

# A Decade of Ubiquitous Computing Research in Mental Health – Supplementary Material

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## REFERENCES

- [1] U. Anliker, J. A. Ward, P. Lukowicz, G. Troster, F. Dolveck, M. Baer, F. Keita, E. B. Schenker, F. Catarsi, L. Coluccini, et al. Amon: a wearable multiparameter medical monitoring and alert system. *IEEE Transactions on information technology in Biomedicine*, 8(4):415–427, 2004.
- [2] J. E. Bardram, M. Frost, K. Szanto, M. Faurholt-Jepsen, M. Vinberg, and L. V. Kessing. Designing Mobile Health Technology for Bipolar Disorder: A Field Trial of the MONARCA System. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '13*, pages 2627–2636, New York, NY, USA, 2013. ACM.
- [3] J. E. Bardram, M. Frost, K. Szanto, and G. Marcu. The MONARCA self-assessment system: a persuasive personal monitoring system for bipolar patients. In *Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium, IHI '12*, pages 21–30, New York, NY, USA, 2012. ACM.
- [4] I. Barnett, J. Torous, P. Staples, L. Sandoval, M. Keshavan, and J.-P. Onnela. Relapse prediction in schizophrenia through digital phenotyping: a pilot study. *Neuropsychopharmacology*, page 1, 2018.
- [5] T. Beiwinkel, S. Kindermann, A. Maier, C. Kerl, J. Moock, G. Barbian, and W. Rössler. Using smartphones to monitor bipolar disorder symptoms: A pilot study. *JMIR Mental Health*, 3(1):e2, Jan 2016.
- [6] A. Briassouli and I. Kompatsiaris. A comprehensive remote monitoring and feedback service for people with dementia living at home. *InImpact: The Journal of Innovation Impact*, 6(1):79, 2016.
- [7] M. N. Burns, M. Begale, J. Duffecy, D. Gergle, C. J. Karr, E. Giangrande, and D. C. Mohr. Harnessing context sensing to develop a mobile intervention for depression. *Journal of medical Internet research*, 13(3), 2011.
- [8] L. Canzian and M. Musolesi. Trajectories of Depression: Unobtrusive Monitoring of Depressive States by means of Smartphone Mobility Traces Analysis. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (ACM UbiComp '15)*. ACM, sep 2015.
- [9] K.-h. Chang, D. Fisher, J. Canny, and B. Hartmann. How’s my mood and stress?: an efficient speech analysis library for unobtrusive monitoring on mobile phones. In *Proceedings of the 6th International Conference on Body Area Networks*, pages 71–77. ICST (Institute for Computer Sciences, Social-Informatics and ), 2011.
- [10] P. Chow, W. Bonelli, Y. Huang, K. Fua, B. A. Teachman, and L. E. Barnes. Demons: an integrated framework for examining associations between physiology and self-reported affect tied to depressive symptoms. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, pages 1139–1143. ACM, 2016.
- [11] M. E. Corden, E. M. Koucky, C. Brenner, H. L. Palac, A. Soren, M. Begale, B. Ruo, S. M. Kaiser, J. Duffecy, and D. C. Mohr. Medlink: a mobile intervention to improve medication adherence and processes of care for treatment of depression in general medicine. *Digital health*, 2:2055207616663069, 2016.
- [12] M. Dang, C. Mielke, A. Diehl, and R. Haux. Accompanying depression with fine-a smartphone-based approach. In *MIE*, pages 195–199, 2016.
- [13] R. F. Dickerson, E. I. Gorlin, and J. A. Stankovic. Empath: a continuous remote emotional health monitoring system for depressive illness. In *Proceedings of the 2nd Conference on Wireless Health*, page 5. ACM, 2011.
- [14] A. Doryab, J. K. Min, J. Wiese, J. Zimmerman, and J. Hong. Detection of behavior change in people with depression. In *Workshops at the Twenty-Eighth AAAI Conference on Artificial Intelligence*, 2014.
- [15] L. Escobedo, D. H. Nguyen, L. Boyd, S. Hirano, A. Rangel, D. Garcia-Rosas, M. Tentori, and G. Hayes. Mosoco: a mobile assistive tool to support children with autism practicing social skills in real-life situations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2589–2598. ACM, 2012.
- [16] A. A. Farhan, C. Yue, R. Morillo, S. Ware, J. Lu, J. Bi, J. Kamath, A. Russell, A. Bamis, and B. Wang. Behavior vs. introspection: Refining prediction of clinical depression via smartphone sensing data. In *2016 IEEE Wireless Health (WH)*, pages 1–8. IEEE, 2016.
- [17] A. Gaggioli, G. Pioggia, G. Tartarisco, G. Baldus, D. Corda, P. Cipresso, and G. Riva. A mobile data collection platform for mental health research. *Personal and Ubiquitous Computing*, 17(2):241–251, 2013.
- [18] A. Gruenerbl, V. Osmani, G. Bahle, J. C. Carrasco, S. Oehler, O. Mayora, C. Haring, and P. Lukowicz. Using smart phone mobility traces for the diagnosis of depressive and manic episodes in bipolar patients. In *Proceedings of the 5th augmented human international conference*, page 38. ACM, 2014.
- [19] A. Grünerbl, A. Muaremi, V. Osmani, G. Bahle, S. Oehler, G. Tröster, O. Mayora, C. Haring, and P. Lukowicz. Smartphone-based recognition of states and state changes in bipolar disorder patients. *IEEE Journal of Biomedical and Health Informatics*, 19(1):140–148, 2015.
- [20] A. Guidi, S. Salvi, M. Ottaviano, C. Gentili, G. Bertschy, D. De Rossi, E. Scilingo, and N. Vanello. Smartphone application for the analysis of prosodic features in running speech with a focus on bipolar disorders: system performance evaluation and case study. *Sensors*, 15(11):28070–28087, 2015.
- [21] D. H. Gustafson, M. G. Boyle, B. R. Shaw, A. Isham, F. McTavish, S. Richards, C. Schubert, M. Levy, and K. Johnson. An e-health solution for people with alcohol problems. *Alcohol Research & Health*, 2011.
- [22] V. Hollis, A. Konrad, A. Springer, M. Antoun, C. Antoun, R. Martin, and S. Whittaker. What does all this data mean for my future mood? actionable analytics and targeted reflection for emotional well-being. *Human-Computer Interaction*, 32(5-6):208–267, 2017.
- [23] G. C.-L. Hung, P.-C. Yang, C.-C. Chang, J.-H. Chiang, and Y.-Y. Chen. Predicting negative emotions based on mobile phone usage patterns: an exploratory study. *JMIR research protocols*, 5(3), 2016.
- [24] M. Kerz, A. Folarin, N. Meyer, M. Begale, J. MacCabe, and R. J. Dobson. Sleepsight: a wearables-based relapse prevention system for schizophrenia. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, pages 113–116. ACM, 2016.
- [25] X. Li, R. Poli, G. Valenza, E. P. Scilingo, and L. Citi. Self-reported well-being score modelling and prediction: Proof-of-concept of an approach based on linear dynamic systems. In *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pages 2205–2208. IEEE, 2017.
- [26] R. LiKamWa, Y. Liu, N. D. Lane, and L. Zhong. Can your smartphone infer your mood. In *PhoneSense workshop*, pages 1–5, 2011.
- [27] H. Lu, D. Frauendorfer, M. Rabbi, M. S. Mast, G. T. Chittaranjan, A. T. Campbell, D. Gatica-Perez, and T. Choudhury. Stresssense: Detecting stress in unconstrained acoustic environments using smartphones. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, pages 351–360. ACM, 2012.

TABLE I

UBIQUITOUS COMPUTING SYSTEMS AND TECHNOLOGIES IN MENTAL HEALTH. SYSTEMS USED AS SEED ARE MARKED IN BOLD.

ICD-10 CATEGORIZATION: MOOD – MOOD (AFFECTIVE) DISORDERS; SCHIZ – SCHIZOPHRENIA, SCHIZOTYPAL AND DELUSIONAL DISORDERS; DEV – DISORDERS OF PSYCHOLOGICAL DEVELOPMENT; NEU – NEUROTIC, STRESS-RELATED AND SOMATOFORM DISORDERS; SUB – MENTAL AND BEHAVIORAL DISORDERS DUE TO PSYCHOACTIVE SUBSTANCE USE; PDIS – DISORDERS OF ADULT PERSONALITY AND BEHAVIOR.

System (N=46)	Year	ICD10 SMI	Disorder(s)	Region	Topics	Technology	Study (N/T)	References
<i>Clinical focus ( N=33 )</i>								
PsychLog	2010	NEU	Stress, PTSD	EU	SEN;INT	WEAR;MOB	100 / 270	[17]
LifeShirt	2010	SCHIZ;MOOD	Schizophrenia, Bipolar	US	SEN	WEAR	28 / 1	[30]
Empath	2011	MOOD	Depression	US	SEN	MOB	1 / 14	[13]
<b>Mobilize!</b>	2011	MOOD	Depression	US	SEN;PRE;CAS	MOB	7 / 56	[7]
A-CHESS	2011	SUB	Alcohol abuse	US	SEN;INT	MOB	280 / 365	[21]
<b>MONARCA</b>	2012	MOOD	Bipolar	EU	UI;SEN;PRE;ASS	MOB	12 / 98	[3], [2]
Moodbuster	2012	MOOD	Depression	EU	UI;INT;CAS	WEAR	52 / 30	[45]
MOSOCO	2012	DEV	Autism	US	INT;UI	MOB	12 / 49	[15]
AGATE	2012	SUB	Alcohol abuse	US	UI;INT	MOB	105 / 56	[43]
<b>StudentLife</b>	2013	MOOD	Depression	US	SEN;CAS	MOB	48 / 70	[49]
<b>MoodRhythm</b>	2013	MOOD	Bipolar	US	SEN;INT;UI	MOB	7 / 28	[46], [29]
MONARCA <sup>1</sup>	2014	MOOD	Bipolar	EU	SEN;PRE	MOB	12 / 48	[18], [19]
BigBlackDog	2014	MOOD	Depression	US	SEN	MOB	3 / 120	[14]
ParentGuardian	2014	DEV	ADHD	US	SEN;UI	MOB	10 / 14	[32]
PSYCHE	2015	MOOD	Bipolar	EU	SEN	WEAR;MOB	26 / 1	[20]
<b>PurpleRobot</b>	2015	MOOD	Depression	US	SEN;UI;CAS	MOB	18 / 14	[36]
MoodTraces	2015	MOOD	Depression	EU	SEN;PRE;CAS	MOB	28 / 14	[8]
Dem@Care	2015	ORG	Dementia	EU	SEN;UI	WEA	n/a / n/a	[6]
Mindful Moods	2015	MOOD	Depression	US	CAS;SEN	MOB	13 / 30	[44]
LifeRhythm	2016	MOOD	Depression	US	SEN;PRE;CAS	MOB	79 / n/a	[16]
SIMBA	2016	MOOD	Bipolar	US	SEN;PRE;CAS	MOB	13 / 360	[5]
AMoSS	2016	MOOD	Bipolar	EU	SEN;CAS	MOB;WEAR	50 / n/a	[39]
NEVERMIND	2016	MOOD	Depression	EU	SEN;UI	WEAR;MOB	15 / n/a	[25]
MOOS	2016	MOOD	Depression	EU	SEN;INT;CAS	MOB	126 / 14	[47]
CrossCheck	2016	SCHIZ	Schizophrenia	US	SEN;PRE	MOB	21 / 180	[48]
SleepSight	2016	SCHIZ	Schizophrenia	EU	SEN	MOB;WEAR	16 / 56	[24]
<b>MOBERO</b>	2016	DEV	ADHD	EU	UI;CAS	MOB	13 / 14	[41]
DEMOS	2016	MOOD;NEU	Depression, Anxiety	US	SEN;CAS	MOB;WEAR	72 / n/a	[10]
MedLink	2016	MOOD	Depression	US	UI;CAS;INT	MOB	11 / 56	[11]
<b>PocketSkill</b>	2018	DEV;MOOD; NEU;PDIS	Depression, Anxiety, Borderline, PTSD, Bipolar	US	UI;INT;CAS	MOB	73 / 28	[40]
BEIWE	2018	SCHIZ	Schizophrenia	US	SEN;PRE	MOB	17 / 90	[4]
BiAffect	2018	MOOD	Bipolar	US	SEN;PRE	MOB	8 / 19	[50]
RADAR	2018	MOOD	Depression	EU	UI;SEN	MOB;WEAR	66 / n/a	[42]
<i>Non-clinical focus ( N=13 )</i>								
<b>EmotionSense</b>	2010	N/A	Emotional state	EU	SEN;PRE	MOB	18 / 10	[34]
MoodSense	2011	N/A	'Daily mood'	ASIA	SEN;PRE	MOB	25 / 30	[26]
Mobile Sensing Platform	2011	MOOD	Depression	US	SEN	WEAR	8 / 10	[33]
StressSense	2012	NEU	Stress	US	SEN;PRE	MOB	14 / 3	[27]
MoodMiner	2012	N/A	'Daily mood'	ASIA	SEN	MOB	15 / 30	[28]
AMON	2012	N/A	Emotion, Mood, Stress	US	SEN	MOB	n/a / n/a	[1]
Funf, Affectiva, MotionLogger	2015	N/A	Sleep, Stress, Mental Health	US	SEN	MOB;WEAR	66 / 30	[37], [38]
MoodPrism	2016	N/A	'Emotional well-being'	AUS	SEN;UI	MOB	11 / 30	[35]
iHOPE	2016	MOOD;NEU	Depres., Anxiety, Stress	ASIA	SEN;PRE	MOB	28 / 14	[23]
Fine	2016	MOOD	Depression	EU	SEN	MOB	4 / 7	[12]
<b>EmotiCal</b>	2017	N/A	'Daily mood'	US	SEN;UI;PRE;INT	MOB	60 / 21	[22]
SHIM	2017	N/A	'Mental well-being'	EU	INT	MOB	28 / 14	[9]
AWEAR	2018	DEV	Dementia	EU	SEN	MOB;WEAR	5 / 7	[31]

[28] Y. Ma, B. Xu, Y. Bai, G. Sun, and R. Zhu. Daily mood assessment based on mobile phone sensing. In *2012 ninth international conference on wearable and implantable body sensor networks*, pages 142–147. IEEE, 2012.

[29] M. Matthews, S. Abdullah, E. Murnane, S. Volda, T. Choudhury, G. Gay, and E. Frank. Development and Evaluation of a Smartphone-Based Measure of Social Rhythms for Bipolar Disorder. *Assessment*, 23(4), 2016.

[30] A. Minassian, B. L. Henry, M. A. Geyer, M. P. Paulus, J. W. Young, and W. Perry. The quantitative assessment of motor activity in mania and schizophrenia. *Journal of affective disorders*, 120(1-3):200–206, 2010.

[31] P. Moore, F. Xhafa, L. Barolli, and A. Thomas. Monitoring and detection

of agitation in dementia: Towards real-time and big-data solutions. In *2013 Eighth International Conference on P2P, Parallel, Grid, Cloud and Internet Computing*, pages 128–135. IEEE, 2013.

[32] L. Pina, K. Rowan, A. Roseway, P. Johns, G. R. Hayes, and M. Czerwinski. In situ cues for adhd parenting strategies using mobile technology. In *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*, PervasiveHealth '14, pages 17–24. ICST, Brussels, Belgium, Belgium, 2014. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[33] M. Rabbi, S. Ali, T. Choudhury, and E. Berke. Passive and in-situ assessment of mental and physical well-being using mobile sensors.

- In *Proceedings of the 13th International Conference on Ubiquitous Computing*, UbiComp '11, pages 385–394, New York, NY, USA, 2011. ACM.
- [34] K. K. Rachuri, M. Musolesi, C. Mascolo, P. J. Rentfrow, C. Longworth, and A. Aucinas. EmotionSense: a mobile phones based adaptive platform for experimental social psychology research. In *Proceedings of the 12th ACM international conference on Ubiquitous computing*, pages 281–290. ACM, 2010.
- [35] N. Rickard, H.-A. Arjmand, D. Bakker, and E. Seabrook. Development of a mobile phone app to support self-monitoring of emotional well-being: a mental health digital innovation. *JMIR mental health*, 3(4), 2016.
- [36] S. Saeb, M. Zhang, M. Kwasny, C. J. Karr, K. Kording, and D. C. Mohr. The relationship between clinical, momentary, and sensor-based assessment of depression. In *2015 9th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth)*, pages 229–232. IEEE, 2015.
- [37] A. Sano, A. J. Phillips, A. Z. Yu, A. W. McHill, S. Taylor, N. Jaques, C. A. Czeisler, E. B. Klerman, and R. W. Picard. Recognizing academic performance, sleep quality, stress level, and mental health using personality traits, wearable sensors and mobile phones. ... *International Conference on Wearable and Implantable Body Sensor Networks. International Conference on Wearable and Implantable Body Sensor Networks*, 2015, June 2015.
- [38] A. Sano, S. Taylor, A. W. McHill, A. J. Phillips, L. K. Barger, E. Klerman, and R. Picard. Identifying objective physiological markers and modifiable behaviors for self-reported stress and mental health status using wearable sensors and mobile phones: Observational study. *J Med Internet Res*, 20(6):e210, Jun 2018.
- [39] K. E. Saunders, A. C. Bilderbeck, P. Panchal, L. Z. Atkinson, J. Geddes, and G. M. Goodwin. Experiences of remote mood and activity monitoring in bipolar disorder: a qualitative study. *European Psychiatry*, 41:115–121, 2017.
- [40] J. Schroeder, C. Wilkes, K. Rowan, A. Toledo, A. Paradiso, M. Czerwinski, G. Mark, and M. M. Linehan. Pocket Skills: A Conversational Mobile Web App To Support Dialectical Behavioral Therapy. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pages 398:1—398:15, New York, NY, USA, 2018. ACM.
- [41] T. Sonne, J. Müller, P. Marshall, C. Obel, and K. Grønbaek. Changing family practices with assistive technology: MOBERO improves morning and bedtime routines for children with ADHD. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pages 152–164. ACM, 2016.
- [42] C. L. Stewart, Z. Rashid, Y. Ranjan, S. Sun, R. J. Dobson, and A. A. Folarin. Radar-base: Major depressive disorder and epilepsy case studies. In *Proceedings of the 2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers*, pages 1735–1743. ACM, 2018.
- [43] S. A. Stoner and C. S. Hendershot. A randomized trial evaluating an mhealth system to monitor and enhance adherence to pharmacotherapy for alcohol use disorders. *Addiction Science & Clinical Practice*, 7(1):9, Jun 2012.
- [44] J. Torous, P. Staples, M. Shanahan, C. Lin, P. Peck, M. Keshavan, and J.-P. Onnela. Utilizing a personal smartphone custom app to assess the patient health questionnaire-9 (phq-9) depressive symptoms in patients with major depressive disorder. *JMIR mental health*, 2(1), 2015.
- [45] P. van de Ven, M. R. Henriques, M. Hoogendoorn, M. Klein, E. McGovern, J. Nelson, H. Silva, and E. Toussset. A mobile system for treatment of depression. *Computing Paradigms for Mental Health*, page 47, 2012.
- [46] S. Voids, M. Matthews, S. Abdullah, M. C. Xi, M. Green, W. J. Jang, D. Hu, J. Weinrich, P. Patil, M. Rabbi, et al. Moodrhythm: tracking and supporting daily rhythms. In *Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication*, pages 67–70. ACM, 2013.
- [47] F. Wahle, T. Kowatsch, E. Fleisch, M. Rufer, and S. Weidt. Mobile Sensing and Support for People With Depression: A Pilot Trial in the Wild. *JMIR mHealth and uHealth*, 4(3), 2016.
- [48] R. Wang, M. S. H. Aung, S. Abdullah, R. Brian, A. T. Campbell, T. Choudhury, M. Hauser, J. Kane, M. Merrill, E. A. Scherer, V. W. S. Tseng, and D. Ben-Zeev. CrossCheck: Toward Passive Sensing and Detection of Mental Health Changes in People with Schizophrenia. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '16, pages 886–897, New York, NY, USA, 2016. ACM.
- [49] R. Wang, F. Chen, Z. Chen, T. Li, G. Harari, S. Tignor, X. Zhou, D. Ben-Zeev, and A. T. Campbell. StudentLife: assessing mental health, academic performance and behavioral trends of college students using smartphones. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pages 3–14. ACM, 2014.
- [50] J. Zulueta, A. Piscitello, M. Rasic, R. Easter, P. Babu, S. A. Langenecker, M. McInnis, O. Ajilore, P. C. Nelson, K. Ryan, et al. Predicting mood disturbance severity with mobile phone keystroke metadata: A biaffect digital phenotyping study. *Journal of medical Internet research*, 20(7):e241, 2018.