

Exploring Soundscaping Options for the Cognitive Environments in an Open- plan Office

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The background is a solid light purple color. On the left side, there are five horizontal lines of varying lengths, all in a slightly darker shade of purple. On the right side, there is a large, dark blue circle that overlaps the edge of the frame.

► Sound

The number 1 complaint in workplaces



Noisy Workplaces- challenges

- Compromised concentration
- Disturbed
- Distracted
- Psychological negativity
- Decreased performance



Concentration in a Noisy Workplace- sound solutions

- White Noise – masks background noise
- Pink Noise - masks background noise with lower intensity as frequency increases
- Music – good for starting work flow
- Soundscaping – nature sounds- also with imaging
- Silence – chosen for test taking or deep concentration

Research Gap- What is the solution for noisy workplaces?

- Top complaint in offices
- Many workplaces are open plan and struggle with noise and noise variance
- Only a few studies comparing different types of sound on cognitive tasks performance
- Inconclusive results for best noise solution for cognitive tasks



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► Methodology

Study Design

Protocol

- Repeated measures design
- 30 min x 4 days

Participants

- Sixteen male and female (n=16)
- Office workers



No
Noise



White Noise
&
Office Noise



Office
Noise



Spring Water
&
Office Noise



Week One

- Blood pressure
- Pulse oximeter
- Cognitive function tests
- Survey



Week Two

- Empatica E4
- Cognitive function tests
- Survey



Acoustic Conditions

Temperature	22-24°C
Humidity	41-49%
CO ₂	510-730 ppm



Participant



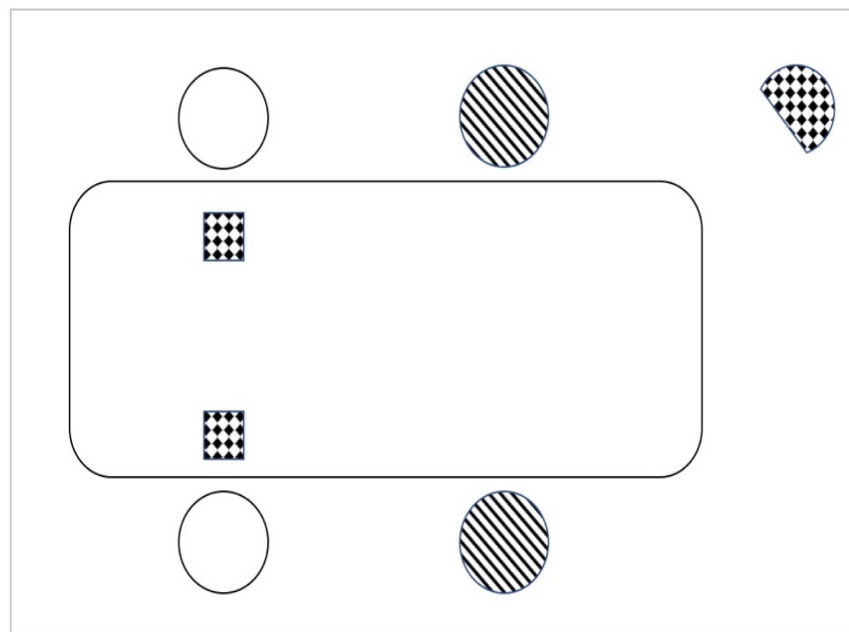
Researcher



Acoustic Condition Speaker (Ceiling)



Office Noise Speaker



Cognitive Function Tests



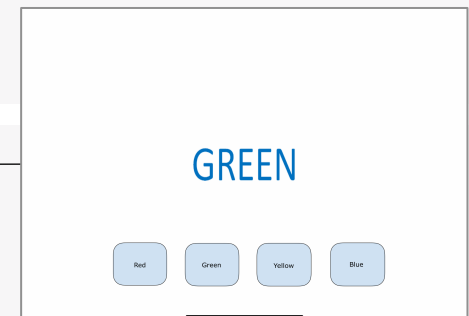
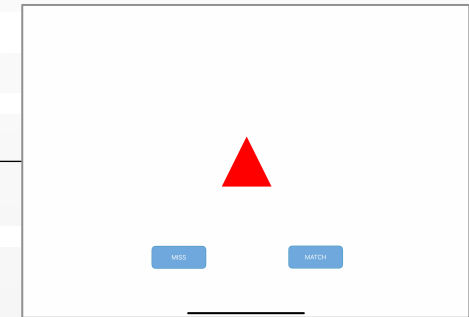
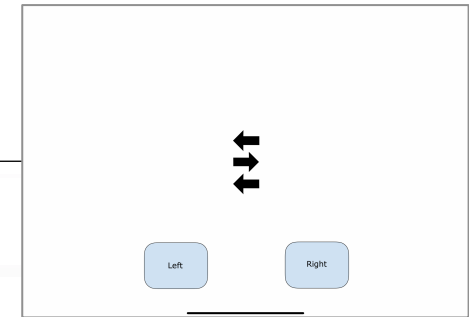
Flanker



Shape N-back



Stroop



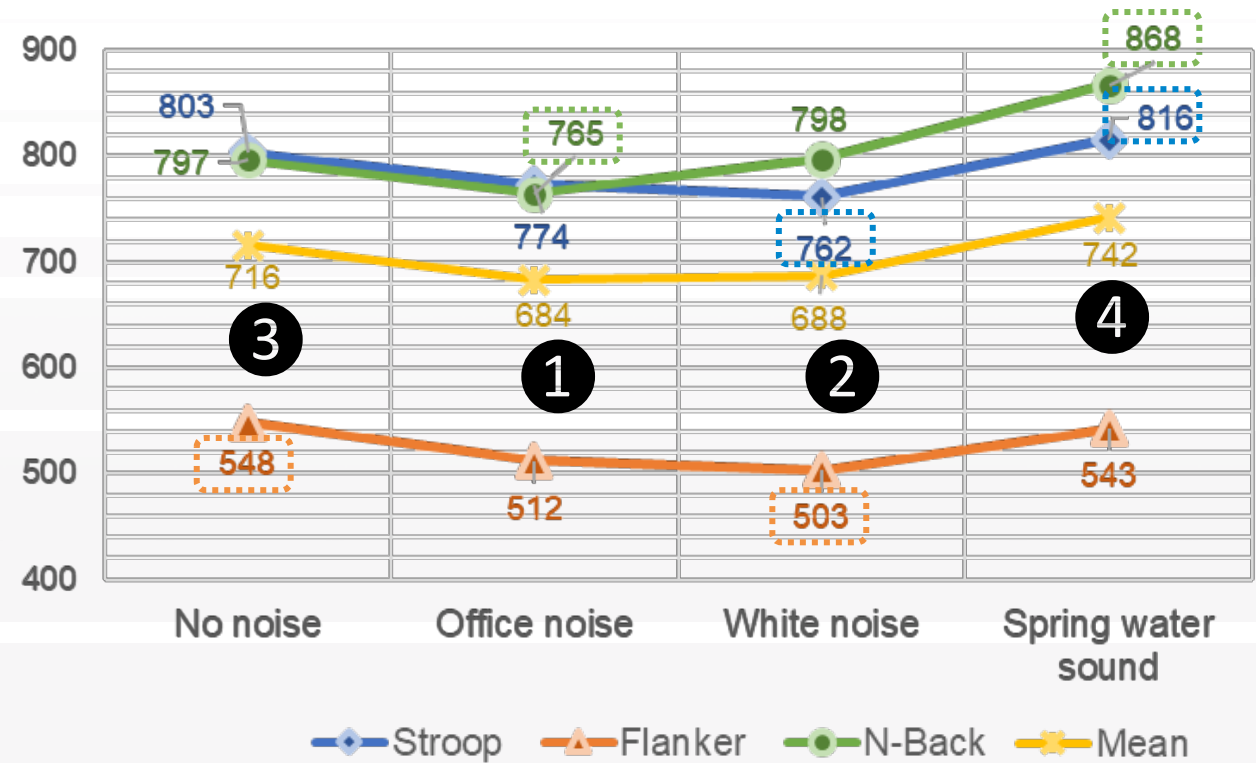


► Findings

Subtitle

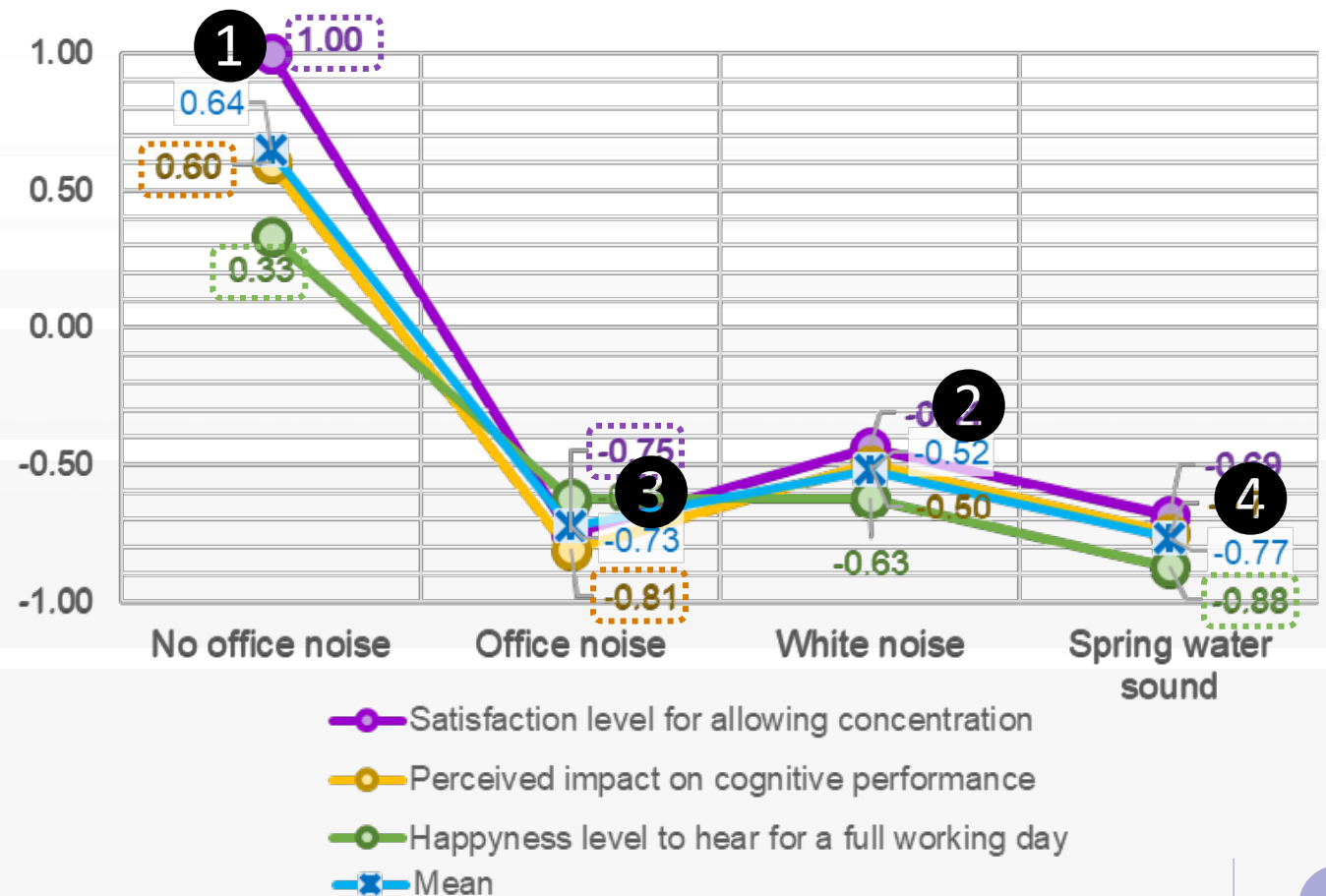
COGNITIVE PERFORMANCE TEST RESULTS : Descriptive Analysis

	Best Performance	Poorest Performance
Stroop	White Noise (Office Noise)	Spring Water Sound
Flanker	White Noise	No Noise (Spring Water)
N-Back	Office Noise	Spring Water Sound



SATISFACTION/PREFERENCE SURVEY RESULTS : Descriptive Analysis

	Highest	Lowest
Satisfaction	No Noise	Office Noise (Spring Water)
Impact	No Noise	Office Noise (Spring Water)
Happiness	No Noise	Spring Water



PHYSIOLOGICAL RESPONSES : Pulse Oximeter

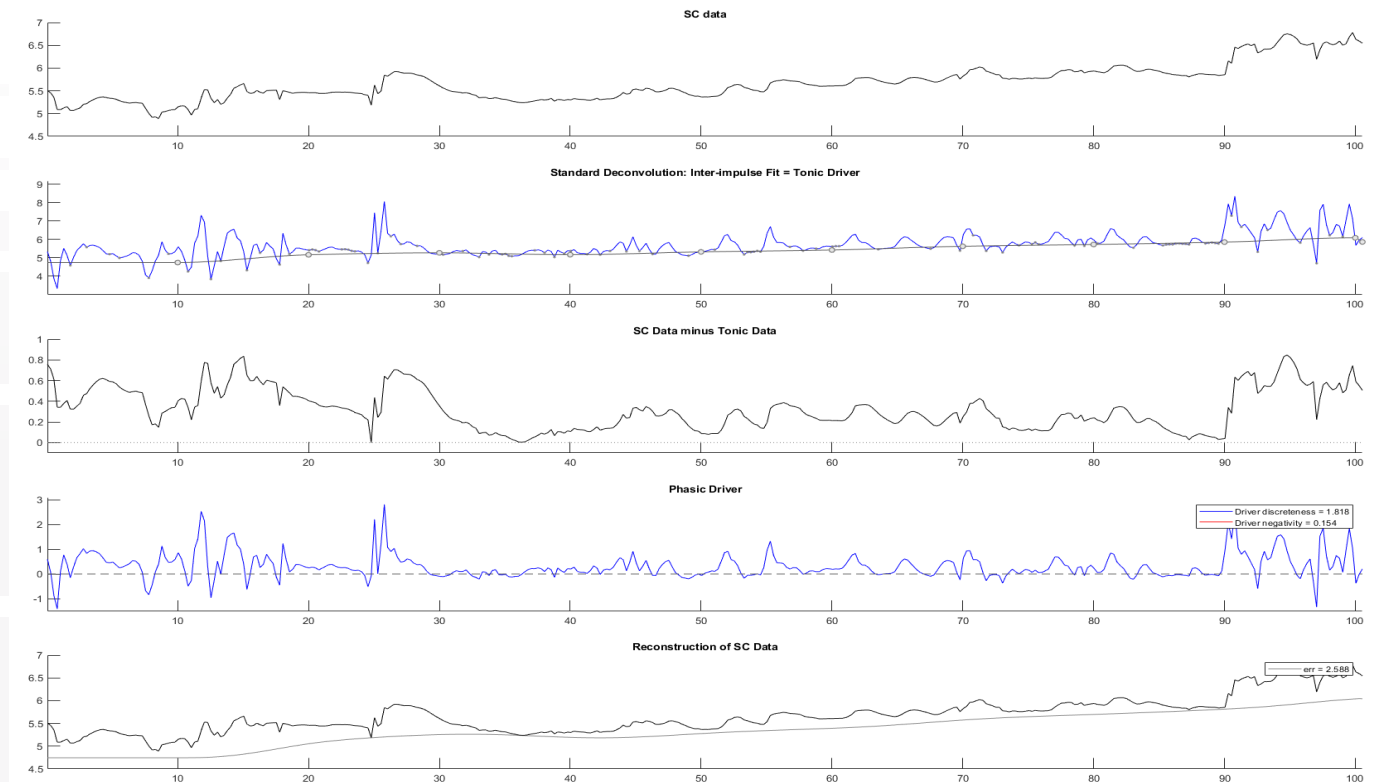
- Heart rate, respiratory rate, perfusion index, O₂ saturation, & pleth variability index
- Stable physiological responses across the different sound conditions
- Acute noise exposure did not impact upon these responses.

	Heart Rate				Respiratory Rate				Perfusion Index				O ₂ Saturation				Pleth Variability Index			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
P1	61	61	62	61	11	11	13	11	1.7	2.3	3.3	4.2	100	98	99	99	20	15	19	23
P2	54	54	58	54	15	14	11	15	0.55	0.6	0.3 ₁	0.62	100	99	100	99	0.5 ₅	0.6	--	19
P3	90	87	84	86	16	17	16	17	9.9	18	13	12	98	98	98	98	18	12	15	20
P4	x	66	71	63	x	13	11	10	x	6.3	6.6	3.7	x	97	96	97		32	30	29
P5	86	80	83	86	17	13	13	18	14	11	5.8	1.3	97	98	99	100	24	28	26	23
P6	71	63	60	65	15	16	15	16	2	1.3	4.3	5.1	100	100	99	99	19	20	19	16
P7	80	74	88	75	17	17	18	18	3.7	2	1.7	4.5	100	99	99	100	21	25	28	24
P8	81	76	77	83	16	17	18	16	3.6	6.2	2.3	6.4	98	98	99	99	28	26	23	31

S: Sound condition P: Participant

PHYSIOLOGICAL RESPONSES : Electrodermal Activity Sensor

- Skin conductance responses (SCRs) extracted.
- SCRs: phasic changes in electrical conductivity of skin measured in microsiemens μS .
- SCR in the analysis of EDA: the activation of sudomotor nerves is related to SCR. The SCR amplitude: an indicator of sympathetic activity.



PHYSIOLOGICAL RESPONSES

Electrodermal Activity Sensor

- The majority of participants: the highest total number of Skin Conductance Responses (SCRs) from Spring Water Sound.
- Including Participant 15 who exhibited SCRs only under the spring water condition.

	SCR Min				SCR Max				Total number of SCRs			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
P9	0.01	0.01	0.01	0.01	0.58	0.76	0.78	0.55	223.0	228.0	235.0	207.0
P10	0.01	0.01	0.01	0.01	0.43	0.65	0.40	1.59	168.0	175.0	185.0	226.0
P11	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.72	10.0	18.0	21.0	223.0
P12	0.01	0.01	0.01	0.01	0.05	0.02	0.10	0.09	22.0	3.00	30.0	45.0
P13	0.01	0.01	0.01	0.01	0.11	0.02	0.04	0.02	180.0	2.0	5.0	14.0
P14	0.01	0.01	0.01	0.01	0.09	0.06	0.07	0.16	36.0	38.0	72.0	110.0
P15	--	--	--	0.01	--	--	--	0.07	0	0	0	128.0
P16	0.01	0.01	0.01	0.01	0.48	1.07	0.32	0.51	168.0	128.0	89.0	136.0

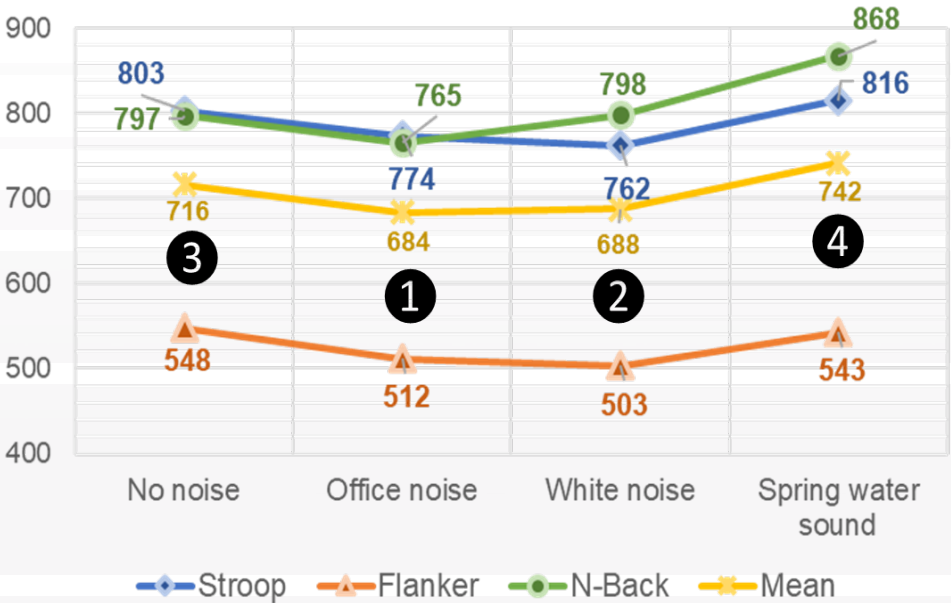
S: Sound condition P: Participant

PATTERNS OBSERVED

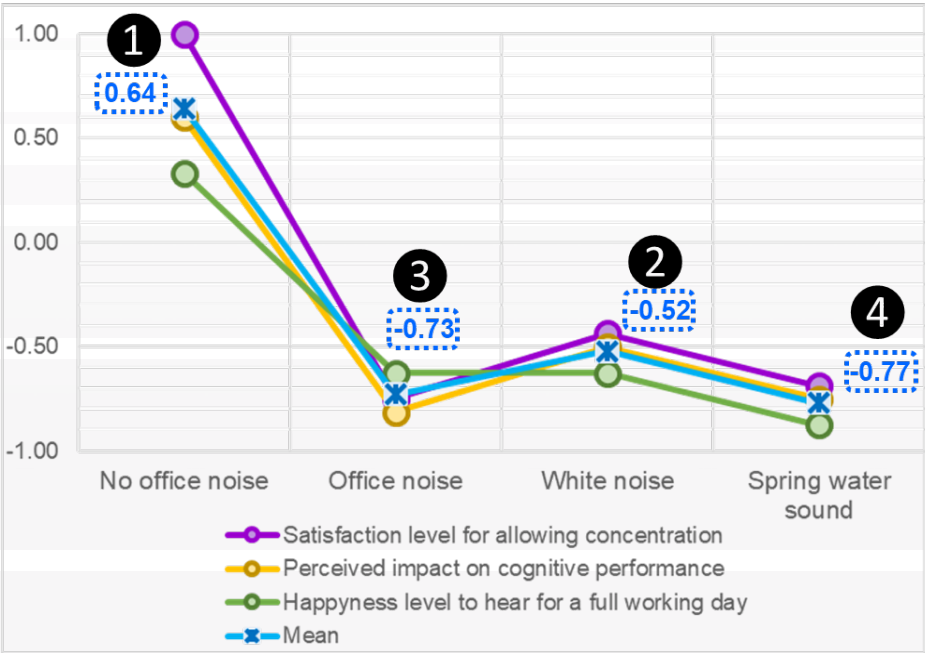
	Total number of SCRs			
	S1	S2	S3	S4
P9	223.0	228.0	235.0	207.0
P10	168.0	175.0	185.0	226.0
P11	10.0	18.0	21.0	223.0
P12	22.0	3.0	30.0	45.0
P13	180.0	2.0	5.0	14.0
P14	36.0	38.0	72.0	110.0
P15	0	0	0	128.0
P16	168.0	128.0	89.0	136.0

S: Sound condition P: Participant

Total Number of SCRs



Cognitive Performance Test



Satisfaction/Preference Ranking



ANALYSIS OF AVARIANCE :Group Comparisons

Satisfaction level with no noise condition: statistically significantly higher than the rest conditions in allowing them to concentrate better

Satisfaction level with noise/sound allowing concentration

	No noise	White noise		No noise	Office noise		No noise	Spring water
Mean	1	-0.4375		1	-0.75		1	-0.6875
Variance	3.14286	1.0625		3.142857	1.533333		3.142857	1.295833
Observations	15	16		15	16		15	16
Hypothesized Mean Difference	0			0			0	
df	22			25			24	
t Stat	2.73658			3.166897			3.130839	
P(T<=t) one-tail	0.00602			0.002015			0.002269	
t Critical one-tail	1.71714			1.708141			1.710882	
P(T<=t) two-tail	0.01205*			0.004029*			0.004538*	
t Critical two-tail	2.07387			2.059539			2.063899	

* Significant at the level of 0.05 ($p < 0.05$)

ANALYSIS OF AVARIANCE :Group Comparisons

Perceived impact level of no noise condition: statistically significantly higher than the rest conditions in completing cognitive performance tasks

Impact level of noise/sound on cognitive function tasks

	No noise	White noise		No noise	Office noise		No noise	Spring water
Mean	0.6	-0.5		0.6	-0.8125		0.6	-0.75
Variance	2.25714	0.66667		2.257143	0.5625		2.257143	0.866667
Observations	15	16		15	16		15	16
Hypothesized Mean Difference	0			0			0	
df	21			20			23	
t Stat	2.50946			3.278397			2.984252	
P(T<=t) one-tail	0.01018			0.001879			0.003315	
t Critical one-tail	1.72074			1.724718			1.713872	
P(T<=t) two-tail	0.02036*			0.003758*			0.006631*	
t Critical two-tail	2.07961			2.085963			2.068658	

* Significant at the level of 0.05 ($p < 0.05$)

IMPLICATIONS

Discrepancy between the Cognitive Performance Test results and the Satisfaction/ Preference ranking:

- Psychologically preferred complete silence for such a highly focused task as a cognitive test
- A certain level of sound/ noise might actually have helped with mental alertness
- Some studies supporting the relationship between auditory stimuli and performance
- Noise annoyance threshold vs. cognitive performance task reduction threshold
- Another big question: longer-term impact of spring water sound for cognitive performance vs. stress reduction/ restoration

Consistency between the Cognitive Performance Test results, the Satisfaction/ Preference ranking, and the total number of SCRs.

- Higher SCRs: more mental effort such as higher focus, attention, and stress.
- Highest amount of SCRs, poorest overall cognitive performance test, and least preferred to hear for a full working day from Spring Water Sound.
- Outdoor soundscape vs. indoor soundscape
- Full examination of various parameters affecting indoor soundscape necessary: shape & geometry of space; acoustic properties of materials; location, distance, and direction of sound masking system; quality and acoustic variation of masking sound; job functions and tasks of the workplace; types and duration of noise from co-workers; and number of people in the space

IMPLICATIONS

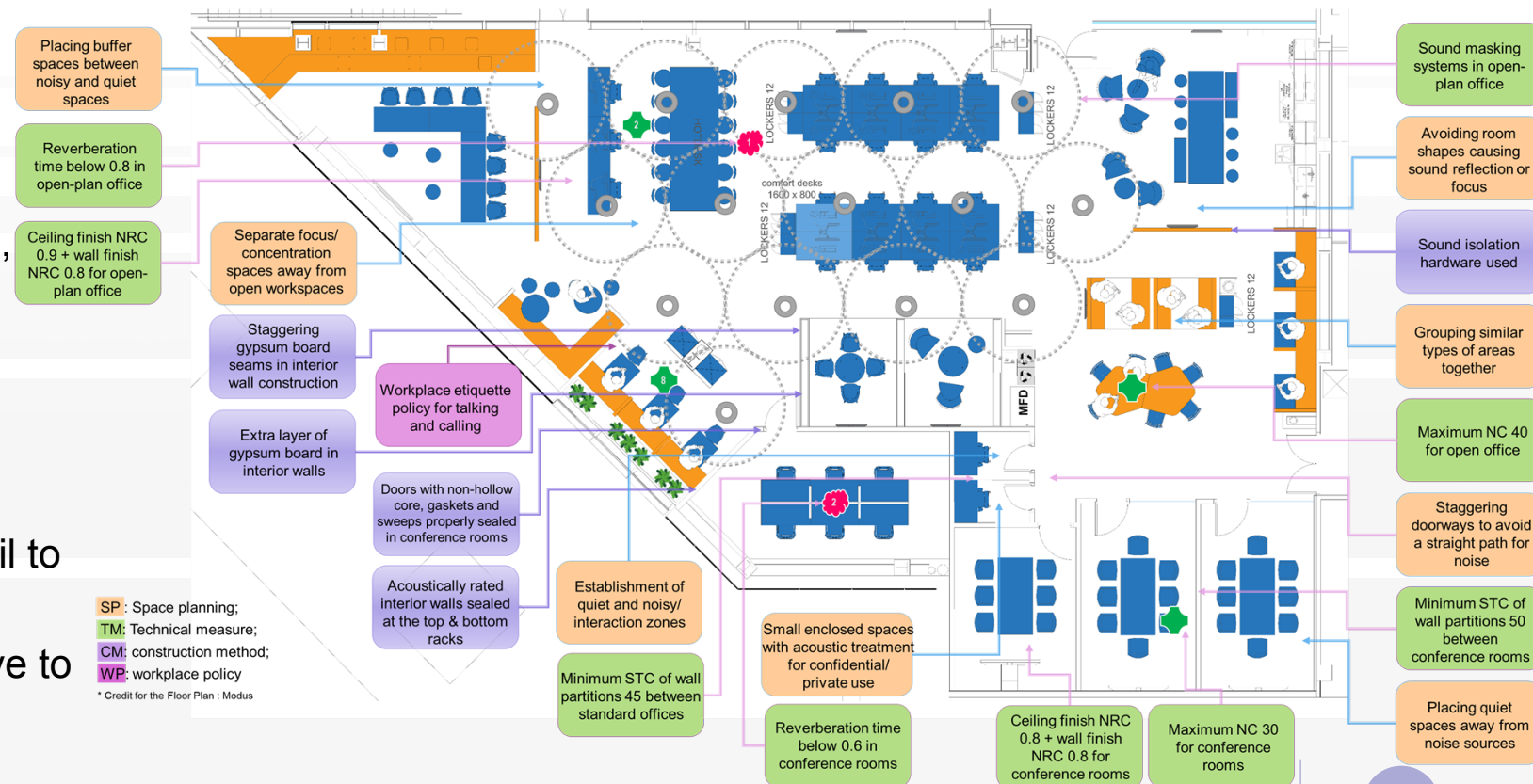
Statistically significant satisfaction/
preference for absence of noise for
cognitively intensive tasks

- Four comprehensive approaches to control noises in open-plan offices: spatial planning, technical measures, construction details, and workplace etiquette policy

Use of more sensitive devices for
physiological responses such as EDA
sensors

- Many cognitive performance tests fail to find statistical significance research
- Conventional sensors not so sensitive to detect subtle physiological changes under different noises/ sounds

Acoustic performance planning and assessment protocols



Conclusions & Future Research Recommendations

- Silence is preferred
- Noise and physiology
- Patterns occurred in outcomes
- Possible difference in personas
- Future research can extend results

THANK YOU

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