PhD Pilot Project #1: Sound Impairment Effect on Cognitive Skill Performance

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Abstract

Autism Spectrum Condition (ASC) is a life-long diagnosis, which has a subset of individualized characteristics consisting of hyper-, seeking- and/or hypo-reactivity to sensory inputs or unusual interests (APA, 2013). These sensitivities are evident in both *environmental* (e.g. apparent response to specific sounds, visual fascination with lights or movements) and *physiological* domains (e.g. anxiety, respiration or euthermia). As part of a larger PhD Research Project (SensorAble), this pilot study proposes that autistic individuals who exhibit greater distractibility and reduced focus/attention resulting stimuli may benefit from interventions that alter, redirect and/or attenuate stimuli. In particular, Irrelevant-Sound Effect (ISE) consisting of un-targeted and/or modulated sonics cause greater disruption of performance of simultaneous and visual simple tasks compared to baseline ISE that are merely directed. Using gold-standard Stroop experiments, data collected among neurotypical (NT) and ASC individuals at baseline and at various ISE modes result in greater reaction time (RT) improvements among ASC than NT participants. In this study, which focuses on aural distractibility only, data supports that signal processing may provide a gateway to enhancing focus and attention while reduce distractibility and anxiety in other domains.

Keywords: Autism Spectrum Condition, Attention, Focus, Distractibility, Anxiety, Digital Signal Processing, Selective Attention Theory, Irrelevant-Sound Effect, Stroop Test

1. Introduction

Individuals with Autism Spectrum Condition (ASC) often exhibit persistent deficits in social communication and interaction across multiple contexts (APA, 2013). An additional hallmark, however, which forms the focus of this pilot study, includes restricted, repetitive patterns of behavior interests (RRBI). Importantly, RRBIs includes hyper-, seeking- and/or hypo-reactivity to sensory inputs co-joined with attainably unusual interests in sensory aspects of the environment and physiological responses to visuals, lights, textures, smells, touch and—as it related to this paper—sounds.

This particular pilot focuses on sonic stimuli to establish if impairment effects on cognitive skill performance exist when distracting sounds are detected and processed by autistic adults. These stimuli are purposefully irrelevant and unfocused when compared to the environment in which they are experienced.

This study further aspires extracting data not only designating differential distraction among stimuli experienced by ASC and neurotypical individuals (NTs); it aims also to compare adjustments to targeted and untargeted stimuli that may result in improved reaction times (RT). Ultimately, these could generalize to scholastic or work-related improvements experienced by a larger autistic community.

1.1 Selective Attention Theory, Stroop Test and Irrelevant-Sound Effect

Selective Attention Theory (SAT) suggests that *colour* recognition, as opposed to *reading* a word, requires more attention (Lamers et al., 2010). SAT proposes that typical cognitive functioning requires increased attentional effort for nominal brain functionality. As such, colour translations take longer to accomplish than term analysis due to cognitive processes (McMahon, 2013).

Ambiguity exists, however, relating to the *causal nature* of observations. Researchers contend that cognitive mismatches occur from either distractibility or neuronal wiring relating to attentional obstructions.

Historically, the gold standard utilised when studying attentional interference is the Stroop Test, where reaction times (RT) are typically stunted due to cognitive encoding and misalliance (Stroop, 1935). In addition to RT presentations, deficiencies persist across task completion and accuracy domains. Importantly, these characteristics occur predictably and absent additional and/or distracting stimuli.

All of this notwithstanding, this pilot study *proposes the inclusion of additional and extraneous stimuli*—by way of Irrelevant-Sound Effect (ISE)—demonstrating an expanded RT between ASC and NT individuals.

Specifically, ISE involves the impairment of immediate serial recall of visually presented lists when irrelevant auditory stimuli are offered either during encoding or retention processes (Buchner et al., 2008). Historically, these experiments employed participants who memorized lists of visually presented digits in silence and/or while ignoring distracting sounds. Critically, these distractions emanated both (i) from *in front* of the participants, and (ii) from the direction in which their *attention was oriented*.

Buchner discovered that while distractor stimuli impaired recall performance, the greatest impairments exist when sonics were directionally and adjacently located near front-facing visual targets. This makes explicit the significance of attentional processing in determining the size of the distracting effect of auditory stimuli on visual stimuli recall (Ibid, 2008).

1.2 Pilot Purpose, Research Question, Hypotheses and Follow-on Study Aspirations

Because ours is a world in which distracting and stimulating environments are the norm, this study aspires advancing understanding and interventions that may improve attention, focus and anxiety. While the project designates genetic and causal underpinnings of autistic distractibility and attention to erstwhile and qualified neuroscientific study, this particular set of experiments are the first step toward developing mediations that may reduce or eliminate the effect of distracting aural stimuli through wearable devices.

Therefore, this pilot is framed by two distinct, but inter-related questions:

- Q1.: To what extent might spatially focused versus un-focused auditory distractions result in increased attention and visual task performance?
- Q2.: How can signal processing technologies be designed, adapted and evaluated to produce acceptable, accessible and flexible supports and outcomes that are responsive to an autistic individual's unique attentional and sensory needs?

Testable pilot predictions suggest that: (i) NT participants will have greater performance on Stroop Test (lower RTs related to correct answers) when audio distractors are presented in a targeted, spatially located monophonic position; (ii) NT participants will exhibit lesser performance (longer RTs) when audio distractors are presented in a stereophonic, un-targeted spatial field or when modulated across a stereo sound-field; and (iii) ASC participants will exhibit longer RTs in both scenarios above, but with marked improvement (by percentage) in the margin between monophonic and stereophonic, un-targeted and modulated distractions.

Prediction number three (iii) above forms the foundation of proposed follow-on studies in which corrected, filtered and targeted sonic distractions are modified in a wearable form-factor that may help diminish, refocus and/or squelch distracting stimuli. Further, and once heterogeneity issues of *all distracting stimuli types* are catalogued, the wearable aims to apply sensing technology to predict, notify/alert, coach and potentially ameliorate disrupting events in *other domains* (e.g. environmental sight, physiological disruptors as well as auditory incitements).

The experimental hypothesis is defined as follows:

- ISE that are untargeted/modulated cause *greater* distractibility on task performance compared to baseline than ISE that are targeted.
- A null hypothesis states there is no effect of degree of targeting of ISE on performance.

The rest of this paper is organized as follows: in Section 2 a review of the study's variables and measurement definitions are presented along with sampling strategy, research design, data collection procedure and statistical analysis. Section 3 provides resulting empirical data and compares this to a previous pilot effort with implications that improve this current study. These data illustrate that smaller ASC participant size has a likely effect on proving the null hypothesis—suggesting that increased sample size may improve the observed power on the sphericity assumed and answer both research questions.

In Section 4, study implications on the overarching PhD effort are explored along with limitations within this particular paper. Section 5 concludes by recounting the pilot project achievements.

2. Methods

This pilot (and the preceding initial study) was created during a 3-week, summer-session doctoral training module (University College London, Centre for

Doctoral Education: FIOER401Z - Intro to Experiment Design); hence, the time allotment was condensed.

2.1 Variable definitions and measurements

This study leverages four *independent* (IV) and three *dependent variables* (DV) outlined in Table 1.

Table 1: Independent & Dependent Variable Descriptions

Variable	Description
IV 1: ISE of spatially *targeted* .wav audio file streams	Monophonic (equal left/right channel distribution/placement) of ISE distractions (e.g.: white noise, oscillator sweeps, cacophony, etc.).
IV 2: ISE of spatially *diffuse* (un-targeted) .wav files	Stereophonic (unequal left/right channel distribution/placement) of ISE distractions (e.g.: white noise, oscillator sweeps, cacophony, etc.).
IV 3: ISE of spatially *modulated* (un-targeted) .wav files	Monophonic (unequal left/right channel distribution/placement) of ISE distractions (e.g.: white noise, oscillator sweeps, cacophony, etc.) that are bilaterally and repetitively panned across a stereophonic plane.
IV 4: Control .wav file	Consisting of silence.
DV 1: Stoop Effect Test One (STO, 2005)	20 Questions where participants select the correct colour of a word (using a computer mouse). This substantiates that participants respond accurately to congruent trials (when words match colour). Further, reading a word is automatic for many participants and most have difficulty completing responses when facing incongruence. Tests are repeated at baseline and ISE.
DV 2: Interactive Stroop Effect Experiment (ISE, 2019)	Requires participants to speak *colours* of a word, not what the word *spells*. Participants read 25 words quickly and click on the "Finish" button at baseline. The study continues with a second list of 25 words with ISE.
DV 3: Open Cognition Lab Test (OCL, 1999).	Participants read 85 words by selecting text colour using one of five computer keys (e.g. R-red, G-green, B-blue, O-orange and P-purple). Median RTs are computed for both congruent and non-congruent pairs at baseline and ISE.
N.B.: IV #1—#4 are presented in identical formats (e.g. 44.1 kHz samples of 16-bit word length), audio recordings not exceeding -10 dBu amplitude, and all were performed over semi-open, circumaural headphones with 30mm drivers and a frequency response of 15Hz-25kHz at 55 ohms impedance. Each recording was randomized, and durations did not exceed ten minutes—twice the anticipated length of each DV listed.	

2.2 Sampling strategy

Because of doctoral training module time constraints, a *convenience/opportunity sampling strategy* was utilised leveraging participants (N = 15) that were most easily resourced and available. Ordinarily, recruitment of autistic individuals utilizing a *stratified random sampling* strategy would be employed to maintain heterogenous selection. Statistical data was be based upon randomization and anonymizing participants. Crosstabulation data for diagnosis, age, gender, ethnicity, handedness and education appear in Table 2.

2.3 Research design

The study employed a repeated measure/split project design utilising a 3x4 matrix (Table 3) with randomization and counterbalancing of test question order and implementation to prevent against practice effects, fatigue and boredom.

Table 2: Case Processing Summary

N = 15		Male	Female
Diagnoses	ASC	2	2
	NT	6	5
Age	14 years and below	0	0
	15—20 years	1	1
	21—35 years	0	0
	36—56 years	5	3
	57—79 year	0	3
	80 years and above	1	1
Gender		7	8
Ethnicity	White	6	8
	Other	1	0
Handedness	Left	1	0
	Right	6	8
Education	Elementary	1	0
	High school	0	1
	Some college	1	1
	Undergraduate Degree	3	4
	Graduate school degree	2	1
	Unknown	0	1

2.4 Materials utilised

A variety of professional-grade, laboratory-specific apparatus was utilised to conduct experiments. The hardware and software systems are listed in Table 5.

Table 3: Research Design Matrix

Split Project Design (3x4)				
	IV 1. Mono ISE (targeted)	IV 2. Stereo ISE (non-targeted)	IV 3. Mono & modulated ISE (non-targeted & moving)	IV 4. Placebo no sound effect (silence)
Mouse/pointing device test	DV 1	DV 1	DV 1	DV 1
Spoken/articulated tests	DV 2	DV 2	DV 2	DV 2
Keyboard tests	DV 3	DV 3	DV 3	DV 3

2.5 Data Collection Procedure

The study's sole investigator is a PhD student who is responsible for all recruitment, ethical reinforcement, research and testing administration, experiment design, data collection and statistical analysis. Participant information and consent forms were included and obtained along with Experimental Study Description Sheets in alignment with UCL's Data Protection and Ethics Departments. All GDPR processes and privacy compliancy was maintained with data retention plans consistent across all participants.

Table 4: Updated SPSS Output - ISEs Less Baseline Scores

Within-Subjects Factors

Measure: MEASURE_1

ISE_Condition	Dependent Variable
1	MAToBasline
2	SAToBaseline
3	MMAToBaseline

Descriptive Statistics

	Mean	Std. Deviation	N
Mono ISE to Baseline	-37.3383	103.14485	15
Stereo ISE to Baseline	13.1880	133.62765	15
Mono Modulated ISE to Baseline	44.9596	121.64971	15

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
ISE_Condition	Pillai's Trace	.172	1.349[b]	2.000	13.000	.294	.172	2.698	.240
	Wilks' Lambda	.828	1.349[b]	2.000	13.000	.294	.172	2.698	.240
	Hotelling's Trace	.208	1.349[b]	2.000	13.000	.294	.172	2.698	.240
	Roy's Largest Root	.208	1.349[b]	2.000	13.000	.294	.172	2.698	.240

a. Design: Intercept
Within Subjects Design: ISE_Condition

b. Exact statistic

c. Computed using alpha =

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
ISE_Condition	Sphericity Assumed	51676.464	2	25838.232	1.481	.245	.096	2.963	.289
	Greenhouse-Geisser	51676.464	1.882	27457.859	1.481	.246	.096	2.788	.280
	Huynh-Feldt	51676.464	2.000	25838.232	1.481	.245	.096	2.963	.289
	Lower-bound	51676.464	1.000	51676.464	1.481	.244	.096	1.481	.206
Error(ISE_Condition)	Sphericity Assumed	488363.431	28	17441.551					
	Greenhouse-Geisser	488363.431	26.348	18534.846					
	Huynh-Feldt	488363.431	28.000	17441.551					
	Lower-bound	488363.431	14.000	34883.102					

a. Computed using alpha =

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	ISE_Condition	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
ISE_Condition	Linear	50797.118	1	50797.118	2.556	.132	.154	2.556	.319
	Quadratic	879.346	1	879.346	.059	.812	.004	.059	.056
Error(ISE_Condition)	Linear	278201.810	14	19871.558					
	Quadratic	210161.621	14	15011.544					

a. Computed using alpha =

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2165.129	1	2165.129	.257	.620	.018	.257	.076
Error	117750.628	14	8410.759					

a. Computed using alpha =

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Epsilon[b] Huynh-Feldt	Epsilon[b] Lower-bound
ISE_Condition	.937	.842	2	.657	.941	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: ISE_Condition

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

2.6 Statistical analysis

IBM SPSS was utilized to analyse all data. Three tests (e.g.: Stroop Effect Test, Interactive Stroop Effect Experiment and Open Cognition Lab) were conducted using four independent variables (IV) levels (e.g. spatially targeted monophonic, spatially diffuse un-targeted stereophonic, spatially diffuse un-targeted modulated monophonic, and a baseline no-audio/silent audio streams). These yielded 12 data points per participant, with IV medians computed for comparison.

A Generalized Linear Model analyses using Repeated Measures Mode was conducted yielding Descriptive Statistics, Multivariate Tests, Mauchly's Test of Sphericity and Tests Within-Subjects Effects and Contrasts and Tests Between-Subjects Effects. These appear in Table 4.

3. Results

Both one-way, within-subjects and between-subjects repeated measured analyses of variance (ANOVA) were conducted to evaluate the null hypothesis such that there is no effect of degree of targeting ISE on multiple Stroop test performance. These were measured using four ISE levels (e.g. baseline/silence, monophonic, stereophonic and modulated monophonic) in both ASC and NT individuals ($N = 15$). The results of the ANOVA indicated an insignificant ISE effect, Wilks' Lambda = 0.83, [F (2,13) = 1.349, p = 0.294] during the first implementation of the pilot.

At the suggestion of Professor Tolmie, an updated pilot ensued in which three values for each participant were calculated by deriving four ISE totals and then subtracting the baseline score from each. This provided three (not four) ISE Conditional Totals per participant for further analysis.

In the premiere pilot version, RT results yielded an ordering for fastest to slowest mean: (i) Mono, (ii) Modulated Mono and (iii) Stereo ISE.

However, the updated pilot resulted in a re-ordering of RTs, hence a shift occurred in the second and third positions; such that: (i) Mono, (ii) Stereo and (iii) Mono Modulated ISEs. Moreover, a *slight increase* in the Wilks' Lambda (0.01) was accompanied by *notable increases* in F (up 0.441) and decrease in p (0.172). Observed Power in the update version (0.240) *increased* 0.108 from the previous pilot results.

Overall, an effect size on the test of within-subjects effects increased to nearly 0.1 (.096) compared to 0.060 from the previous pilot attempt. Critically, the observed power on the sphericity assumed resulted in a 0.289 value compared to the initial pilot's observed power of 0.228. While this does not resemble an ideal target value (e.g. ~0.80), this upward trend *may* eventually approach the desired and more robust value provided a larger sample size is achieved.

3.1 Previous reflections

While targeted (e.g. monophonic) ISE produced the fastest mean response time across all participants regardless of pilot version, the statistical significance of the data yielded a value considerably greater than 0.05 thus rendering the null hypothesis as valid.

After discarding the first two Stroop Tests and then analysing only data from the Open Cognition Lab experiment, a similar rejection of the experimental hypothesis exists in favour of the null hypothesis. Specifically, the resulting ANOVA of *only* OCL data indicates insignificant ISE effect, Wilks' Lambda = .88, [F (3,12) = 0.556, p = .654].

Table 5: Experimental Materials

Hardware	
Computer #1: Testing Laptop	Apple MacBook Air 11-inch, Mid 2012. Processor @ 1.7 GHz Intel Core i5 Processor. Memory @ 4 GB 1600 MHz DDR3. Graphics @ Intel HD Graphics 4000 1536 MB.
Testing Audio Playback System	iPhone XR Model MT3M2LL/A. iOS 12.3.1 @ 64 GB.
Transducers	Audio-Technica ATH-M50x closed-back Circumaural headphones with self-adjusting Headband. 15Hz-25kHz frequency range. 200mW maximum input power. Driver Size: 30mm. Impedance: 55 ohms.
Computer #2: Data Recording Scoring & Analysis	Apple MacBook Air 11-inch, Mid 2012. Processor @ 1.7 GHz Intel Core i5 Processor. Memory @ 4 GB 1600 MHz DDR3. Graphics @ Intel HD Graphics 4000 1536 MB.
Software	
Stroop Tests	• Online Stroop Test (Reading) @ http://www.onlinestrooptest.com/stroop_effect_test.php • Interactive Stroop Effect Experiment @ https://faculty.washington.edu/chudler/words.html#seffect • 3. Open Cognition Lab Stroop Test @ http://opencoglab.org/stroop/
Audio Playback	iTunes (Ver. 10.6.3)
Data Analytics	MS-Excel (Ver. 16.33), Apple Numbers (Ver. 6.2.1), IBM SPSS (Ver. 25)

4. Discussion

By making distracting sonic stimuli spatially relevant to the task at hand, this study data indicates that autistic individuals may perform visually cognitive assignments with greater speed, ease and comfort. Specifically, adjusting spatially diffuse audio—vis à vis digital signal processing—may render modulated monophonic and stereophonic irrelevant sound effects (ISE) more manageable. Faster RT are achieved by harmonizing monophonic ISE with visual stimuli, even when optical inducements are complex (e.g. Stroop tests). While ASC RT generally lagged neurotypical performance, autistic improvements exceed NT with interventions.

While the conclusion appears positive in answering the research questions, the results are not without flaws. Most notably, the sample size fails to support the null hypotheses; moreover, the adaptability of the research to a larger neurodiverse population is hindered by significantly low power performance.

The research, therefore, points to a replication of the experiments with a larger sample size and ideally without time constraints in order to minimize any errors.

Given the potential to increase statistical power and hypotheses improvement, the next step naturally extends research *beyond auditory* stimuli and includes *irrelevant optical stimuli*. Increasing scope modality may permit greater impact to neurodiverse populations who experience multimodal sensory distractions, attentional and anxiety issues.

5. Conclusion

The study design is appropriate to answer the research questions and the aim of this project. Data builds upon existing research related to irrelevant sound effect, and further provide that *localization* of sound may be helpful when *harmonized* with visual tasks—particularly when these activities are: (i) not trivial and/or difficult to perform, (ii) require greater attention; or, (iii) are anxiety producing.

While consistent within its aim, this study is associated with the beginning stages of a PhD research project. Due in large part to the small sample size, results may support that while neurotypical individuals are better able to avoid distraction, interventional support may be more meaningful to autistic adults when presented with irrelevant-sound effect, regardless of the existence of spatially diffuse aural locale.

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