Supplementary Information

Predicting Calmness, Anxiety, and Depression using Wearable Sensors

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1 A snapshot of literature review for H2SEC framework

#	Title Of The Paper	Author	Year	Method/Sensor Used
Habituation				
1	Autonomic stability and transcendental meditation.	Orme-Johnson, D. W.	1973	GSR
2	Physiological Effects of Transcendental Meditation	Robert Keith Wallace	1970	EEG
3	An electroencephalographic study on the zen meditation (zazen)	Kasamatsu M.D., Hirai M.D.	1966	EEG
4	Deficient Amygdala Habituation to Threatening Stimuli in Borderline Personality Disorder Relates to Adverse Childhood Experiences	Marlena L., Stößel, et. al.,	2019	fMRI
5	Diminished EEG habituation to novel events effectively classifies Parkinson's patients	Cavanagh, et. al.,	2018	EEG
6	Electroencephalographic delta/alpha frequency activity differentiates psychotic disorders: a study of schizophrenia, bipolar disorder and methamphetamine-induced psychotic disorder	M Howells, et. al.,	2018	EEG
8	Clinical Significance of the Electrodermal Habituation Rate in Anxiety Disorders	A.D. Rabavilas	1989	EDR-HR
9	Habituation and Sensitization Processes in Depressive Disorders	Inmaculad, et. al.,	1999	DSM-III-R
10	More Meditation, Less Habituation? The Effect of Mindfulness Practice on the Acoustic Startle Reflex	Antonov, et. al.,	2015	Auditory Startle Response (ASR)
11	Habituation and cortisol dysregulation in depression	Reus, et. al.,	1985	SCM
Hypoactivity and hyperactivity				
12	Automated detection of conduct disorder and attention deficit hyperactivity disorder using decomposition and nonlinear techniques with EEG signals	Hui Tian Tor, et al.,	2021	EEG
13	Personality Traits Show Differential Relations With Anxiety And Depression In A Nonclinical Sample	Takahashi, et al.,	2015	BIS & BAS Theory (Gray's Reinforcement Sensitivity)
14	Hyperactivity within an extensive cortical distribution associated with excessive sensitivity in error processing	Yingying Tang, et al.,	2013	ERN, CRN

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	in unmedicated depression: A combined event-related potential and sLORETA study			
15	Mental state and electrodermal activity in depressed patients during acute suicidal period	Roland Straub, et al.,	2003	BDI, SCL, SFL, SCR, HS, HR
16	Frontal Brain Hypoactivity as a Biological Substrate of Anxiety in Patients with Panic Disorders	Jotaro Akiyoshi, et al.,	2003	State-Trait Anxiety Inventory; Near-infrared reflection spectroscopy
17	Habituation and Sensitization Processes in Depressive Disorders	Marta Miquel, et al.,	1999	DSM-III-R
18	Electrodermal activity (EDA) and suicidal behavior	M Wolfersdorf, et al.,	1996	EDA
19	Electrodermal hypoactivity in depression: psychobiological marker or differential psychophysiologic disposition?	Straub R, et al.,	1992	EDA
20	Clinical Significance of the Electrodermal Habituation Rate in Anxiety Disorders	A.D. Rabavilas	1989	EDR-HR
21	Electrodermal Activity Among Subtypes of Depression	Karl M. Williams, et al.,	1985	SC, EDA
Synchronization				
22	Oscillations of Heart Rate and Respiration Synchronize During Affective Visual Stimulation	Gaetano Valenza, et al.,	2012	ECG, RR
23	Effects of a cardiorespiratory synchronization training mobile application on heart rate variability and electroencephalography in healthy adults	I-MeiLin, et al.,	2018	ECG, EEG, HR, HRVB
24	The synchronization of electrodermal activity and heart rate and its relationship to energetic arousal: a time series approach	Joni Kettunen, et al.,	1998	EDA, HR, Arousal
25	A Pilot Study on the Effects of Heart Rate Variability Biofeedback in Patients with Depression and in Healthy Subjects	Martin Siepmann, et al.,	2008	HRV biofeedback
26	Effects of controlled breathing, mental activity and mental stress with or without verbalization on heart rate variability	Luciano Bernardi, et al.,	2000	RR, BP
27	The Impact of Resonance Frequency Breathing on Measures of Heart Rate Variability, Blood Pressure, and Mood	Patrick R. Steffen, et al.,	2017	HRVB ; PASAT
28	Cardiorespiratory synchronization during Zen meditation	Dirk Cysarz & Arndt Büssing, et al.,	2005	RSA, ECG
Experience – Valence				
29	Differences of sympathetic and parasympathetic modulation in major depression	Andy Schumann, et al.,	2017	HRV, BPV, BRS, SC, PUI
30	Parasympathetic predominance is a risk factor for future depression: A prospective cohort study	Hoyoung An, et al.,	2020	Linear regression analysis, HRV, GDS

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31	Parasympathetic nervous system activity predicts mood repair use and its effectiveness among adolescents with and without histories of major depression.	Yaroslavsky, I., et al.,	2016	RSA patterns
32	Heart rate variability during motor and cognitive tasks in females with major depressive disorder	Allison CarolNugent, et al.,	2011	HRV, PET, ECG, rCBF
33	Cardiac Vagal Control in Non-Medicated Depressed Women and Non-Depressed Controls: Impact of Depression Status, Lifetime Trauma History and Respiratory Factors	Jill M. Cyranowski, et al.,	2011	EKG, RR
34	Adjunct yoga therapy: Influence on heart rate variability in major depressive disorder - A randomized controlled trial	Kankan Gulati, et al.,	2021	HRV
35	Depression affects autonomic system of the body? Yes, it does!	Sheena Singla,, et al.,	2020	HRV
36	Effects of yoga on the autonomic nervous system, gamma-aminobutyric-acid, and allostasis in epilepsy, depression, and post-traumatic stress disorder	C.C. Streeter, et al.,	2012	HRV
37	Effects of stress, depression, and their interaction on heart rate, skin conductance, finger temperature, and respiratory rate: sympathetic-parasympathetic hypothesis of stress and depression	Hsiao-Pei Lin, et al.,	2011	PHR, PSC, PTEMP, PRESPR
38	Exploring valence bias as a metric for frontoamygdalar connectivity and depressive symptoms in childhood	Nathan M. Petro, et al.,	2021	Valence bias task, frontoamygladar connectivity
39	Autonomic reactivity to emotion: A marker of sub-clinical anxiety and depression symptoms?	Lucas De Zorzi, et al.,	2021	STAI-B & BDI scores, SC, ST, PUI, HR
40	Heart rate variability as a potential indicator of positive valence system disturbance: A proof of concept investigation	June Gruber, et al.,	2015	HRV-HF
41	Autonomic nervous system reactivity to positive and negative mood induction: The role of acute psychological responses and frontal electrocortical activity	Willem J.Kop, et al.,	2011	HRV, SCWT
42	Heart Rate Variability Predicts Emotional Flexibility in Response to Positive Stimuli	Tomomi Fujimura, et al.,	2012	HRV
43	Emotion regulation of others' positive and negative emotions is related to distinct patterns of heart rate variability and situational empathy	Josiane Jauniaux, et al.,	2020	RRI, HF, EDR, HRV
44	Brain-IoT based Emotion Recognition System	Bhagyashree Shirke, et al.,	2020	EEG Headset, HRV, GSR
45	EEG-based Dominance Level Recognition for Emotion-enabled Interaction	Yisi Liu, et al.,	2012	EEG, IADS

#	Title Of The Paper	Author	Year	Method/Sensor Used
46	Brain circuitry for both positive and negative 'valence' affected by trauma	Talma Hendler, MD, PhD, and Ziv Ben-Zion, PhD	2021	fMRI

2 Statistical analysis

2.1 Evaluation of Groups – Overall

Table 1 shows the mean scores and their standard deviation of the H2SEC parameters by groups.

Table 1: Mean Scores & SD of H2SEC Parameters by Groups

#	H2SEC	Anxiety	Depression	Neutral
1	Habituation	0.84 ± 0.08	0.89 ± 0.05	0.89 ± 0.05
2	Hypoactivity	0.80 ± 0.13	0.88 ± 0.08	0.88 ± 0.07
3	Synchronization	0.23 ± 0.36	0.24 ± 0.35	0.17 ± 0.30
4	Experience	0.81 ± 0.13	0.87 ± 0.09	0.87 ± 0.08
5	Calmness	0.02 ± 0.13	-0.11 ± 0.36	-0.009 ± 0.20

By performing the Shapiro-Wilk test of Normality on scores of the Neutral, Anxiety and Depression groups, we ascertained that the samples are not normally distributed. Levene's test showed the samples were not homogeneous. We thus applied the nonparametric Kruskal Wallis test and found the Neutral, Anxiety and Depression groups are significantly different from each other ($p < 0.05$). Finally, we performed Dunn's test to learn about which pair of groups are different from one another (Table 2).

Table 2: Post-hoc Group Differences

Scores	Comparison	Z	W_i	W_j	P	p_{Bonf}	p_{Holm}
Habituation	A – D	-0.324	3460.38	3479.037	0.373	1	0.373
	A – N	-6.277	3460.38	3796.241	**< .001*** **	< .001***	< .001***
	D – N	-4.877	3479.037	3796.241	**< .001*** **	< .001***	< .001***
Hypoactivity	A – D	1.647	3555.701	3461.122	**0.05**	0.149	0.1
	A – N	-1.311	3555.701	3625.696	0.095	0.285	0.1
	D – N	-2.536	3461.122	3625.696	**0.006*** **	**0.017***	**0.017***
Synchronization	A – D	-5.264	3422.356	3665.228	**< .001*** **	**< .001*** **	**< .001*** **
	A – N	-6.932	3422.356	3719.695	**< .001*** **	**< .001*** **	**< .001*** **
	D – N	-1.045	3665.228	3719.695	0.148	0.444	0.148
Experience	A – D	-3.578	3377.868	3587.464	**< .001*** **	**< .001*** **	**< .001*** **
	A – N	-9.016	3377.868	3868.838	**< .001*** **	**< .001*** **	**< .001*** **
	D – N	-4.251	3587.464	3868.838	**< .001*** **	**< .001*** **	**< .001*** **
Calmness	A – D	5.961	3691.124	3319.179	**< .001*** **	**< .001*** **	**< .001*** **
	A – N	3.684	3691.124	3477.468	**< .001*** **	**< .001*** **	**< .001*** **
	D – N	-2.245	3319.179	3477.468	**0.012***	**0.037***	**0.012***

* $p < .05$, *** $p < .001$

2.2 Evaluation of Groups - Based on STP and Non-STP Segments

We also examined the groups and their scores within and outside STP segments. Table 3 shows the mean scores and the standard deviation (SD) of the H2SEC parameter scores, both within and outside STP segments.

Table 3: Mean Scores & SD of H2SEC Parameters by Groups in STP & Non-STP Segments

		In STP segment			Non- STP segment		
#	H2SEC	Neutral	Anxiety	Depression	Neutral	Anxiety	Depression
1	Habituation	0.90±0.05	0.84±0.10	0.80±0.29	0.88±0.13	0.83±0.08	0.90±0.06
2	Hypoactivity	0.90±0.08	0.80±0.15	0.77±0.29	0.85±0.15	0.80±0.14	0.88±0.10
3	Synchronization	0.15±0.31	0.23±0.37	0.22±0.35	0.19±0.32	0.22±0.36	0.22±0.34
4	Experience	0.88±0.08	0.81±0.14	0.77±0.28	0.85±0.14	0.81±0.12	0.87±0.10

		In STP segment			Non- STP segment		
#	H2SEC	Neutral	Anxiety	Depression	Neutral	Anxiety	Depression
5	Calmness*	0.009±0.16	0.01±0.12	0.01±0.15	0.009±0.14	0.009±0.14	-0.07±0.30

Calmness score is the within-group score, where InSTP Score ($\bar{F}(X)+\varphi\_in$) is used within STP, and OutSTP Score ($\bar{G}(X)+\varphi\_out$) is used in Non-STP segments

The test of normality (Shapiro Wilk) and homogeneity of variance (Levene's) showed that our samples were not normally distributed and non-homogeneous. We thus used the Mann-Whitney U Test to compare outcomes between the STP and the Non-STP segments (Table 4).

Table 4: Between Group (STP and Non-STP) Difference of H2SEC Scores

	W	p	VS-MPR*	Hodges-Lehmann Estimate	Rank-Biserial Correlation
Habituation Score	6.217e+6	0.250	1.062	-4.152e-6	-0.015
Hypoactivity Score	6.324e+6	0.848	1.000	1.457e-5	0.002
Synchronization Score	6.479e+6	0.008***	9.706	4.114e-5	0.027
Experience Score	6.280e+6	0.724	1.000	-2.059e-5	-0.005
Calmness Score	6.011e+6	< .001***	84.697	-0.008	-0.047

Note. For the Mann-Whitney test, effect size is given by the rank biserial correlation.

* Vovk-Sellke Maximum p-Ratio: Based on a two-sided p-value, the maximum possible odds in favor of H_1 over H_0 equals $1/(-e\, p \log(p))$ for $p \leq .37$ (Sellke, Bayarri, & Berger, 2001).

We performed the non-parametric Kruskal-Wallis test to find out if the H2SEC scores between Neutral, Anxiety and Depression groups were different within the STP and Non-STP segments (**Error! Reference source not found.**) respectively. Since the Kruskal-Wallis test showed that except Hypoactivity in the Non-STP segment, the three groups Neutral (N), Anxiety (A) and Depression(D) are statistically different in terms of the H2SEC scores ($p < 0.05$), we performed the Dunn's post-hoc test to find out which groups were different (Table 5).

Table 5: Post-hoc Group Differences within STP and Non-STP Segments

Segment	Scores	Comparison	Z	W_i	W_j	P	p_{Bonf}	p_{Holm}
STP	Habituation	A – D	0.392	1770.189	1752.825	0.348	1	0.348
		A – N	-5.799	1770.189	1987.573	**< .001*** **	**< .001*** **	**< .001*** **
		D – N	-4.758	1752.825	1987.573	**< .001*** **	**< .001*** **	**< .001*** **
	Hypoactivity	A – D	1.5	1820.437	1753.987	0.067	0.2	0.08
		A – N	-1.748	1820.437	1885.948	**0.04***	0.121	0.08
		D – N	-2.676	1753.987	1885.948	**0.004****	**0.011***	**0.011***
	Synchronization	A – D	-4.236	1784.093	1931.958	**< .001*** **	**< .001*** **	**< .001*** **
		A – N	-2.143	1784.093	1847.362	**0.016***	**0.048***	**0.03***
		D – N	2.177	1931.958	1847.362	**0.015***	**0.044***	**0.03***
	Experience	A – D	-1.31	1743.134	1802.321	0.095	0.285	0.095
		A – N	-7.007	1743.134	2010.871	**< .001*** **	**< .001*** **	**< .001*** **
		D – N	-4.147	1802.321	2010.871	**< .001*** **	**< .001*** **	**< .001*** **
	Calmness	A – D	5.961	3691.124	3319.179	**<.001*** **	**<.001*** **	**<.001*** **
		A – N	3.684	3691.124	3477.468	**<.001*** **	**<.001*** **	**<.001*** **
		D – N	-2.245	3319.179	3477.468	**0.012***	**0.037***	**0.012***
Non-STP	Habituation	A – D	-0.779	1690.029	1719.727	0.218	0.654	0.218
		A – N	-3.01	1690.029	1805.256	**0.001****	**0.004****	**0.004****
		D – N	-1.964	1719.727	1805.256	**0.025***	0.074	**0.05***
	Hypoactivity	A – D	1.025	1737.349	1698.399	0.153	0.458	0.458
		A – N	-0.032	1737.349	1738.557	0.487	1	0.487
		D – N	-0.926	1698.399	1738.557	0.177	0.532	0.458
	Synchronization	A – D	-3.32	1638.641	1741.855	**< .001*** **	**0.001****	**< .001*** **
		A – N	-7.695	1638.641	1878.735	**< .001*** **	**< .001*** **	**< .001*** **
		D – N	-3.855	1741.855	1878.735	**< .001*** **	**< .001*** **	**< .001*** **
	Experience	A – D	-3.62	1633.456	1773.684	**< .001*** **	**< .001*** **	**< .001*** **
		A – N	-5.73	1633.456	1856.219	**< .001*** **	**< .001*** **	**< .001*** **
		D – N	-1.866	1773.684	1856.219	**0.031***	0.093	**0.031***
	Calmness	A – D	5.884	1832.588	1589.856	**< .001*** **	**< .001*** **	**< .001*** **
		A – N	3.911	1832.588	1670.666	**< .001*** **	**< .001*** **	**< .001*** **
		D – N	-1.715	1589.856	1670.666	**0.043***	0.129	**0.043***

* $p < .05$, ** $p < .01$, *** $p < .001$