN showed marginal significance in congruency, $F(2, 18) = 3.917$, $p < .05$, $\eta_p^2 = 0.303$. However, all post-hoc t-tests were not significant between all three congruency types ($p > .05$) and further all other main effects were not significant, $F < 1$. In meanHR, a significant main effect of transition, $F(1, 9) = 10.255$, $p < .05$, $\eta_p^2 = 0.533$, was observed and further a significant main effect of T-D position combination was found, $F(2, 18) = 11.642$, $p < .01$, $\eta_p^2 = 0.564$. Main effects in noise and in congruency were not observed, $F < 1$. More detailed results can be found in Figure 7.

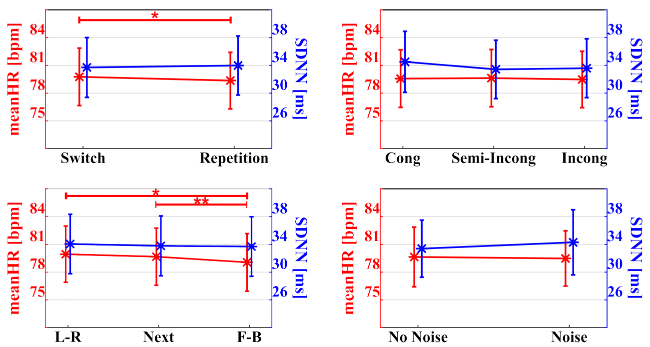

Figure 7: Results of independent variables considering average heart rate (meanHR) and total heart rate variability(SDNN) are presented from top-left to bottom-right: transition, congruency, target-distractor position combination and noise. Number of stars indicates level of significance of main effect and corresponding t-tests.

Correlating cognitive and vital parameters

A multiple linear regression was conducted to predict RT and ER from meanHR, SDNN, RMSSD and pNN50 (cf. Figure 8). These variables statistically significantly predicted RT, $F(4, 355) = 30.631$, $p < .001$, $R^2 = 0.247$. meanHR, SDNN, and RMSSD added statistically significantly to the prediction, $p < .05$.

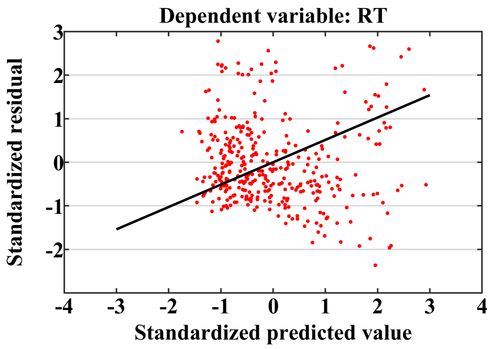

Figure 8: Multiple linear regression of heart rate variability including average heart rate (meanHR), total variability (SDNN), RMSSD and pNN50 predicting participants' reaction time (RT). A statistically significant relation was found.

However, no significant association with ER was found, $F(4, 355) = .245$, $p > .05$, $R^2 = .003$ (cf. Figure 9).

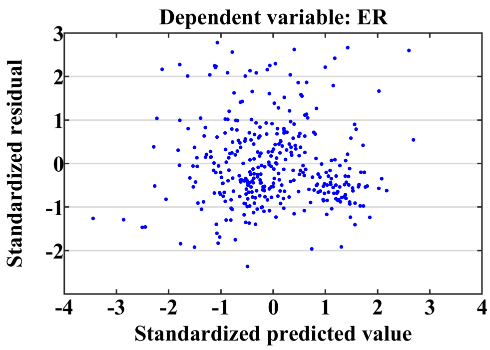

Figure 9: Multiple linear regression of heart rate variability including average heart rate (meanHR), total variability (SDNN), RMSSD and pNN50 predicting participants' error rate (ER). No statistically significant association was found.

Conclusion

Results of this pre-study validate several aspects of the chosen methods. Evidence for attention switch costs were found and a significant increase of complexity of irrelevant information suppression can be observed using the three congruency categories. Furthermore, benefit of spatial hearing processing is reflected in the present results. Observations from this study are comparable to previous work (cf. Oberem et al. [6] and Loh et al. [3]). The extended task including four possibilities to answer is therefore suitable to examine intentional switch of auditory selective attention. Interestingly, an inverse tendency in reaction time compared to error rate can be observed for congruency even though RT was not significant, which might be explainable by a speed-accuracy trade off due to increasing complexity to suppress irrelevant information. This phenomen should be further examined in the upcoming study. The missing noise effect in this study might be caused by the low noise level which might not bother adults. Noise level should be increased in further studies.

Considering heart rate variability, effects were only found for transition and target-distractor-position combination. This leads to the assumption that heart rate variability is only connected to orientation processes in spatial setup. High variances in the heart rate variability parameters were limiting the interpretation of present results and might lead to missing significances. In further evaluation, results should be normalized to individual baselines. This also means that resting heart rate measurements should be considered in the test procedure.

From the multiple linear regression results, it can be assumed that heart rate variability is not directly connected to information processing abilities which would be otherwise reflected in the association with error rate. However, there seems to be a link between heart rate variability and executive functions in cognitive processes which mostly require time to be resolved.

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