Predicting Aggression in the Brain Injury Population: Preliminary Research Using Wearable Technology and a Machine Learning Approach

and

Clinical Research Portfolio

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CHAPTER 1: SYSTEMATIC REVIEW

Neurofeedback Interventions in Traumatic Brain Injury: A Systematic Review

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ABSTRACT

Introduction*:* Severe and diverse deficits in cognitive, behavioural, social, emotional and physical domains are well documented in individuals following a traumatic brain injury (TBI). Many treatment options have been investigated, with varying quality of evidence (e.g. cognitive rehabilitation, talking therapies, pharmaceutical interventions). Neurofeedback involves the real-time recording of brain patterns that are presented back to the individual. The individual then uses self-regulation to normalise or optimise neuronal activity and modify specific behaviours or cognitive function. This systematic review aims to evaluate the effectiveness of neurofeedback in improving behaviour or cognition in the TBI population, and assess the methodological quality of the research in this area.

Methods. Five databases were electronically searched. Three studies met the inclusion/exclusion criteria. The Clinical Trials Assessment Measure (CTAM) was used to assess methodological quality. A meta-analysis could not be carried out due to study heterogeneity.

Results. Small to large effect sizes were found across measures of post-brain injury symptoms, mood and fatigue, compared to a control group. Medium to large effect sizes were found for measures of quality of life, compared to control group. However, studies are limited by poor methodological quality.

Discussion. There is promising evidence for the potential effectiveness of neurofeedback in the management of post-brain injury symptoms. However, findings are limited by a lack of high-quality evidence. Ongoing studies may offer more robust evidence for the role of neurofeedback in the TBI population.

Keywords: Traumatic Brain Injury, Neurofeedback, Systematic Review, Rehabilitation

INTRODUCTION

Traumatic Brain Injury (TBI) "is involved in nearly half of all trauma deaths" and has "great economic costs for individuals, families and society" (WHO, 2006: p164). A recent meta-analysis of TBI incidence reported a rate of 262 per 100,000 per year (Peeters, 2015). Severe and diverse deficits in cognitive (Millis et al, 2001), behavioural (Benedictus, Spikman & van der Naalt 2010), social (Colantonia et al, 2004), emotional (Pachalska et al, 2011) and physical (Langlois, Rutland-Brown & Wald, 2006) domains have been well documented following TBI.

Clinical Guidelines for TBI

Clinical guidelines offer recommendations for improving the cognitive and psychosocial consequences following brain injury in adults (Bayley et al, 2014; Rees et al, 2017: Scholten, Vasterling & Grimes, 2017; SIGN, 2013). This may include cognitive rehabilitation (e.g. compensatory strategies, attention retraining; Cicerone et al, 2011) for memory and thinking difficulties and individual or group therapy (e.g. Cognitive Behavioural Therapy and Mindfulness-Based Stress Reduction) for emotional difficulties such as anxiety, anger and post-traumatic stress symptoms (Rees et al, 2017; Scholten, Vasterling & Grimes, 2017; Soo & Tate, 2007; The Matrix, 2015). Recommendations also include contingency management, positive behaviour interventions, comprehensive neurobehavioural rehabilitation (Ylvisaker et al, 2007), and pharmaceutical interventions (Fleminger, Greenwood and Oliver, 2006) for challenging or aggressive behaviour. However, clinical guidelines highlight the lack of high quality meta-analyses, systematic reviews and randomised-controlled trials (RCTs) in order to provide conclusive results of the effectiveness of cognitive, emotional or behavioural interventions in the TBI population (SIGN, 2013).

Research emphasises the use of holistic neuropsychological rehabilitation, which incorporates a combination of strategies to improve cognitive, emotional and behavioural difficulties (Cicerone et al, 2011; SIGN, 2013). Research has also explored the use of biofeedback interventions in the TBI population. For example, research has explored using heart rate variability (e.g. Kim et al, 2013) and neurofeedback (Thornton & Carmody, 2013). The use of neurofeedback has also been considered a promising alternative for rehabilitation in other areas (e.g. stroke; Renton, Tibbles & Topolovec-Vranic, 2017).

What is Neurofeedback?

Neurofeedback is a form of biofeedback. Biofeedback has been used for many decades, most commonly to improve symptoms of anxiety using techniques (e.g. relaxation) to alter associated physiological measures such as heart rate and galvanic skin response (see Schoenberg and David (2014) for review). More recently, the possibility of neurofeedback has emerged, which involves the real-time recording of brain patterns, which are then presented to the individual via a visual, auditory, touch or electrical stimulation representation. The goal is to use self-regulation to normalise or optimise the neuronal activity underlying symptoms e.g. cognitive impairment (Yucha & Montgomery, 2008). Methods used to measure brain activity include electrophysiological (magnetoencephalography (MEG), invasive electrocorticography (ECoG), electroencephalography (EEG)), and haemodynamic imaging (functional near-infrared spectroscopy (fNIRS), functional magnetic resonance imaging (fMRI)) approaches (Sitaram et al, 2016).

For example, EEG neurofeedback involves electrodes placed on the scalp to record brain patterns, which are fed back to the individual via computerised software. The individual is then trained to alter the brainwave pattern (e.g. speed or size of waves) to increase or decrease the brain activity to a pre-specified parameter to improve task performance (Enriquez-Geppert, Huster & Herrmann, 2017; Hammond, 2011a). Various neurofeedback systems and protocols can be utilised, which may include a normative reference group or other pre-determined parameters, and focus on alpha, beta or theta brain wave activity (Thornton & Carmody, 2009).

Research into the brain mechanisms underpinning explicit self-regulation is ongoing, with several theories proposed, including operant conditioning, motor learning, awareness theory, and dual process theory, amongst others (Sitaram et al, 2016).

Neurofeedback and TBI

Several studies have explored the use of neurofeedback to improve cognitive function, mood, quality of life, pain, and brain activity in the brain injury population (e.g. Keller, 2001; Reddy et al, 2013; Surmeli et al, 2017). A non-systematic review of neurofeedback in the TBI population identified studies of small sample sizes that found improvements in measures of cognition, symptom control (e.g. seizures) and self-reported symptoms such as mood and sleep (e.g. May et al, 2013). However, conclusions are limited by the number of databases searched (Google Scholar^{tm} only) and search terms used ("neurofeedback" and "TBI"*;* May et al, 2013: p.291). Further, there have been several relevant studies published since this review (e.g. Rostami et al, 2017; Thornton and Carmody, 2013).A recent systematic review of neurofeedback following stroke (Renton, Tibbles & Topolovec-Vranic, 2017) also found positive findings from the eight included studies, however studies werealso limited by small sample sizes. More promising evidence has been found for improving ADHD symptoms in children and adolescents, with a meta-analysis of 10 studies finding a large effect size for changes in measures of hyperactivity/impulsivity and medium effect size for changes in measures of inattention ($N = 256$; Van Doren et al, 2018). There is currently no known high quality systematic review that evaluates the current evidence of the effectiveness of neurofeedback in the TBI population.

Aims

This systematic review aimed to assess whether neurofeedback interventions are effective in the management of long-term sequelae of TBI, compared to a control group.

METHODS

Search Procedures

The following databases were searched on 2nd September 2017: Cochrane Central Register for Controlled Trials (CENTRAL; latest issues); EMBASE (1947 to week of search); MEDLINE (1947 to week of search); PsychINFO (1597 to date of search); ClinicalTrials.gov (clinicaltrials.gov/). See Appendix 1.2 for search strategies.Included studies were hand searched for further articles. The British Library grey literature for Medical Sciences database was also searched to identify unpublished dissertations and theses (http://ethos.bl.uk).

Inclusion Criteria

- *Types of Studies:* Due to the estimated small number of high quality randomised controlled trials (RCTs), any study that included an appropriate control group was eligible for inclusion.
- *Types of Participants:* Studies with adults (≥16 years old) with a TBI (brain damage occurring through external trauma after the age of 16 years).
- *Types of Interventions:* Any type of neurofeedback intervention (e.g. EEG) where the protocol involves conscious (or voluntary) modulation of brain activity, and where the primary aim is the management of symptomatic consequences of TBI.
- *Types of Control Groups:* Any control condition (e.g. treatment as usual, wait list control group, psychoeducation group) where outcome measures have been compared between neurofeedback and control groups.
- *Types of Outcome Measures:* Any outcome measure that assesses a brain injury-associated symptom of interest was included (e.g. cognition, emotion, behaviour).

Exclusion Criteria

- Single case studies
- Conference abstracts
- Book chapters
- Review studies or meta-analyses
- Commentaries or opinion articles

Study Selection and Data Extraction

Titles and abstracts were screened by the lead researcher, discarding those that did not meet the inclusion criteria. A second researcher independently screened a proportion (10%) of the titles and abstracts to improve the validity of the search. Any disagreements between selected studies were resolved via discussion. Eligible studies were then identified via full-text retrieval. Where eligibility was unclear, the study was discussed with a senior expert. Study authors were contacted for additional information where necessary.

Each selected study was examined and the following data extracted: participant characteristics (e.g. gender, age, traumatic brain injury severity), recruitment information (e.g. adherence and attrition), neurofeedback intervention details, method, time-points of outcome measure assessments, details of the results (continuous and dichotomous outcome data, statistical findings).

Quality Rating

There are several available tools for assessing study quality and risk of bias such as The Cochrane Collaboration's risk of bias tool (Higgens et al, 2011), the Clinical Trials Assessment Measure (CTAM; Tarrier & Wykes, 2004), the Risk of Bias in Non-Randomised Studies – of Interventions (ROBINS-I; Sterne et al, 2016) and the GRADE guidelines (Guyatt et al, 2011). The CTAM was chosen to assess the methodological rigour of each study due to the inclusion of items relating to a control group that controls for non-specific effects, and an analysis appropriate to the design of the study, which were felt to be critical for the design of a high-quality neurofeedback study (see Appendix 1.3). The CTAM was developed using the CONSORT checklist of information when reporting an RCT (Schulz, Altman & Moher, 2009) to assess the quality of non-pharmacological trials in mental health. It contains 15 items in the six domains of sample, allocation to treatment, outcome assessment, control groups, analysis, and description/quality of treatments. There is a maximum score of 100 points. The CTAM is reported to have excellent concurrent validity, good inter-rater agreement, and adequate internal consistency (Wykes et al, 2008). Adequate quality was defined as a CTAM score of 65 or above, as suggested by Wykes et al (2008) to ensure no domain was of poor quality. Two researchers independently assessed the

methodological quality of each study to improve the reliability of assessment. Any disagreements were resolved via discussion.

RESULTS

Study Selection

Results of the search procedure are illustrated in Figure 1. A search of MEDLINE, PsychINFO, EMBASE and Cochrane Central Register for Controlled Trials yielded 2517 results. After removing duplicates and screening by title and abstract, 11 articles remained to be reviewed in full. There were no disagreements between researchers during the screening process. Of the remaining articles, eight studies did not meet the inclusion/exclusion criteria and were removed; reasons for exclusion can be found in Appendix 1.4. The full texts of the remaining three articles met the inclusion criteria for quantitative synthesis. Hand-searched reference lists of the included articlesyielded no further studies. A search of clinicaltrials.gov identified five relevant ongoing trials (Evans, 2017; Elbogen, 2018; Glen, 2017; Huang, 2017; Van Boven, 2014). A search of the British Library grey literature identified no further relevant results. A total of three studies are reviewed; five ongoing studies are also discussed. Due to the small number of studies identified, excluded studies that offer additional findings are briefly summarised.

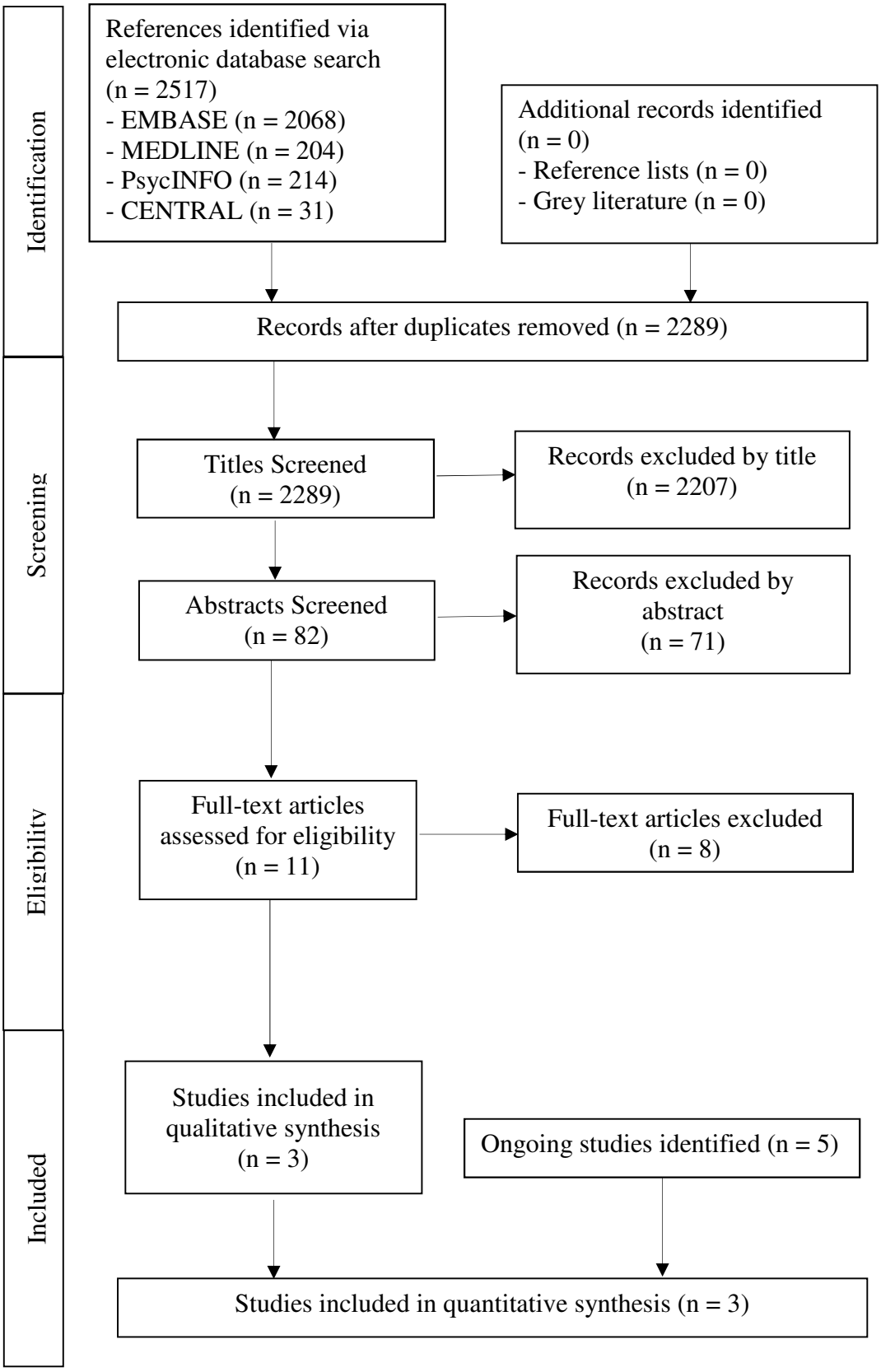

Figure 1. Search Procedure

Study Characteristics

Table 1 provides details of the characteristics of the three included studies. All three studies investigated the use of EEG neurofeedback (Reddy et al, 2013; Rostami et al, 2017; Tinius & Tinius, 2001). Outcome measures included cognition (Reddy et al, 2013; Rostami et al, 2017; Tinius & Tinius, 2001), quality of life (Reddy et al, 2013) and overall post brain injury symptom severity e.g. sleep, fatigue, visual difficulties, headache, communication (Reddy et al, 2013). No study compared changes in brain wave activity before and after neurofeedback. Two types of control group were used including wait-list control (Reddy et al, 2013; Rostami et al, 2017), or treatment as usual (Tinius & Tinius, 2001). Tinius and Tinius (2001) compared findings from a TBI group with a healthy control group, which did not receive the intervention, and an ADHD group, which did receive the intervention. All studies gathered pre- and immediate post-intervention data but no study gathered long-term follow-up data.

Methodological Quality Rating

There was an average of 82% inter-rater reliability for quality ratings, with some disagreement regarding appropriateness of analyses and suitability of the control group. It was agreed that analyses were considered appropriate when neurofeedback training was found to produce expected changes in brain activity, rather than changes in cognitive or self-reported outcome measures alone. A suitable control group which was considered to control for non-specific effects was agreed to include a sham neurofeedback or other active control group (e.g. EMG biofeedback). A wait-list group was not considered to be a suitable control group.

Final methodological quality ratings ranged from 21-32. Therefore no studies were considered to meet adequate methodological quality, as determined by Wykes et al's (2008) cut-off of 65.

Sample

All three studies used a convenience sample of clinic attenders. Tinius and Tinius (2001) also likely included volunteers for a healthy control group, however this was unclear. Reddy

et al (2013) included a sample size greater than 27 participants in each group, and therefore was the only study to meet the sample size requirement for this CTAM item (Tarrier & Wykes, 2004). No study provided a justification for their sample size, or completed a post-hoc power calculation.

Allocation

Two of the three studies reported using randomisation to allocate participants to treatment or control groups (Reddy et al, 2013; Rostami et al, 2017). However no details were provided regarding the process of randomisation or whether randomisation was carried out independently from the research team. The third study used a control group consisting of healthy participants and a different clinical population and therefore randomisation was not possible (Tinius & Tinius, 2001).

Outcome Assessment

None of the studies provided details regarding independent assessment of the outcome measures. All three studies used standardised measures to assess symptoms. No study indicated how of whether outcome assessments were carried out blind to the treatment group allocation, or whether blinding was verified.

Control groups

Two studies used a wait-list control group (Reddy et al, 2013; Rostami et al, 2017).The third study used a healthy control group that received no intervention (Tinius and Tinius, 2001). No study was considered to have adequately controlled for the non-specific effects of neurofeedback.

Table 1. Summary of Study Characteristics and Quality Rating for Included Studies

Study	Design	Intervention Group	Control Group	Intervention	Outcome Measures	Primary Findings	CTAM rating
Reddy et al 2013	RCT (pre-post measures)	*N* = 30 (3 female) M_{age}= 28.27 yrs (±7.66) Mild-severe TBI	*N* = 30 (3 female) M_{age}= 30.80 yrs (±8.38) Mild-severe TBI	*Intervention:* 20 x 40min sessions over 4-5 weeks EEG NFT to improve alpha/theta activity *Wait-list Control*: TAU followed by intervention	**Post concussion symptoms** RHIFQ, RPQ, VAS **Cognition** NIMHN **Quality of Life** QOL	Significant improvements across all outcome measures post-intervention, compared with control group.	34
Rostami et al 2017	RCT (pre-post measures)	*N* = 8) (all male M_{age}= 26.75 yrs (±15.16) Mild-mod TBI	*N* = 5 (all male) M_{age}= 27.60 yrs (±8.17) Mild-mod TBI	*Intervention:* 20 sessions NFT across weeks 1-4 (5 per week) to improve beta and alpha activity *Wait-list Control:* TAU followed by intervention	**Cognition** WMS-IV, DUAF	No significant improvements found between intervention and control groups.	24
Tinius & Tinius 2001	Non-RCT (pre-post measures)	*N* = 16 (11 females) $M_{age\ (SD)}$ = 29.0 (11.4) Mild TBI	Non-TBI - *N* = 15 (7 females) $M_{age\ (SD)}$ = 25,1 (6.8) ADHD - *N* = 13 (9 females) $M_{age\ (SD)}$ = 37.4 (10.2)	*Intervention:* 30-45mins computerised EEG neurofeedback via coherence training with simultaneous cognitive retraining Average number sessions (SD): TBI = 21.2 (4.7) ADHD = 18.5 (4.3) Non-TBI group received no intervention	**Cognition** FSAQ, IVA CPT, NIS, WAIS-R, WCST **Post-Concussion Symptoms** NIS	Significant Group by Treatment Interaction across measures.	21

Abbreviations: *DUAF* = unreferenced attention test; *IVA CPT* = Intermediate Visual and Auditory Continuous Performance Test; *NIMHN* = National Institute of Mean Health and Neurosciences; *NIS* = Neuropsychological Impairment Scales; *QOL* = Quality of Life Scale; *RHIFQ* = Rivermead Head Injury Follow-up Questionnaire; *RPQ* = Rivermead Post-Concussion Symptoms Questionnaire; *TAU* = Treatment as Usual; *VAS* = Visual Analog Scale; *WAIS-R* = Wechsler Adult Intelligence Scale – Revised; *WCST* = Wisconsin Card Sorting Test

Analysis

All three studies provided details of statistical analyses. No study analysed whether the neurofeedback intervention produced expected changes in brain activity, therefore no conclusions could be made as to whether the neurofeedback was effective in modifying targeted brain activity. Therefore, no study was considered to use statistical analyses appropriate to the design of the study. All three studies completed between-group analyses pre- and/or post-intervention relating to the primary outcome measure(s).

Regarding attrition, Reddy et al (2013) stated 70% of participants dropped out prior to randomisation however all participants randomised were subsequently included in the analyses. Rostami et al (2017) indicated a greater than 15% attrition rate but no details were provided regarding how the data were handled. There was no participant drop-out in the third study (Tinius & Tinius, 2001).

Description of Treatment

Two of the three studies provided an adequate description of the treatment (Rostami et al, 2007; Tinius & Tinius, 2001). All studies referred to a protocol or specific software that was being used to complete the intervention. No studies provided details regarding adherence to the protocol.

Results of individual Studies

A full summary of the findings of the included studies is provided in Appendix 1.5, including group means, standard deviations, and effect sizes. Where possible, effect sizes not included in the studies were calculated. One study used non-parametric statistical analyses as some data were not normally distributed, therefore effect sizes should be interpreted with caution (Reddy et al, 2013). The authors of the same study were contacted to obtain further information regarding between-group comparisons. The information obtained highlighted a discrepancy between the individual pre- and post-score means and the group mean differences, which authors clarified as an error in the published pre- and post-score means. The results described here are the updated values obtained from the authors. The authors stated the updated scores do not impact the overall findings of the study.

There was significant heterogeneity between included studies regarding research design, participant characteristics, intervention, outcome measures, statistical analyses and there was overall poor study quality. Therefore a meta-analysis could not be carried out. A descriptive account and synthesis of the included studies was completed. No imputation was carried out for missing data.

Cognition

Reddy et al (2013) found a statistically significant improvement in the intervention group for all measures of cognition ($p < 0.05$); a statistically significant improvement was found in four cognitive measures of the wait-list group ($p < 0.05$). Small to large effect sizes were found for both between-group post-intervention scores (d = 0.14-1.08) and for the mean difference between groups (d = 0.01-1.62).

Rostami et al (2017) did not find a significant improvement in cognition in the intervention group, or a significant difference between treatment and control groups. There were small to large effect sizes across cognitive tasks for both post-intervention scores (d = 0.13-1.27) and for mean differences (d = 0.09-1.44) between groups.

Tinius and Tinius (2001) found a significant Group by Treatment Interaction across sub-scores of the Intermediate Visual and Auditory Continuous Performance Test (IVA CPT) outcome measures ($p< 0.05$). Post-hoc tests found mild TBI and ADHD groups to score significantly less compared to the control group at pre-intervention, which was no longer found at post-intervention. Small to large effect sizes were found for post-intervention comparisons between mild TBI and control group scores (d = 0.01-0.91). A significant Group by Treatment Interaction was also found across sub-scores of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981); effect sizes could not be calculated as means and standard deviations were not provided.

Quality of Life

Reddy et al (2013) found a statistically significant improvement in quality of life in the intervention group ($p <0.001$); a statistically significant improvement was not found in the wait-list group. Medium to large effect sizes were found for both post-intervention scores (d = 0.70-1.18) and the mean difference (d = 0.75-1.57) between groups.

Post-Concussion Symptoms

Reddy et al (2013) found a statistically significant improvement in the intervention group for two post-concussion symptoms questionnaires (p <0.001); a statistically significant improvement was also found in the wait-list group (p <0.05). Large effect sizes were found both for post-intervention scores (d = 1.00-2.10) and the mean difference (d = 1.47-3.25) between groups.

Tinius and Tinius (2001) found a Group by Treatment Interaction for self-reported symptoms. Post-hoc tests found a significantly higher score in the mild TBI group pre-intervention, compared to the control group, which was no longer found post-treatment for several measures. Small to large effect sizes were found for post-intervention comparisons between mild TBI and control group scores (d = 0.46-1.39)

Brain Activity

No study reported brain activity recordings, or compared brain wave recordings pre- vs post-intervention, or between intervention and control group. Reddy et al (2013) stated "there was not statistically significant improvement in the EEG post neurofeedback" (Reddy et al, 2013: p. 221) however no details of the data or analyses were reported.

Excluded Studies

It is worth noting that several excluded studies have included analyses of brain activity following neurofeedback. For example, Keller (2001) explored neurofeedback to improve attention, and found increased beta wave brain activity for participants in the neurofeedback group. However between-group comparisons were not completed. Other single case (Nash, 2005) and cohort (Rostami et al, 2011; as cited by May et al, 2013) studies have also found normalisation or improvements in brain wave activity following neurofeedback sessions (see May et al, 2013 for review).

Ongoing Studies

Table 2 provides details of the characteristics of the five relevant ongoing studies. All five studies propose an RCT design including a neurofeedback group and at least one control

group. Two studies estimate a small sample size of 14 (Evans, 2017) or 20 (Glenn, 2017) and three estimate a large sample size of over 100 (Elbogen, 2018; Huang, 2017; Van Boven, 2014). All four studies include measures of cognition and other self-reported measures (e.g. pain, mood), as well as measures of brain activity.

Table 2. Summary Of Study Characteristics For Ongoing Studies

Study ID, Status	Design	Participant Characteristics	Intervention	Outcome Measures
Evans 2017 NCT03324178, Recruiting	Pilot RCT	14 participants with a non-progressive brain injury and impaired sustained attention	*Intervention:* 16 x 30min sessions of neurofeedback over four weeks *Control:* 16 x 30min sessions of video game playing over four weeks Both groups will complete 16 x 30min sessions involving 7 x 3min blocks with 3min rest	**Cognition:** MAAS, CTET, TEA
Elbogen 2018 NCT02237885, Not Yet Recruiting	RCT	300 veterans with a TBI and self-reported moderate-severe musculo-skeletal and/or neuropathic pain	*Arm I:* Mobile App mindfulness *Arm II:* Mobile App neurofeedback *Arm III:* Mobile App Relaxation All conditions will engage in the Mobile App for a minimum of 10minutes a day, 4 days per week, for 12 weeks.	**Pain:** DVPRS **EEG changes:** changes in alpha power
Glenn 2017 NCT02615535, Active, not recruiting	RCT	20 participants with a TBI randomly allocated via parallel assignment	*Intervention*: EEG neurofeedback-assisted Meditation *Control*: non-EEG feedback-assisted meditation Both groups will completed approximately 10 minutes of daily meditation for 6-8 weeks.	**Neurobehavioural Symptoms:** NIS **Cognition:** WAIS-IV Subtests (Digit Span, Digit Symbol Coding, Trail Making Test) **Mood:** BAI, BDI-II **Mindfulness:** CAMS-R **EEG:** Percentage of EEG activity associated with alpha, beta, and theta rhythms
Huang 2017 NCT03244475, Recruiting	Double -blind RCT	175 participants that are veterans with a mild TBI	*Intervention:* EEG across 14 visits with a one week follow-up *Placebo Comparator:* Sham EEG *Control:* no intervention	**Post-Battle Experience:** DRRI-2 **Lifetime history of TBI:** OSU TBI-ID **Sleep:** PSQI **Pain:** MGPQ

			Both Intervention and Placebo Comparator groups will have 14 active visits, with a follow up visit at one week and one month.	**Psychiatric Symptoms:** MINI-7 **PTSD:** CAPS-5 **Post-Concussion:** PCL-5 **Alcohol/Substance Use:** ASSIST**,** AUDIT **Cognition:** CVLT-II, WAIS-IV, DKEFS, CPT-II, BIS, FrSbe, WTAR, ToMM, CogState Ltd **EEG:** number of abnormal MEG slow-waves **MRI:** MRI T1-weighted 3D-IRSPGR pulse sequence, susceptibility weighted MRI
Van Boven 2014 NCT01908647, Unknown Status	RCT	150 participants: 18-45years old with mild TBI and cognitive dysfunction randomly allocated via parallel assignment	*Arm I:* fMRI with neurofeedback and computer based attention training *Arm II:* fMRI with neurofeedback and control cognitive training condition (computer-based games) *Arm III:* fMRI without neurofeedback and computer based attention training. *Arm IV:* fMRI without neurofeedback and control cognitive training condition All conditions to be completed over 8 weeks	**Cognition:** Neuropsychological assessment **Functioning:** Undisclosed self-reported measure, TIADL, MPAI-4 **Working/School Status:** Employment/schooling status, number of hours in work/school/volunteering per week **Exercise:** Undisclosed exercise-based assessments

Abbreviations: *ASSIST* = Alcohol, Smoking and Substance Involvement Screening Test; *AUDIT* = Alcohol Use Disorders Identification Test*; BAI* = Beck Anxiety Inventory; *BDI-II* = Beck Depression Inventory-II; *BIS* = Barratt Impulsivity Scale*; CAMS-R* = Cognitive and Affective Mindfulness Scale-Revised; *CAPS-5* = Clinician-Administered PTSD Scale-5 for DSM-5; *CPT-II* = Connors Continuous Performance Task-II*; CTET* = Continuous Temporal Expectancy Test; *CVLT-II* =California Verbal Learning Test-Second Edition*; DKEFS* = Delis Kaplan Executive Function System*; DRRI-2* =Deployed Risk and Resilience Inventory 2; *DVPRS* = Defense and Veterans Pain Rating Scale; *FrSbe* = Frontal Systems Behaviour Scale*; MAAS* = Mindful Attention Awareness Scale; *MEG* = Magnetoencephalography; *MGPQ* = McGill Pain Questionnaire; *MINI-7* =Mini-International Neuropsychiatric Interview;*MPAI-4* = Mayo-Portland Adaptability Inventory; *NIS*= Neurobehavioral Symptom Inventory; *OSU TBI-ID*= Ohio State University Traumatic Brain Injury Identification Method; *PCL-5* = Post-concussion checklist-5**;** *PSQI* = Pittsburgh Sleep Quality Index**;** *TEA* = Test of Everyday Attention; *TIADL* = Timed Instrumental Activities of Daily Living*; ToMM* = Test of Memory Malingering*; WAIS-IV* =Wechsler Adult Intelligence Scale-Forth Edition; *WTAR* = Wechsler Test of Adult Reading

DISCUSSION

Findings

This review aimed to evaluate the current evidence investigating the effectiveness of neurofeedback interventions for the management of TBI symptoms. Two randomised controlled trials and one non-randomised controlled clinical trial were included in the review. Two studies found significant improvements in cognition, compared to control group. One study did not find cognition to improve with neurofeedback. One study found improvements in quality of life, and two studies found improvements in post-concussion symptoms, compared to control group. However, conclusions are limited by study heterogeneity.

All studies were of a low quality rating. Of particular significance was a failure to compare brain activity before and after neurofeedback. Therefore findings could not be summarised with regard to the effectiveness of neurofeedback protocols in altering brain wave patterns. Research investigating the relationship between physiological markers (e.g. heart rate, galvanic skin response) and psychological state have been extensively explored (e.g. Gorman & Sloan, 2000). Therefore biofeedback interventions targeting these physiological markers offer an understood relationship to psychological improvement (Schoenberg & David, 2014). However, there are ongoing challenges in understanding the neural mechanisms that underpin self-regulation of brain activity during neurofeedback, and difficulties with not all participants achieving self-regulation (Sitaram et al, 2016). There is evidence to suggest a relationship between anxiety and decreased alpha and increased theta waves, and therefore neurofeedback protocols often focus on altering these brain waves (e.g. Moore, 2000; Ros et al, 2014). However further research is required to identify the process in which these brain wave patterns are altered e.g. relaxation, cognitive tasks (Sitaram et al, 2016). Therefore it is important for studies to include measures of brain activity and to analyse whether the chosen neurofeedback protocol and self-regulation approach has been effective, to improve the validity of the findings.

The control groups' chosen were not considered appropriate with regard to controlling for non-specific effects of neurofeedback. For example, the use of an active control group, as well as including other key aspects of being involved in this type of intervention (e.g. exposure to a therapeutic environment, positive expectations, motivation for improvement)

have been indicated as important contributions for positive findings (Loo & Makeig, 2012). Future studies using an active (e.g. EMG) or sham neurofeedback would offer higher quality findings into the effectiveness of neurofeeback interventions.

All three studies also failed to gather long-term follow-up data. Further, ongoing emotional, addictions and social circumstances impacting recovery in the TBI population (e.g. Corrigan, 1995; Ponsford et al, 2000; Ruff, Camenzuli & Mueller, 1996) may influence long-term outcomes of neurofeedback interventions. It is also unrealistic to expect wide ranging changes to quality of life with such a focused intervention as neurofeedback. Therefore future studies that collect long-term follow-up data and include these variables as potential confounding factors may offer further evidence as to the effectiveness of neurofeedback in improving the outcomes of individuals with a TBI.

Limitations of the Review

Four databases were searched, which included published studies, and the references of included studies were hand-searched. One database was searched for identification of unpublished dissertations and theses, and one database was searched to identify ongoing clinical trials. Nevertheless, the review may have failed to identify all eligible studies, particularly those that have not been published. Further, due to the inclusion criteria chosen, very few studies were included in the review and, as such, excluded non-controlled studies may have offered some useful findings that were not summarised. Study quality findings are also restricted by the quality measure selected. An alternative quality rating tool may have provided additional findings in areas not evaluated by the CTAM, e.g. bias due to confounding (Sterne et al, 2016). Other risk of bias tools also offer the opportunity to explore other sources of bias that may be specific to the study of interest (Higgins et al, 2011). Nevertheless, due to the nature of the intervention, the inclusion of studies with a control group and appropriate between group comparisons was considered paramount for a high quality systematic review, and therefore the CTAM was chosen in an attempt to offer the best conclusions.

Conclusions

Due to the lack of eligible studies, and the included studies being of low-quality, the overall applicability of the evidence for clinical practice is limited. Further, as the studies were rated as low-quality, any findings should be interpreted with caution. There are guidelines available for the use of neurofeedback, developed by the International Society for Neurofeedback and Research (ISNR; Hammond et al, 2011b).Whilst there is currently insufficient evidence to make any recommendations regarding the clinical use of neurofeedback in the TBI population, researchers may wish to use these guidelines when developing studies to exploreneurofeedback further. Nevertheless this review highlights the need for further research,and current ongoing clinical trials may be able to offer stronger evidence, with appropriate power, which explore the effectiveness of neurofeedback in the TBI population.

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CHAPTER 2: MAJOR RESEARCH PROJECT

Predicting Aggression in the Brain Injury Population: Preliminary Research Using Wearable Technology and a Machine Learning Approach

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PLAIN ENGLISH SUMMARY

Introduction

People with a brain injury often have difficultly regulating their emotions. These difficulties can lead to verbal and/or physical aggression, and subsequently significantly affect their ability to live independently. Physiological measures such as heart rate, sweat and temperature are sensitive to changes in emotion. These physical recordings can now be collected through wearable devices (smartwatches). With the development of computer science approaches, it is possible to use information from one set of data to make predictions about another. This approach would be useful if it can be applied to physiological recordings to predict verbal or physical aggression in the future.

Aims

This study investigated whether computer scienceapproaches could be used to predict physical and verbal aggression before it happens.

Method

Participants were recruited from a brain injury inpatient rehabilitation unit. They were asked to wear a smartwatch and were prompted to wear the smartwatch at all times, apart from in the shower, and to charge the smartwatch each day. They were also asked to carry a phone on their person, which was used to store the information gathered on the smartwatch. During this time, staff recorded physical and verbal aggression.

Results

Five patients were included in the study. Technical and practical problems made data collection difficult. These included WiFi connection problems, forgetting to charge and wear the smartwatch or carry the phone, and smartwatches breaking. It was not possible to explore the computer science approaches with two participants, as there were too few aggressive behaviours observed by staff. Therefore, computer science approaches were used to create calculations on available data for three participants. Although the calculations created were able to predict some episodes of aggression, there were also many false alarms where aggression was incorrectly predicted. Possible reasons included a lack of sufficient observed aggressive behaviours for developing the calculations, staff failures to report all aggressive behaviours leading to some physical recordings being labelled incorrectly, and changes in

physical recordings associated with stress that did not ultimately lead to an aggressive behaviour.

Conclusions

The identification of a potential tool for predicting physical and verbal aggression would provide important warning signs to help patients and staff alleviate distress and prevent the aggressive behaviour occurring. In the current study, it was not possible to develop a calculation that predicted future episodes of aggressive behaviour, without too many false alarms for it to be useful in a real-world inpatient environment. Nevertheless, the current study provides useful insight into conducting technology research in the brain injury population. Recommendations for future research would include a careful choice of smartwatch that is durable, with a long battery life and large storage capacity, a reliable Internet connection, and prompts for individuals with memory difficulties. It might also be useful to use a patient questionnaire to measure times of stress, in order to determine whether calculations can also be used to predict increased stress levels, which may not lead to an aggressive behaviour.

ABSTRACT

Introduction. Emotional dysregulation often occurs in people with an acquired brain injury (ABI), and can lead to challenging behaviour including aggression. Emotion regulation is associated with the autonomic nervous system and physiological recordings (e.g. heart rate variability) can be used as index measures of self-regulation. The development of wearable devices allows for real-time continuous physiological recording. Advances in machine learning techniques also open avenues for analysing these data, which involves identifying patterns to predict behaviours. This study aimed to explore whether physiological and sleep recordings could be used to accurately predict challenging behaviour in individuals with an ABI.

Methods. Participants were recruited from a brain injury inpatient unit. Participants wore a Smartwatch, which collected physiological and sleep data. Staff recorded episodes of verbal and physical aggression. Ethical approval was obtained for the study. Data mining techniques were used to develop models for predicting aggressive behaviour.

Results. Five participants were included in the study. Technical and practical problems led to unanticipated data collection difficulties, including participants failing to wear or charge the devices, smartwatches breaking, and poor WiFi connection. Machine learning was used to create predictive models both for individual participants, and a combined model. Models successfully predicted 9-100% or episodes of aggressive behaviour however there were a large number of false alarms impacting the clinical applicability of the models.

Discussion. This study failed to create a model that predicted episodes of aggression without a sufficiently low number of false alarms that would suggest it was clinically useful in an inpatient setting. Several possible reasons are discussed. Practical recommendations for future research include a careful choice of smartwatch,a reliable internet connection, consistent aggression reporting, and the inclusion of a self-reported measure of emotional dysregulation.

Conclusions. The development of a clinical tool that can accurately predict and warn individuals, or staff, of imminent emotional dysregulation opens avenues for its prevention.

This study provided useful insight into the initial attempts to explore this using a machine learning approach in the ABI population.

Keywords: acquired brain injury, wearable devices, challenging behaviour

INTRODUCTION

Emotional Dysregulation

The ability for humans to regulate their emotions involves a complex interplay between affective, cognitive, behavioural, and physiological systems, enabling us to interact effectively with our environment. When working well, this network of connected systems allows individuals to cope with, and respond to, difficult emotions, and to coordinate selection of an appropriate goal-directed behaviour whilst inhibiting inappropriate behaviours (Thayer et al, 2012). This process involves multiple feed-forward and feedback mechanisms occurring in less than a second, including information processing, appraisal of threat, biochemical processes (e.g. hormone release), coordination of breathing rate, and muscle contraction (Thayer & Lane, 2000). When this network is not working effectively, individuals can become stuck in a pattern of inappropriate behaviours that are maladaptive to the demands of the environment. This dysregulation has been associated with self-monitoring and self-awareness difficulties, and can result in mental and physical health pathologies, such as generalised anxiety disorder and hypertension (Thayer & Lane, 2000).

Difficulty identifying emotions in the self (alexithymia), empathy and social cognition are more prevalent following an acquired brain injury (ABI) than the general population (McDonald, 2013; Wood & Williams, 2007). This can lead to emotional dysregulation and often presents as behaviours that challenge care providers (Tateno, Jorge & Robinson, 2003). Several measures have been developed to record challenging behaviour that have strong inter-rater reliability within the neurological population, such as the Overt Behaviour Scale (OBS; Kelly et al, 2006), the Over Aggression Scale (Yudofsky et al, 1986), which are often reported by an individual in close contact with the person e.g. staff or family member. For example, a study of 507 severe ABI patients reported 54% to exhibit challenging behaviour as assessed using the OBS; inappropriate social behaviour was most commonly reported (33%; Sabaz et al, 2014). A study of 227 moderate to severe traumatic brain injury (TBI) patients found 25% to exhibit aggressive behaviour (Baguley, Cooper & Felmingham, 2006). These behaviours can lead to difficulties with educational, vocational, and social pursuits, and family re-integration (Morton & Wehman, 1995; Ylvisaker, Turkstra & Coehlo, 2005).

Physiological Indicators of Emotional Dysregulation

Physiological measures involved in autonomic nervous system (ANS) regulation have been associated with emotion regulation (Thayer et al, 2012). Cardiac vagal tone has been identified as an indicator of ANS regulation. High cardiac vagal tone has been associated with behavioural flexibility and environment adaptability, whereas low cardiac vagal tone is associated with reduced ability to assess the environment and organise an appropriate response, the latter leading to emotional dysregulation (Thayer & Lane, 2000). Cardiac vagal tone is reflected in heart rate variability (HRV), which is a measure of the change (or variability) in time between successive heartbeats, measured in milliseconds. A meta-analysis of functional neuroimaging studies identified a relationship between HRV and the amygdala and ventromedial prefrontal cortex, brain areas associated with cognitive, emotional and behavioural responses (Thayer et al, 2012). Other indicators of ANS arousal and emotion regulation include skin resistance (a measure of sweat; Critchley et al, 2000), skin temperature (Gross, 2002) and sleep quality (Mauss, Troy & LeBourgeois, 2013). In the ABI population, lower HRV has been associated with poorer social and emotional functioning (Francis et al, 2015), antisocial and violent behaviour (Raine, 2002) and worsened neurological state (Rapenne et al, 2001). Sleep disturbance also commonly occurs following brain injury (e.g. Orff, Ayalon & Drummond, 2009; Parcell et al, 2008) and evidence has found poor sleep to be associated with aggression (Kamphuis et al, 2012). For example, research has proposed that the prefrontal cortex and amygdala may be dependent upon homeostasis of the sleep system, suggesting poor sleep leads to impulsivity and emotional reactivity (Gruber and Cassoff, 2014). Evidence also supports the association of aggressive behaviour with skin resistance (Raine, 2002).

Physiology and Technology

Research previously relied on large technical devices, such as functional MRI machines to measure brain activity and electroencephalography (EEG) to measure sleep, or awkward devices, such as finger electrodes to measure skin conductance and chest straps to measure HRV. These devices often meant participants were monitored for short time periods in laboratory settings. The emergence of wearable physiological monitoring systems now allows individuals to wear devices throughout the day and track their physiology via a mobile phone application. A review of 17 wearable fitness trackers found heart rate and step count to have an accuracy of 79.8-99.1%, when compared to observer-counted steps and a heart rate recording medical device (El-Amrawy & Nounou, 2015). Therefore the evolution

of accurate wearable devices broadens research opportunities for measuring emotion regulation in real-time (Banee, Ahemed & Loutfi, 2013).

Research investigating wearable devices to measure physiology and infer emotional states, is in its infancy. Advances in machine learning offer approaches to help make sense of large quantities of sensory information from wearable devices (Banee, Ahmed & Loutfi, 2013). Machine learning uses data mining processes, which typically involves data collection, preprocessing, defining features, modelling and model testing (e.g. Hand, 2007). This can provide valuable information for identifying patterns that can aid diagnosis, prediction and anomaly detection (Banee, Ahmed & Loutfi, 2013). For example, specific data mining techniques can interpret continuous data (e.g. heart rate) and detect, or predict, inconsistencies in patterns to indicate abnormal behaviour (e.g. stress; Sun et al, 2012). Previous research using physiological recordings collected from wearable devices has found promising findings for identifying poor mental health and for predicting future stress levels (Ghandeharioun et al, 2017; Sano et al, 2018; Umematsu et al, 2018).

Research in the ABI population has focused on using physiological measures for biofeedback. Biofeedback aims to alter a person's physiological activity via (in)voluntary self-regulation, to improve physical or mental functioning (e.g. Kim et al, 2015). However biofeedback interventions often involve prescheduled time-limited sessions. The use of a wearable device that continuously monitors physiological recordings, with the ability to indicate increased stress levels, could help individuals prevent (potentially) harmful emotional dysregulation. There is limited research that has investigated data mining techniques for predicting future episodes of emotional dysregulation using physiological data. Recent research with two participants has found promising evidence with successful predictions of up to 82% of aggressive behaviours up to four hours prior to their occurrence (Turner et al, 2017). The current study aimed to provide further evidence for the ability to predict future episodes of aggression via data mining approaches in individuals with an ABI, using a wearable device.

Aims

To investigate whether a machine learning model can be developed to predict aggressive behaviour prior to it's occurrence, using data collected from a smartwatch.

Hypotheses

- A machine learning model can be developed to predict aggressive behaviour one hour in advance, using physiological data.
- A machine learning model can be developed to predict aggressive behaviour using sleep data the night before it occurs.

METHOD

Ethical Approval

Ethical approval was sought from the North of Scotland NHS Research Ethics Committee and the Disabilities Trust Research Ethics Committee (Appendix 2.1). Approval via the Medicines and Healthcare products Regulatory Agency was not required, as the study did not involve randomisation, change to standard treatment or aim to claim generalisation of findings. NHS Research and Development approval was not required, as the research was conducted at a non-NHS site.

Design

A case series design was used.

Participants

Participants were recruited from Graham Anderson House (GAH), a specialist assessment and rehabilitation hospital for people with complex needs requiring residential support following a non-progressive ABI.

Eligibility Criteria

Participants had sustained a severe brain injury, were aged ≥16 years old, were presenting with challenging behaviour during the recruitment period, and were deemed to have capacity to consent to participation in research by professionals responsible for their care.

Recruitment

The recruitment period was between 2nd April and 7th May 2018. Seven identified participants met inclusion criteria. After being approached regarding participation by the clinical team, a member of the research team approached participants to discuss the details of the study. This included information regarding data collected by the devices, device maintenance, and data confidentiality. Participants were also provided with an information sheet and offered at least 24 hours before obtaining written informed consent (Appendices 2.2, 2.3). Two participants were withdrawn within two weeks of enrolment as they failed to wear the smartwatch. Details of the remaining five participants are provided in Table 1; all participants were male and exhibiting both verbal and physical aggression at recruitment.

Table 1. Participant Demographics

	Participant				
	1	**2**	**3**	**4**	**5**
Age (years)	30-40	40-50	20-30	60-70	30-40
Brain Injury Type	TBI	Hypoxia	TBI	Stroke	TBI
Time since admission	>2years	<3months	<6months	>1year	>1year
Number of aggressive episodes reported in the eight weeks prior to recruitment	34	33*	33	24	20

Note: Demographic ranges used to protect anonymity
**since admission, TBI = traumatic brain injury*

Measures

Aggression - the Overt Aggression Scale - Modified for Neurorehabilitation (OAS-MNR; Alderman, Knight & Morgan, 1997) was used to record episodes of aggression. The OAS-MNR has good inter-rater reliability and validity in an inpatient setting (Alderman, Knight & Morgan, 1997). It is routinely incorporated into clinical tools used at GAH (Appendix 2.5) and forms a key component for reviewing patient progress.

The following measures were obtained from the smartwatch:

Physiological Data –

- Average Heart Rate (beats per minute; bpm)
- Maximum Heart Rate (bpm)
- Minimum Heart Rate (bpm)
- Heart Rate Variability (HRV)
- Step Count
- Skin Resistance (ohms)
- Skin Temperature (degrees Celsius)

Sleep Data –

- Total Duration (seconds)
- Time Awake (seconds)
- Light sleep (seconds)
- Number of Wake Ups
- Sleep Efficiency (percentage of time actually asleep in total sleep period)

Materials

The following equipment and software were utilised:

1. The *Microsoft Band 2* smartwatch was used to record heart rate, heart beat interval, steps, skin resistance, skin temperature and sleep.
2. A *Samsung Smartphone* was used to gether the smartwatch data via two phone applications:
    a. The *Microsoft Health* application collected and summarised the data in hours (heart rate, step count) and nights (sleep).
    b. The *TEAMED (Technology Evaluating and Measuring Emotional Dysregulation) Patient* application collected real-time continuous data from the smartwatch to calculate heart rate variability, to collect skin resistance and skin temperature data, and identify within-hour changes in physiology (e.g. rising heart rate).
3. The *TEAMED Admin* computer program was used to monitor data collection and input staff-reported aggression reports.
4. *InfluxDB* (*https://influxdata.com*) – this time-series database is run on a secure server managed by the University of Stirling and stored data gathered by the TEAMED Patient application and aggressive episodes recorded in the TEAMED Admin program.
5. *Microsoft Health Vault* – this server is managed by Microsoft and stored data gathered by the Microsoft Health application

Procedure

The data collection period was 2nd April –2nd July 2018. Data was not collected for the first three weeks due to technical difficulties requiring re-registering and updating applications, leaving a maximum of ten weeks data collection. Following enrolment, participants were asked to wear a smartwatch at all times whilst at GAH, including whilst asleep, except when showering or charging the watch. Participants were also asked to carry the smartphone on their person, or keep the phone within 10metres when asleep (e.g. on bedside table). Participants were provided with memory prompts, via a poster in their bedrooms. A member of the research team also approached participants on weekdays to offer technical support and a further memory prompt, if required. Throughout the study, staff reported aggressive behaviours via an adapted OAS-MNR.

Data Analysis

Descriptive Statistics

Descriptive statistics for physiological and sleep data (average, standard deviation) and type and severity of aggression were calculated.

Machine Learning

The machine learning package Waikato Environment for Knowledge Analysis (WEKA; Eibe, Hall & Whitten, 2016) was used. Advice regarding all components of the data analysis was sought from Dr Kevin Swingler (Computer Scientist, University of Stirling). One hour and the night prior to the aggressive episode were considered a clinically relevant warning time in an inpatient setting.

Preprocessing

Alongside hourly and daily summaries, features were created to account for the continuous nature of the data. Hours containing the aggressive episodes were not included in the analysis, unless an aggressive episode occurred in the subsequent hour. Data collected from the Microsoft Health application were processed to create the following features:

Feature	**Explanation**	**Variable**
Diff	Difference in value from hour (physical) or day (sleep) before	*Physical* – MaxHRDiff, AvHRDiff, MinHRDiff, StepCountDiff *Sleep* – DurationDiff, AwakeDiff, LightSleepDiff, WakeUpsDiff, SleepEffDiff
DiffMean	Difference in value from overall mean of value for dataset	*Physical* – MaxHRDiffMean AvHRDiffMean, MinHRDiffMean StepCountDiffMean *Sleep* – DurationDiffMean, AwakeDiffMean, LightSleepDiffMean, WakeUpsDiffMean, SleepEffDiffMean

Abbreviations: Diff = Difference*, HR* = Heart Rate*, Av* = Average*, Min* = Minimum*, SleepEff* = Sleep Efficiency

Real-time physiological data collected from the TEAMED Patient application were processed by Professor Ken Turner (Computer Scientist, University of Stirling), who created

the following features:

Feature	Explanation	Variable
Standard Deviation (SD)	Number of standard deviations the maximum physiological measure in the previous hour is from the mean for the hour before that	HRSD, HRVSD, SkinResistanceSD, SkinTempSD, StepCountSD
Peaks	Number of peaks in physiologicalmeasurefor the previous hour	HRPeaks, HRVPeaks, StepCountPeaks SkinTempPeak
Trough	Number of troughs in physiological measure for the previous hour	SkinResistanceTrough,
Trend (rising)	Largest number of rising steps in the physiological measure for the previous hour	HRTrend, HRVTrendSkinTempTrend, StepCountTrend
Trend (falling)	Largest number of falling steps in the physiological measure for the previous hour	SkinResistanceTrend

Abbreviations: Max = Maximum, *HR* = Heart Rate, *HRV* = Heart Rate Variability, *SkinTemp* = Skin Temperature

There were not enough sleep data collected via the TEAMED Patient application to create sleep features.

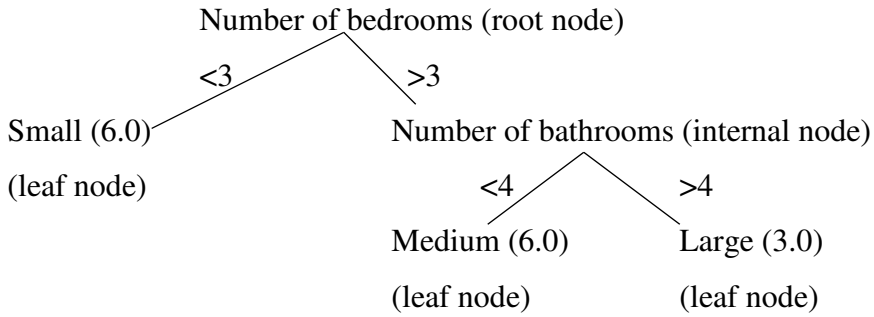
Preprocessing methods were also used to account for the small number of hours with aggressive behaviours, and large number of hours without aggression. Imbalanced datasets lead to difficulties implementing data mining techniques to create prediction models, as the simplest model is to class all data as 'normal' (Chawla et al, 2002). In a real-world setting, the cost of 'misclassifying' an abnormal event as normal is often much higher than the reverse. Two methods were explored to decrease misclassification errors: the Synthetic Minority Over-Sampling Technique (SMOTE; Chawla et al, 2002) and Cost Sensitive Classification (University of Waikato, 2018a). SMOTE creates new (or 'synthetic') data points near to collected data points up to a desired percentage. For example, if the majority class contained 100 data points and the minority class contained 25 data points, over-sampling at 400% would create an equal number of data points in each class. Cost-Sensitive

Classification increases the "cost" of misclassification and the selected algorithm will attempt to produce a model that minimises the number of misclassifications in the chosen class (Quin et al, 2010).

Algorithm Selection

Three algorithms were explored: J48 (Bhargava et al, 2013), Logistic Regression and Multilayer Perceptron.

J48 is a decision tree algorithm that makes flowchart-like decisions to classify the dependent variable (aggression or no aggression) with the independent variables (physiological and sleep data). The first decision is made at the "root node", which will either lead to a "leaf node" (a classification) or an "internal node" (another decision). Below is a simplified example for classifying house size:

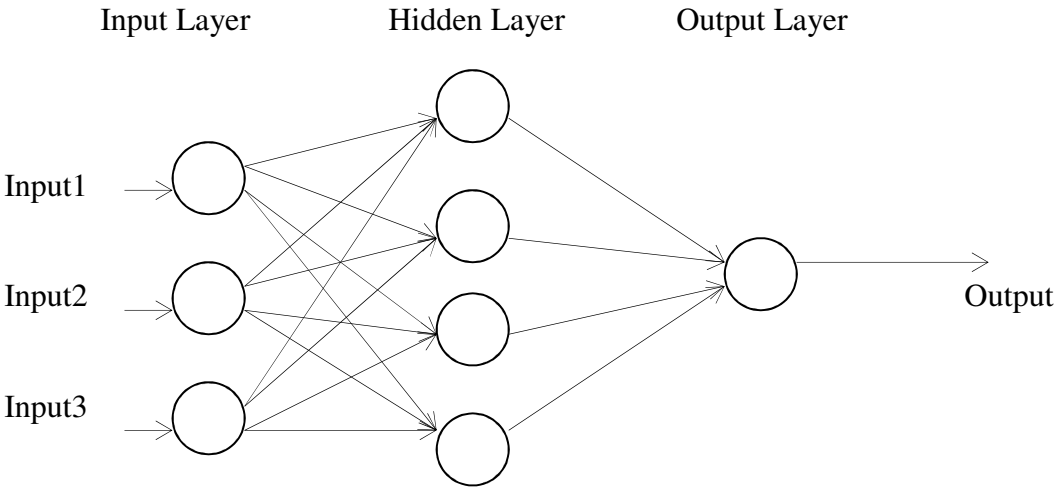


Increasing the minimum number of objects a leaf can contain decreases the number of internal nodes. This helps manage the complexity of the tree, and reduces bias to a tree that may be overfitting to the training data, and subsequently would poorly predict new testing data it is presented with.

Logistic Regression is used to build a model based on the relationship between the dependent variable and independent variable(s) to estimate one of two outcomes (Kumar & Sahoo, 2012). The model is built using coefficients, which measure each independent variables' predictive capability, and odds ratios, which indicate the effect of the independent variable on the likelihood the outcome will occur.

Multilayer Perceptron is an artificial "neural network" whereby a network of mathematical functions ("hidden layers") are placed on the independent variables ("inputs") in order to predict the dependent variable (Kumar & Sahoo, 2012). Increasing the number of hidden layers increases the model complexity. A simple multilayer perceptron layout is provided

below:



Modelling

When building and evaluating a model there is a training phase, a validation phase, and a testing phase. The training phase takes a proportion of the data to build the model, and the validation phase uses a proportion of the data to validate the predictability of the model. These training and validation phases are repeated with all selected algorithms and preprocessing methods to develop one final model. The testing phase uses unseen data kept separately from the data used in the training and validation phases, which evaluates the final predictability of the chosen model.

When carrying out the training and validation phases, a Cross-Validation method can be used. Cross-Validation divides a proportion of the data into 10 equal subsets ("folds"), builds a model with 9 of the folds, and validates the model on the 10^{th}. This process is repeated 10 times using different partitions of the same proportion of data. The subsequent model is then validated a final time on the entire proportion (University of Waikato, 2012b). This reduces overfitting of the model by using different subsets of the data. This method was adopted when using Cost-Sensitive Classification. However, this method was not adopted when using SMOTE, to ensure the validation phase only contained real data points. Therefore when using SMOTE, the data were manually split into a training set (66%) and a validation set (33%).

Modelling

Different models were explored using the three algorithms, and using Cost-Sensitive Classification and SMOTE. The following values were obtained to determine the

predictability of each model:

Accurate Predictions	Number of correct predictions of aggressive episodes (true positives)
False Alarms	Number of incorrect predictions of aggressive episodes (false positives)
Misses	Number of aggressive episodes not predicted (false negatives)
Precision	Rate of accurate predictions compared with total number of predictions
Recall	Rate of accurate predictions compared with total number of aggressive episodes

Precision and Recall values range between 0.00 and 1.00, with 1.00 indicating that all predictions were accurate predictions i.e. no false alarms (Precision) or that all aggressive episodes were predicted i.e. no misses (Recall).

A final model indicating the best balance between precision and recall values was identified for each participant. A model using all available training data across participants was also explored, to determine whether a single model could be used to predict aggression. The final models were evaluated using the unseen testing data.

RESULTS

Attrition

Three participants withdrew from the study.

Participant 1 sustained an arm injury and chose to withdraw from the study as they did not wish to wear the watch on their alternate wrist. This adverse event was not an anticipated consequence of participation and was unrelated to the study procedures and device. This led to four fewer days of data collection than anticipated.

Participant 3 chose to withdraw from the study due to concerns about losing the phone. This led to 24 fewer days of data collection than anticipated.

Participant 5 developed delusional beliefs, associated with social circumstances whilst away from the unit and not wearing the devices, and chose to withdraw from the study upon their return. This adverse event was not an anticipated consequence of participation was unrelated to the study procedures and device. This led to 19 fewer days of data collection than anticipated.

Missing Data

Table 2 provides a summary of data collected for each participant. Reasons for missing data included:

- Participants not charging or wearing the smartwatch or carrying the phone
- Significant aggression leading to risk associated with prompting participants
- Staff failing to provide a time on aggression reports
- Bluetooth reconnection difficulties between the smartwatch and phone
- WiFi reconnection difficulties causing data to become lost before it could be uploaded to the server
- Smartwatches becoming unusable (e.g. stopped charging, would not switch on, buttons not working; reason(s) unknown)

Table 2. Summary of Data Collection for Physiological Data, Sleep Data, and Aggression Reports

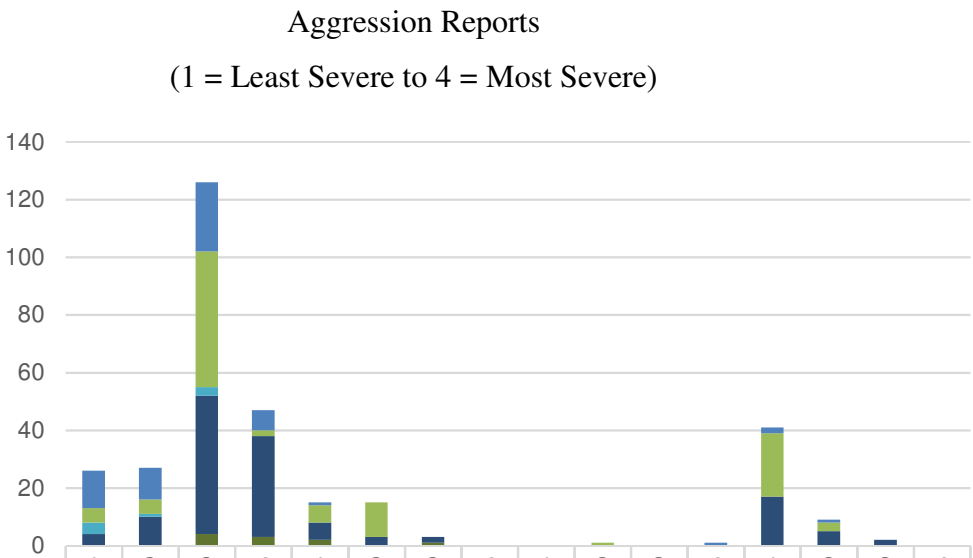
	Participant				
	1	2	3	4	5
Data collection period (excluding home passes)					
Days (*N*(hours))	59(1416)	70(1680)	40(960)	70(1680)	19(456)
N of Nights	58	69	22	69	19
Number of hours physiological data collected (% total)					
TEAMED patient	536(38%)	139(8%)	92(10%)	270(16%)	33(4%)
Microsoft Health	1009(71%)	803(48%)	628(65%)	976(58%)	369(81%)
Sleep data collected (excluding home passes)					
N of nights(%)	34(59%)	32(46%)	22(100%)	30(43%)	17(89%)
Aggressive episodes					
Total reported	32	76	7	67	4
N reported with time/date(%)	27(84%)	66(87%)	7(100%)	59(88%)	4(100%)

Note: physiological data could not be collected for all aggressive reports

Descriptive Statistics

Figure 1 provides a summary of the types of aggression recorded for each participant. Each completed OAS-MNR aggression report (episode) often contained more than one type of aggressive behaviour and/or behaviour severity rated from 1 (least severe) to 4 (most severe).

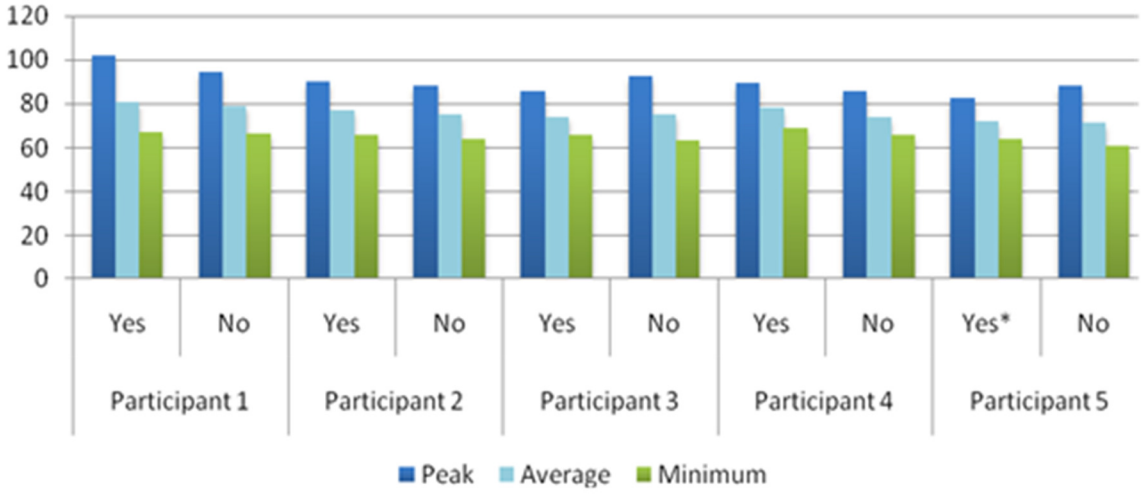
Figure 2 and 3 provide examples of the data gathered for physiological and sleep measures. A detailed summary of the means and standard deviations for all variables can be found in Appendix 2.5.



	Verbal Aggression				Physical Aggression Against Objects				Physical Aggression Against Self				Physical Aggression Against Other Person			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Participant 1	13	11	24	7	1	0	0	0	0	0	0	1	2	1	0	0
Participant 2	5	5	47	2	6	12	0	0	0	1	0	0	22	3	0	0
Participant 3	4	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Participant 4	4	10	48	35	6	3	2	0	0	0	0	0	17	5	2	0
Participant 5	0	0	4	3	2	0	1	0	0	0	0	0	0	0	0	0

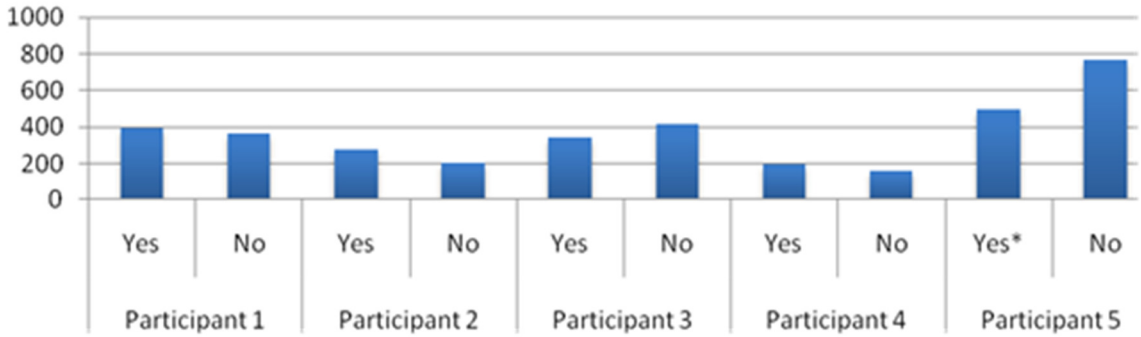
Figure 1. Summary of Aggressive Behaviour Reports

Heart Rate



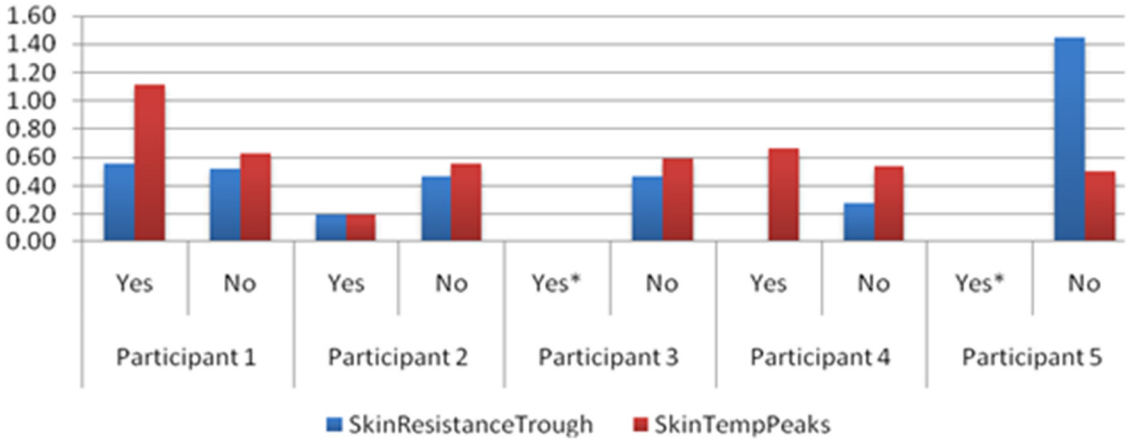
**Value based on one aggression report*

Step Count



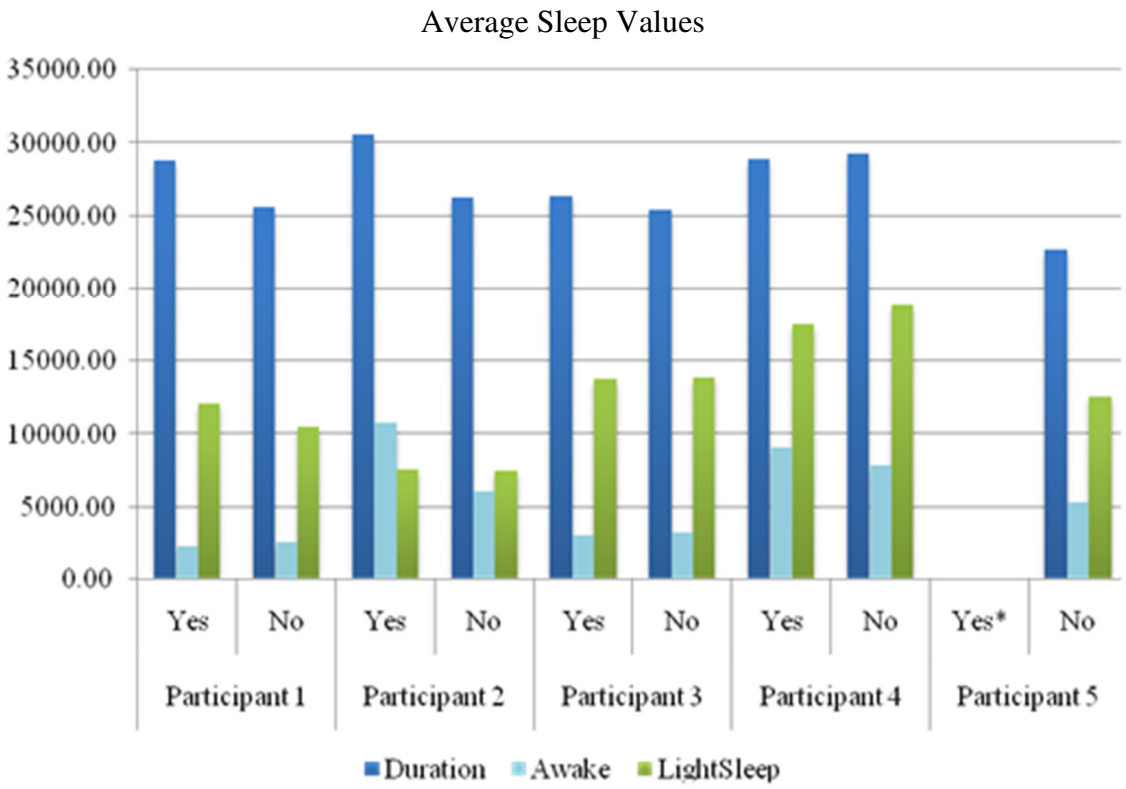
**Value based on one aggression report*

Skin Resistance and Skin Temperature



**No aggressive episodes captured by the data*

Figure 2. Summary of Heart Rate, Step Count, Skin Resistance and Skin Temperature



**No aggressive episodes capture by the data*

Figure 3. Summary of Average Sleep Values for Duration Asleep (Duration), Time Awake During Sleep Period (Awake), Light Sleep Duration (LightSleep)

Machine Learning

Due to the small number of aggressive episodes for Participant 3 and Participant 5, individual models for these participants were not possible with Microsoft Health or TEAMED application data. Nevertheless, all participant training and testing data were included in a combined model. Due to the lack of consecutive nights of sleep collected by the TEAMED application, analysis of this data was not possible.

Details of the characteristics of the final individual and combined models can be found in Table 3. Predictability of the final individual and combined models can be found in Tables 4 and 5, respectively. Appendix 2.6 provides details of alternative models explored. Both SMOTE and Cost-Sensitive Classification and all three selected algorithms were chosen when developing the models for the Microsoft Health data. Only Cost-Sensitive Classification preprocessing could be explored with the TEAMED Application data as there

were too few aggressive episodes with associated physiological recordings to explore SMOTE.

Physiological Models

Most individual models developed using Microsoft Health data performed worse in the testing phase, identifying 14-33% of reported aggressive episodes compared to 50-71% identified in the validation phase. Further, of the model predictions, 94-96% were false alarms, compared with actual episodes. Models developed using TEAMED Patient data improved in the testing phase for Participants 2 and 4, with 50% and 100% of reported aggressive episodes accurately predicted, respectively, compared with 33 and 75% predicting during the validation phase. However, a large proportion of predictions were false alarms (90-93%).

The combined model developed using Microsoft Health data performed poorly for Participants 1 and 2 in the testing phase, identifying 0% and 29% of aggressive episodes respectively. The model improved for Participant 4, identifying 83% of aggressive episodes. The combined model developed from the TEAMED Patient data performed poorly across participants, identifying 0-50% of aggressive episodes.

Sleep Models

Individual models developed using Microsoft Health data for Participants 1 and 4 performed well in the testing phase, identifying 100% of aggressive episodes, compared with 100% and 46% identified in the validation phase, respectively. Fifty percent and 60% of predictions were false alarms, compared with actual episodes, respectively. The model developed for Participant 2 performed worse in the testing phase, identifying 0% of aggressive episodes, compared to 25% during the validation phase; therefore 100% of predicted episodes were false alarms. Performance of the combined model varied across Participants 1, 2 and 4, identifying 0%, 100% and 67% of aggressive episodes respectively in the testing phase; 0%. 60% and 100% of predictions were false alarms, respectively.

Table 3. Summary of Final Models

		Model Details		
1. Individual Models		Participant 1	Participant 2	Participant 4
Physiological Data				
Microsoft Health	Preprocessing	SMOTE (8300%)	Cost (45, yes)	SMOTE (1200%)
	Algorithm	J48 (MinNumObj = 40)	J48 (MinNumObj = 40)	Logistic Regression
	Best Predictors	MaxHRDiff, AvHRDiff, MinHR Diff, StepCount	MaxHR, StepCount, MinHR, MinHRDiff	AvHRDiffMean, MinHRDiff
TEAMED Patient	Preprocessing	Cost (120, yes)	Cost (65, yes)	Cost (45, no)
	Algorithm	Multilayer Perceptron (Hidden Layers = 22)	Logistic Regression	J48 (MinNumObj = 50)
	Best Predictors	HRSDMax, StepCountPeaks, HRTrend	HRTrend, HRPeaks, StepCountTrend	HRVPeaks
Sleep Data				
Microsoft Health	Preprocessing	SMOTE (400%)	Cost (1.5, yes)	Cost (2, no)
	Algorithm	Logistic Regression	J48 (MinNumObj = 3)	J48 (MinNumObj = 2)
	Best Predictors	SleepEffDiffMean, WakeUps, SleepEff, SleepEffDiff	SleepEffDiff	WakyUpsDiff, WakeUps
2. Combined Models		**Model Details**		
Physiological Data		Participants 1 - 5		
Microsoft Health	Preprocessing	Cost (35, yes)		
	Algorithm	Multilayer Perceptron (Hidden Layers = 15)		
	Best Predictors	MaxHRDiff, MinHR, StepCountDiff, StepCountDiffMean		
TEAMED Patient	Preprocessing	Cost (70, yes)		
	Algorithm	Multilayer Perceptron (Hidden Layers = 18)		
	Best Predictors	SkinResistanceTrough, SkinResistanceTrend, StepCountPeak, HRVTrend		
Sleep Data				
Microsoft Health	Preprocessing	SMOTE (100%)		
	Algorithm	Multilayer Perceptron (Hidden Layers = 20)		
	Best Predictors	Duration, WakeUpsDiff, DurationDiff, WakeUpsDiffMean		

Table 4. Summary of Findings of Individual Models

	Participant 1		Participant 2		Participant 4	
Physiological Data						
Microsoft Health	**Validation**	**Testing**	**Validation**	**Testing**	**Validation**	**Testing**
Accurate Predictions (*N*)	3	1	8	3	5	6
False Alarms (*N*)	18	67	165	70	56	92
Misses (*N*)	2	6	8	5	2	12
Precision	0.14	0.02	0.05	0.04	0.08	0.06
Recall	0.60	0.14	0.50	0.38	0.71	0.33
TEAMED Patient						
Accurate Predictions (*N*)	2	1	1	1	3	2
False Alarms (*N*)	75	14	15	9	57	38
Misses (*N*)	2	4	2	1	1	0
Precision	0.03	0.07	0.06	0.10	0.05	0.05
Recall	0.50	0.20	0.33	0.50	0.75	1.00
Sleep Data						
Microsoft Health						
Accurate Predictions (*N*)	4	4	3	0	6	3
False Alarms (*N*)	1	6	4	0	3	3
Misses (*N*)	0	0	9	3	7	0
Precision	0.80	0.40	0.43	-	0.67	0.50
Recall	1.00	1.00	0.25	0.00	0.46	1.00

Table 5. Summary of Findings of Combined Models

	Validation Phase	**Testing Phase**				
Physiological	Participants 1 - 5	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Microsoft Health						
Accurate Predictions (*N*)	29	2	0	-	15	1
False Alarms (*N*)	600	168	41	43	217	4
Misses (*N*)	21	5	8	-	3	0
Precision	0.05	0.01	0.00	-	0.07	0.20
Recall	0.58	0.29	0.00	-	0.83	1.00
TEAMED Patient						
Accurate Predictions (*N*)	1	0	1	-	0	-
False Alarms (*N*)	56	28	10	3	6	0
Misses (*N*)	10	5	1	-	2	-
Precision	0.02	0.00	0.09	-	0.00	-
Recall	0.09	0.00	0.50	-	0.00	1.00
Sleep						
Microsoft Health						
Accurate Predictions (*N*)	9	0	3	-	2	-
False Alarms (*N*)	9	2	0	0	3	0
Misses (*N*)	5	4	0	-	1	-
Precision	0.50	0.00	1.00	-	0.40	-
Recall	0.70	0.00	1.00	-	0.67	-

- = No physiological data available for staff –reported episodes of aggression

DISCUSSION

This study aimed to provide new insight into the possibility of using data gathered from a smartwatch to predict, in advance, aggressive behaviour in an inpatient ABI population via machine learning. It was possible to develop both individual and combined models that could predict episodes of aggression, however there were a large number of false alarms that meant the models lacked clinically utility.

Unanticipated practical and technical problems led to data collection difficulties. The cognitive demand of carrying a phone and wearing a smartwatch proved difficult for some participants. This meant one device was neglected and data could not be collected and/or uploaded. Adverse events unrelated to the study also led to unanticipated data collection difficulties, which highlight the ongoing social and emotional difficulties faced by this clinical population. Further, relying on the local WiFi connection, where multiple devices are competing for access, meant TEAMED Patient data were lost before it could be uploaded. In a real-world environment, it is expected these difficulties would have been reduced as participants could download the application onto their own phone, which will likely have 4G capability.

Due to the above difficulties, data analyses were completed with fewer than expected episodes of aggression, which contributed to overfitting of the models. The study was also limited by the use of a staff-reported measure of challenging behaviour. There were OAS-MNR aggression reports where staff members' failed to report a time, therefore physiological data will have been labelled incorrectly. Variations in staff threshold for reporting aggression, staff time constraints, and relying on staff to be present during all episodes, will also have led to under-reporting. Considering the interpersonal nature of challenging behaviour, there are likely situations where staff interactions may have improved participant arousal thus preventing the aggressive behaviour from occurring. Further, previous studies have explored the use of machine learning techniques to identify physiological changes associated with fluctuations in self-reported stress levels (Sano et al, 2018; Umematsu et al, 2018) therefore difficulties with developing a suitable model may have been associated with higher arousal levels identified by the algorithm but below the threshold of aggressive behaviour reported by staff. This may offer some explanation for the high number of false alarms, where participants were able to use self-management, seek

support or where staff intervened during these experiences, leading to de-escalation. Therefore alternative measures, such as a self-report diary, may have been useful to include in addition to staff reporting.

Recommendations

The following recommendations are proposed:

Practical Considerations

- Visual and verbal prompts – incorporating prompts into routine clinical care, e.g. personal care, may reduce burden to participants
- Participant involvement – training the participant to use the applications may help to reduce data collection difficulties requiring manual re-synchronisation or Internet connection.

Technical Considerations

- Available Internet connection – using a phone with 4G access as well as a WiFi connection will help reduce missing data
- Battery life – a long battery life for both the smartwatch and phone will reduce the cognitive demands placed on individuals to charge the devices
- Storage capacity –a large storage capacity would reduce the likelihood of losing data during Bluetooth and Internet connection difficulties
- Computer software – the ability to remotely monitor whether data is being collected from technology allows staff to identify when prompting is required

Other Considerations

- Self-reported aggression – including self-report measures (e.g. stress, anger) may improve the detection of associated physiological changes
- Adverse event reporting – considering the clinical population and novel nature of the study, it is important for future studies to report details of any adverse events via appropriate guidelines (e.g. NHS Health Research Authority; 2018)

Future research might also like to explore different algorithms, explore physiological data gathered during wake and sleep separately, or compare physical and verbal aggression, or aggression severity. For example, the models developed in this study included physiological data gathered during sleep as aggressive episodes were also reported overnight. There is much research identifying the impact of stress on HRV during sleep (e.g. Brosschot, Van

Dijk and Thayer, 2007; Martica et al, 2004), which may have been sufficient for models to detect physiological change.

Conclusions

Being one of a few studies of its kind, this study provides useful considerations for conducting research with wearable devices in the ABI inpatient population. Due to the unanticipated data collection and aggression reporting difficulties, it is unlikely that the current findings truly reflect the applicability of machine learning for the purpose explored here. Therefore future research that incorporates the proposed recommendations would offer further insight into the possibility of using smartwatch technology and data mining approaches for predicting challenging behaviour in the ABI population.

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SYSTEMATIC REVIEW APPENDICES

Appendix 1.1 Instructions to authors for submission to Neuropsychological Rehabilitation

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Updated 26-01-2018

Appendix 1.2 Search Strategies

MEDLINE

1. exp Anoxia/ or anoxia.mp.
2. exp Brain concussion/ or brain conscussion.mp.
3. exp Brain edema/ or brain edema.mp.
4. exp Brain injuries/ or brain injur*.mp.
5. exp Cerebral Hemorrhage/ or cerebral hemorrhage.mp.
6. exp Cerebral Hemorrhage, Traumatic/ or cerebral haemorrhage, traumatic.mp.
7. exp cerebrovascular trauma/ or cerebrovascular trauma.mp.
8. exp craniocerebral trauma/ or craniocerebral trauma.mp.
9. exp coma/ or coma.mp.
10. exp glasgow outcome scale/ or Glasgow outcome scale.mp.
11. exp glasgow coma scale/ or Glasgow coma scale.mp.
12. exp Hypoxia, Brain/ or Hypoxia, brain.mp.
13. exp unconsciousness or unconsciousness.mp.
14. exp encephalitis/ or encephaliti*.mp.
15. exp meningitis/ or meningitis*.mp.
16. (Glasgow adj (coma or outcome) adj (scale* or score*)).mp.
17. diffuse axonal injur*.mp.
18. ((brain* or capitis or cerebr* or crani* or hemispher* or inter-cran* or intra-crani* or skull* or head or forebrain or cerebellar or brainstem or vertebrobasilar) adj3 (contusion* or bleed* or hemorrhag* or haemorrhag* or haematoma* or hematoma* or apoplexy or emboli* or pressure or damag* or fractur* or injur* or trauma* or wound* or aneurysm* or anoxi* or hypoxi* or ischaem* or ischem* or thrombo* or oedema or edema or swell*)).mp.
19. or/1-18
20. exp Neurofeedback/ or neurofeedback.mp.
21. neurotherapy.mp.
22. exp Biofeedback, Psychology/ or biofeedback.mp.
23. or/20-22
24. 19 and 23

EMBASE

1. exp Anoxia/ or anoxia.mp.
2. exp Brain concussion/ or brain conscussion.mp.
3. exp Brain edema/ or brain edema.mp.
4. exp Brain injury/ or brain injur*.mp.
5. exp BrainHemorrhage/ or brain hemorrhage.mp.
6. exp Traumatic brain injury/ or traumatic brain injury.mp.
7. expHead Injury/ or head injury.mp.
8. exp coma/ or coma.mp.
9. exp glasgow outcome scale/ or Glasgow outcome scale.mp.
10. exp glasgow coma scale/ or Glasgow coma scale.mp.
11. exp Brain hypoxia/ or brain hypoxia.mp.
12. exp unconsciousness or unconsciousness.mp.
13. exp encephalitis/ or encephaliti*.mp.
14. exp meningitis/ or meningitis*.mp.
15. (Glasgow adj (coma or outcome) adj (scale* or score*)).mp.
16. diffuse axonal injur*.mp.
17. ((brain* or cerebr* or crani* or hemispher* or inter-cran* or intra-crani* or skull* or head or forebrain or cerebellar or brainstem or vertebrobasilar) adj3 (contusion* or bleed* or hemorrhag* or haemorrhag* or haematoma* or hematoma* or apoplexy or emboli* or pressure or damag* or fractur* or injur* or trauma* or wound* or aneurysm* or anoxi* or hypoxi* or ischaem* or ischem* or thrombo* or oedema or edema or swell*)).mp.
18. or/1-17
19. exp Neurofeedback/ or neurofeedback.mp.
20. (neurotherapy or EEG feedback).mp.
21. exp feedback system or biofeedback.mp.
22. or/19-21
23. 18 and 22

PsycINFO Search Strategy

1. SU Anoxia or KW anoxia
2. SU Brain concussion or KW brain concussion
3. SU Brain edema or KW brain edema
4. SU Brain injury or KW brain injur*
5. SU Brain Hemorrhage or KW brain hemorrhage
6. SU Traumatic Brain Injury or KW traumatic brain injury
7. SU Head Injury or KW head injury
8. SU Cerebral Hemorrhage or KW cerebral hemorrhage
9. SU cerebrovascular accident or KW cerebrovascular accident
10. SU craniocerebral trauma or KW craniocerebral trauma
11. SU coma or KW coma
12. SU glasgow outcome scale or KW Glasgow outcome scale
13. SU glasgow coma scale or KW Glasgow coma scale
14. SU hypoxic brain injury or KW hypoxia brain injury
15. SU unconsciousness or KW unconsciousness
16. SU encephalitis or KW encephaliti*
17. SU meningitis or KW meningitis*
18. KW (Glasgow adj (coma or outcome) adj (scale* or score*))
19. KW diffuse axonal injur*
20. KW ((brain* or capitis or cerebr* or crani* or hemispher* or inter-cran* or intra-crani* or skull* or head or forebrain or cerebellar or brainstem or vertebrobasilar) adj3 (contusion* or bleed* or hemorrhag* or haemorrhag* or haematoma* or hematoma* or apoplexy or emboli* or pressure or damag* or fractur* or injur* or trauma* or wound* or aneurysm* or anoxi* or hypoxi* or ischaem* or ischem* or thrombo* or oedema or edema or swell*))
21. or/1-20
22. SU Neurofeedback or KW neurofeedback
23. SU neurotherapy or KW neurotherapy
24. SU biofeedback or SU biofeedback therapy or KW biofeedback
25. or/22-24
26. 21 and 25

CENTRAL

1. MeSH descriptor: [Hypoxia] explode all trees
2. MeSH descriptor: [Brain Concussion] explode all trees
3. MeSH descriptor: [Brain Edema] explode all trees
4. MeSH descriptor: [Brain Injuries] explode all trees
5. MeSH descriptor: [Intracranial Hemorrhages] explode all trees
6. MeSH descriptor: [Craniocerebral Trauma] explode all trees
7. MeSH descriptor: [Cerebral Hemorrhage] explode all trees
8. MeSH descriptor: [Unconsciousness] explode all trees
9. MeSH descriptor: [Glasgow Outcome Scale] explode all trees
10. MeSH descriptor: [Glasgow Coma Scale] explode all trees
11. MeSH descriptor: [Hypoxia, Brain] explode all trees
12. MeSH descriptor: [Encephalitis] explode all trees
13. MeSH descriptor: [Meningitis] explode all trees
14. ((brain* or capitis or cerebr* or crani* or hemispher* or inter-cran* or intra-crani* or skull* or head or forebrain or cerebellar or brainstem or vertebrobasilar) next/3 (contusion* or bleed* or hemorrhag* or haemorrhag* or haematoma* or hematoma* or apoplexy or emboli* or pressure or damag* or fractur* or injur* or trauma* or wound* or aneurysm* or anoxi* or hypoxi* or ischaem* or ischem* or thrombo* or oedema or edema or swell*)):ti,ab,kw (Word variations have been searched)
15. (Glasgow next (coma or outcome) next (scale* or score*)):ti,ab,kw (Word variations have been searched)
16. "unconsciousness" or "diffuse axonal injur*" or "encephaliti*" or "meningiti*":ti,ab,kw (Word variations have been searched)
17. MeSH descriptor: [Biofeedback, Psychology] explode all trees
18. "neurofeedback" or "neurotherapy" or "biofeedback":ti,ab,kw (Word variations have been searched)
19. {or #1-#16}
20. {or #17-#18}
21. #19 and #20

ClinicalTrials.gov

Conditions: Brain Injury

Interventions: neurofeedback OR neurotherapy OR biofeedback

Appendix 1.3 Clinical Trials Assessment Measure (CTAM)

Trial design area	Item	Score
Sample two questions: maximum score = 10	Q1: is the sample a convenience sample (score 2) or a geographic cohort (score 5), or highly selective sample, e.g., volunteers (score 0) Convenience sample—e.g., clinic attenders, referred patients or Geographic cohort—all patients eligible in a particular area	
	Q2: is the sample size greater than 27 participants in each treatment group (score 5) or based on described and adequate power calculations (score 5)	
Allocation three questions: maximum score = 16	Q3: is there true random allocation or minimisation allocation to treatment groups (if yes score 10)	
	Q4: is the process of randomisation described (score 3)	
	Q5: is the process of randomisation carried out independently from the trial research team (score 3)	
Assessment (for the main outcome) five questions: maximum score = 32	Q6: are the assessments carried out by independent assessors and not therapists (score 10)	
	Q7: are standardised assessments used to measure symptoms in a standard way (score 6), idiosyncratic assessments of symptoms (score 3)	
	Q8: are assessments carried out blind (masked) to treatment group allocation (score 10)	
	Q9: are the methods of rater blinding adequately described (score 3)	
	Q10: is rater blinding verified (score 3)	
Control groups one question: maximum score = 16	Q11: TAU is a control group (score 6) and/or a control group that controls for non-specific effects or other established or credible treatment (score 10)	
Analysis two questions: maximum score = 15	Q12: the analysis is appropriate to the design and the type of outcome measure (score 5)	
	Q13: the analysis includes all those participants as randomised (sometimes referred to as an intention to treat analysis) (score 6) and an adequate investigation and handling of drop outs from assessment if the attrition rate exceeds 15% (score 4)	
Active treatment two questions: maximum score = 11	Q14: was the treatment adequately described (score 3) and was a treatment protocol or manual used (score 3)	
	Q15: was adherence to the treatment protocol or treatment quality assessed (score 5)	
Total score =		

Where the criterion is not reached for any question score = 0, Total maximum score = 100

Appendix 1.4 Reasons for Excluded Full-Text Articles

Study	Reason for Exclusion
Ayers 1999	Review
Ayers 2006	Review and Case Studies
Burke et al 1991	Case Study Design
Keller & Rottensteiner 2000	No between group comparisons completed
Keller 2001	No between group comparisons completed
Manko et al 2013	No between group comparisons completed
Schoenberger et al 2001	Involuntary modulation neurofeedback protocol
Thornon & Carmody 2013	Normative reference group used as control group

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Appendix 1.5 Summary of Means, Standard Deviations (SD) and Effect Sizes (ES)

	Neurofeedback Group			Control Group			ES (Cohen's *d*)[b]	
	Pre-	Post-	*Mean Diff*	Pre-	Post-	*Mean Diff*	Post-Intervention Means	*Mean Diffs*
Reddy et al 2013(n = 60) *Cognition*	Mean(SD)	Mean(SD)[a] *After 3-5 weeks*	Mean(SD)	Mean(SD)	Mean(SD)[a] *After 1 month*	Mean(SD)		
Finger Tapping (sec) Right	40.07(13.44)	47.57(7.45)**	-7.50(10.79)	44.59(8.64)	44.63(10.08)^{NS}	-0.03(6.81)	0.33	0.83
Left	37.46(11.80)	42.04(7.97)**	-4.58(9.73)	40.18(9.95)	40.31(11.22)^{NS}	-0.13(5.84)	0.18	0.55
DSST (sec)	327.41 (194.87)	302.24 (173.09)**	25.17 (176.65)	402.21 (249.05)	350.41 (159.84)^{NS}	51.79 (163.70)	0.29	0.16
Digit Vigilance Test (sec)	685.59 (346.54)	564.48 (256.23)**	121.10 (304.16)	699.41 (279.89)	665.24 (280.32)^{NS}	34.17 (146.59)	0.38	0.36
Animal Names Test	18.50(54.66)	35.23(133.53)**	-16.73(147.19)	10.13(3.81)	10.17(3.26)^{NS}	-0.03(2.85)	0.27	0.16
Working Memory 1Back Hits	7.73(2.43)	8.20(1.86)*	-0.47(1.53)	7.83(1.76)	8.13(1.11)^{NS}	-0.30(1.82)	0.05	0.10
2Back Hits	4.63(2.67)	6.83(1.84)**	-2.20(2.40)	5.70(2.07)	5.33(2.09)^{NS}	0.37(2.37)	0.76	1.08
Tower of London Test	6.87(3.52)	9.20(1.81)**	-2.33(3.58)	8.59(2.51)	8.45(2.40)^{NS}	0.14(2.61)	0.35	0.79
WCST Perseverative Errors	41.47(34.53)	19.80(16.18)**	21.67(34.43)	38.90(27.71)	35.97(20.78)^{NS}	2.93(28.47)	0.87	0.59
Conceptual Level Responses	36.77(24.97)	56.40(16.11)**	-19.63(25.03)	33.66(19.59)	39.34(17.80)^{NS}	-5.69(19.20)	1.00	0.63
Stroop Test (sec)	159.83 (138.10)	124.93 (86.74)**	34.90 (109.42)	138.43 (120.97)	127.39 (124.20)^{NS}	11.04 (110.73)	0.02	0.22
Token Test	28.47(9.13)	34.30(2.44)**	-5.83(7.51)	32.17(3.69)	32.07(4.19)^{NS}	0.10(3.17)	0.65	1.03
AVLT Total	31.27(13.97)	48.83(11.86)**	-17.57(9.95)	38.30(13.35)	43.43(15.56)*	-5.13(9.19)	0.39	1.30
Immediate Recall	6.23(3.77)	10.60(3.62)**	-4.37(2.87)	8.87(3.48)	8.87(3.79)*	0.00(2.52)	0.47	1.62
Delayed Recall	5.80(3.64)	10.33(3.80)**	-4.53(2.84)	8.33(3.44)	8.90(3.56)*	-0.57(2.22)	0.39	1.56
CFT Copy	28.40(11.89)	33.90(4.51)**	-5.50(9.55)	30.97(6.23)	31.86(3.90)*	-0.90(3.94)	0.48	0.63
Immediate Recall	12.67(8.41)	22.10(9.58)**	-9.43(7.30)	15.90(8.16)	19.72(7.93)^{NS}	-3.83(7.40)	0.27	0.76
Delayed Recall	13.07(8.42)	22.40(9.22)**	-9.33(8.37)	16.52(8.13)	19.03(8.19)^{NS}	-2.52(6.40)	0.39	0.92

continued

Post-Concussion Symptoms								
Visual Analog Scale	7.87(2.22)	2.83(2.13)**	-5.03(1.49)	6.20(3.02)	5.77(3.07)*	-0.43(1.33)	1.11	3.25
RHIFQ	30.20(7.59)	13.20(7.85)**	-17.00(8.82)	26.57(10.29)	22.27(10.15) ^{NS}	-4.30(8.72)	1.00	1.47
RPQ	41.33(9.80)	12.90(7.02)**	-28.43(9.09)	38.40(11.94)	35.33(12.62)	-3.06(9.06)	2.10	2.79
Quality of Life Scale								
Physical	17.00(3.42)	22.90(2.02)**	5.90(3.88)	19.67(3.19)	19.77(3.52)*	0.10(3.49)	1.09	1.57
Psychological	15.17(3.05)	19.10(1.82)**	3.93(2.49)	16.73(2.59)	17.27(3.23)^{NS}	0.53(2.90)	0.70	1.25
Social	8.47(1.97)	10.47(0.97)**	2.00(1.76)	8.97(1.45)	9.33(1.47)^{NS}	0.36(1.62)	0.92	0.96
Environmental	28.00(5.11)	30.77(2.81)**	2.76(4.26)	27.80(3.56)	27.80(3.38)^{NS}	0.00(3.09)	0.96	0.75
Total	68.63(11.85)	83.23(5.68)**	14.60(10.01)	73.16(8.38)	74.16(9.28)^{NS}	1.0(8.90)	1.18	1.43
Rostami et al 2017 (n = 13)								
Cognition		*After 4 weeks*			*After 4 weeks*			
WMS-IV Memory quotient	84.83(23.02)	87.66(16.44)^{NS}	2.83(11.50)	79.40(13.42)	88.60(23.07)^{NS}	9.2(11.08)	0.05	0.56^{NS}
General info	3.75(1.38)	4.50(1.30)^{NS}	0.75(1.16)	4.20(1.78)	4.80(2.16)^{NS}	0.60(1.94)	0.17	0.09^{NS}
Orientation	3.75(1.58)	4.25(0.88)^{NS}	0.50(1.06)	4.00(1.22)	4.20(1.78)^{NS}	0.20(0.83)	0.04	0.32^{NS}
Learning association	12.75(5.46)	15.00(4.65)^{NS}	2.25(2.95)	11.60(3.59)	15.60(4.56)*	4.00(2.26)	0.13	0.67^{NS}
Mind control	3.87(3.31)	3.75(2.60)^{NS}	-0.12(1.88)	4.80(2.28)	4.80(2.04)^{NS}	0.00(1.87)	0.45	0.06^{NS}
Logical memory	6.68(2.75)	2.75(0.97)^{NS}	0.56(2.14)	6.00(2.97)	4.18(1.87)^{NS}	0.00(1.45)	0.96	0.31^{NS}
Repeat numbers	8.62(1.92)	8.50(1.51)^{NS}	-0.12(1.35)	8.20(0.44)	8.00(2.00)^{NS}	-0.20(2.38)	0.28	0.04^{NS}
Visual memory	7.12(3.64)	3.58(1.26)^{NS}	1.37(3.62)	9.60(1.51)	2.16(0.96)^{NS}	0.60(1.67)	1.27	0.27^{NS}
DUAF Correct answers	-.	38.42(-.)^{NS}	-1.14(7.74)	-.	51.40(-.)*	10.00(7.74)	-.	1.44*
Reaction time	-.	49.00(-.)^{NS}	1.85(16.05)	-.	50.00(-.)^{NS}	11.20(12.19)	-.	0.66^{NS}
Incorrect answers	-.	51.80(-.)*	-15.28 (139.15)	-.	44.57(-.)^{NS}	36.80(25.40)	-.	0.52^{NS}
Tinius and Tinius 2001(n = 31)								
Cognition								
IVA CPT								
Full Scale Attention Q	74.30(27.30)	97.10(19.30)*	5.90(-.)	100.70(8.90)	104.30(11.00)^{NS}	3.60(-.)	0.46	-.

continued

Full Scale Response Q		91.20(19.90)	104.70(9.10)*	13.50(-.)	117.60(11.00)	112.20(12.40)^{NS}	-5.40(-.)	0.69	-.
Attention Q	Auditory	75.70(27.60)	94.70(13.40)*	19.00(-.)	102.00(9.30)	104.80(10.60)^{NS}	2.80(-.)	0.84	-.
Visual		77.00(29.50)	97.80(19.90)*	20.80(-.)	98.70(13.10)	103.20(12.50)^{NS}	4.50(-.)	0.32	-.
Response control Q	Auditory	90.70(20.90)	103.80(10.60)*	13.10(-.)	115.30(8.70)	108.80(10.60)^{NS}	-6.50(-.)	0.47	-.
	Visual	93.20(14.60)	106.90(10.40)*	13.70(-.)	117.10(11.0)	113.50(14.80)^{NS}	-3.60(-.)	0.52	-.
Prudence	Auditory	91.70(23.80)	103.10(10.20)^{NS}	11.40(-.)	107.00(6.50)	105.70(9.10)^{NS}	-1.30(-.)	0.27	-.
	Visual	91.50(15.90)	100.70(14.30)*	9.20(-.)	105.30(6.90)	106.50(8.40)^{NS}	1.20(-.)	0.49	-.
Consistency	Auditory	87.50(18.30)	97.60(12.00)*	10.10(-.)	111.50(10.70)	108.00(10.80)^{NS}	-3.5(-.)	0.91	-.
	Visual	98.70(12.90)	111.60(13.50)*	12.90(-.)	115.20(17.70)	116.10(16.20)^{NS}	0.90(-.)	0.30	-.
Comprehension	Auditory	72.80(38.70)	103.00(10.20)*	30.20(-.)	105.70(6.90)	103.10(11.90)^{NS}	-2.60(-.)	0.01	-.
	Visual	70.20(39.80)	106.80(4.70)*	36.60(-.)	106.70(4.10)	103.20(7.70)^{NS}	-3.5(-.)	0.56	-.
WCST Number of trials		107.90 (21.60)	89.00(19.70)*	-18.90(-.)	85.90(16.90)	88.50(19.10)^{NS}	2.90(-.)	0.03	-.
Perseverative errors		22.60(9.20)	10.40(9.20)*	-12.20(-.)	8.50(6.40)	7.80(5.40)^{NS}	-0.70(-.)	0.34	-.
Post-Concussion Symptoms									
Inconsistency		7.90(3.60)	5.00(2.30)*	-2.90(-.)	3.70(2.60)	3.80(2.80)^{NS}	0.10(-.)	0.47	-.
General measure of impairment		147.00 (44.90)	107.60(57.60)*	-39.40(-.)	46.70(30.80)	44.10(29.00)^{NS}	-2.60(-.)	1.39	-.
Total items checklist		60.70(10.00)	53.70(15.40)*	-7.00(-.)	31.10(16.60)	32.90(19.30)^{NS}	1.80(-.)	1.19	-.
Attention		22.40(6.80)	15.80(8.40)*	-6.60(-.)	8.70(7.50)	7.50(6.20)^{NS}	-1.20(-.)	1.12	-.
Language-verbal learning		12.90(4.90)	8.40(6.20)*	-4.50(-.)	2.70(2.60)	3.50(2.80)^{NS}	0.80(-.)	1.02	-.
Academic problems		18.80(7.00)	18.60(16.30)*	-0.20(-.)	6.40(4.30)	7.70(5.20)^{NS}	1.30(-.)	0.90	-.

* = p<0.05, ** = p <0.01, ^{NS} = Not significant; ^{a} = compared to baseline, ^{b} = compared to control group; -. = value could not be calculated

Abbreviations: *AVLT* = Auditory Verbal Learning Test; *CFT* = Complex Figure Test; *DSST*= Digit Symbol Substitution Test; *DUAF* = unreferenced attention test; *ES*= Effect Size; *IVA CPT* = Intermediate Visual and Auditory Continuous Performance Test; *NIMHN*= National Institute of Mean Health and Neurosciences; *NIS* = Neuropsychological Impairment Scales; *NFB*= Neurofeedback; *Q* = Quotient; *RHIFQ* = Rivermead Head Injury Follow-up Questionnaire; *RPQ*= Rivermead Post Concussion Symptoms Questionnaire; *TAU* = Treatment as Usual; *WAIS-R* = Wechsler Adult Intelligence Scale – Revised; *WCST* = Wisconsin Card Sorting Test

MAJOR RESEARCH PROJECT APPENDICES

Appendix 2.1 Letters of Ethical Approval

North of Scotland Research Ethics Service
Summerfield House
2 Eday Road
Aberdeen
AB15 6RE

Telephone: 01224 558458
Facsimile: 01224 558609
Email: nosres@nhs.net

13 March 2018

Professor Jonathan Evans
Institute of Health and Wellbeing
University of Glasgow
1st Floor Admin Building
Gartnavel Royal Hospital
GLASGOW
G12 0XH

Dear Professor Evans

Study title:	**Technology Evaluating and Measuring Emotional Dysregulation (TEAMED)**
REC reference:	**18/NS/0030**
IRAS project ID:	**243255**

The Research Ethics Committee reviewed the above application at the meeting held on 8 March 2018. Thank you for attending to discuss the application.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this favourable opinion letter. The expectation is that this information will be published for all studies that receive an ethical opinion but should you wish to provide a substitute contact point, wish to make a request to defer, or require further information, please contact hra.studyregistration@nhs.net outlining the reasons for your request. Under very limited circumstances (e.g. for student research which has received an unfavourable opinion), it may be possible to grant an exemption to the publication of the study.

Ethical opinion

The members of the Committee present gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Conditions of the favourable opinion

The REC favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements. Each NHS organisation must confirm through the signing of agreements and/or other documents that it has given permission for the research to proceed (except where explicitly specified otherwise).

Guidance on applying for HRA Approval (England)/ NHS permission for research is available in the Integrated Research Application System, at www.hra.nhs.uk or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of management permissions from host organisations.

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database. This should be before the first participant is recruited but no later than 6 weeks after recruitment of the first participant.

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to request a deferral for study registration within the required timeframe, they should contact hra.studyregistration@nhs.net. The expectation is that all clinical trials will be registered, however, in exceptional circumstances non registration may be permissible with prior agreement from the HRA. Guidance on where to register is provided on the HRA website.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

NHS Sites

The favourable opinion applies to all NHS sites taking part in the study taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Summary of discussion at the meeting

The Committee thanked you, Miss Day and Dr O'Neill for attending the meeting via teleconference and clarifying the following points:

Social or scientific value; scientific design and conduct of the study

The Committee asked whether 8 participants would be enough of a sample size to answer the research question.

Dr O'Neill replied that this was a project in the early stages. The watch had been worn by two people in the past and they had found physiology. As they had a limited time to carry out the study, 4 of each would be sufficient to collect and test the data. Dr O'Neill went on to say that their Statistician had assured them that a lot of data rather than a lot of participants would demonstrate proof of concept rather than generalisibility. You added that each participant would predict their own behaviour and each participant would stand on their own.

The Committee was satisfied with this response.

Care and protection of research participants; respect for potential and enrolled participants' welfare and dignity

It was noted that participants would be wearing the watch continuously except when in the shower. The Committee asked how likely it would be that participants could encounter some skin irritation.

You confirmed that the watch would be worn continuously but it was extremely unlikely that there would be any skin irritation as the strap was just a regular strap.

The Committee was satisfied with this response.

Clarity was required on where the data would be stored.

Dr O'Neill replied that all data collected would be held on a secure database managed by the University of Stirling.

The Committee was satisfied with this response.

Informed consent process and the adequacy and completeness of participant information

The Committee asked for details of the consent process, in particular, who was assessing capacity and what that might look like as the potential participants were vulnerable.

You replied that the Brain Injury Rehabilitation Trust (BIRT) unit was a specialist service. Potential participants would be assessed by the clinical care team, who did this as part of everyday practice. The service included those who were there under the Mental Health Act, those with incapacity, and those with capacity. The team were highly experienced in terms of challenging behaviour and capacity to consent.

The Committee asked if the assessment of capacity would be independent of the researcher.

You replied that it would be.

The Committee asked why there was a need for the easy-read Information Sheet if all potential participants would have the ability to consent to take part in the study.

Miss Day replied that the reason for this was that some participants would have differing levels of understanding, therefore, by providing the easy-to-read version, it would make the study more accessible.

The Committee asked if it was likely that there could be fluctuations in capacity.

You replied that this was unlikely as most of the potential participants would be months post injury and would not have fluctuating levels of understanding. Dr O'Neill added that the population was stable in terms of capacity, however there could be potential participants with a urinary tract infection which could cause an issue. Nursing staff in the unit were continually looking out for/monitoring this and it would be picked up quickly.

The Committee was satisfied with the clarifications on capacity to consent.

Other general comments

Clarification was required on who would be responsible for charging the watch and phone.

Dr O'Neill replied that there was a system in place to deal with this. The Rehab Support Workers were aware of the study, along with the Psychologist, and they would be responsible for charging the equipment. No data would reside on the phone.

You, Dr O'Neill and Miss Day were thanked for attending and left the meeting.

Please contact the REC Manager if you feel that the above summary is not an accurate reflection of the discussion at the meeting.

Approved documents

The documents reviewed and approved at the meeting were:

Document	*Version*	*Date*
Covering letter on headed paper	1	21 February 2018
IRAS Checklist XML: Checklist 26022018		26 February 2018
Challenging Behaviour Tool		22 February 2018*
Similar Study Unfavourable Opinion Letter		8 November 2017
Participant Information Sheet (Easy Read)	1	23 February 2018
University of Glasgow Approval		9 February 2018
BIRT Project Approval		5 December 2017
Evidence of Sponsor Insurance or Indemnity		27 July 2017
Confirmation of Disclosure from BIRT		26 February 2018
Participant Consent Form	1	23 February 2018
Participant Information Sheet (PIS)	1	23 February 2018
REC Application Form: REC Form 22022018	243255/1179 267/1/748	22 February 2018
Research protocol or project proposal	1.0	23 February 2018
Summary CV for Chief Investigator (CI): Jonathan Evans		4 July 2017

* date received

Document	*Version*	*Date*
Summary CV for Student: Julia Day		24 July 2017
Summary CV for Supervisor (student research): Jonathan Evans		4 July 2017

Membership of the Committee

The members of the Ethics Committee who were present at the meeting are listed on the attached sheet.

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website: http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

HRA Training

We are pleased to welcome researchers and R&D staff at our training days – see details at http://www.hra.nhs.uk/hra-training/

18/NS/0030	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project.

Yours sincerely

Professor Helen Galley
Chair

Enclosures: List of names and professions of members who were present at the meeting and those who submitted written comments
"After ethical review – guidance for researchers" SL-AR2 for other studies

Copy to: Miss Emma-Jane Gault

North of Scotland Research Ethics Committee (2)

Attendance at Committee meeting on 8 March 2018

Committee Members:

Name	*Profession*	*Present*	*Notes*
Dr Ruth Stephenson	Vice Chair and Consultant in Anaesthesia	Yes	Chair
Dr Hanne Bruhn	Alternate Vice-Chair & Research Fellow - Psychology	Yes	
Ms Abiola Crown	Fountain of Love Church Outreach Officer/Time to Heal Manager (Volunteer)	No	
Mr Craig Cunningham	Global Inventory Analyst	Yes	
Dr Ian Fleming	Lecturer	No	
Professor Helen Galley	Chair of Anaesthesia & Intensive Care	No	
Dr Sarah Henderson	Senior Lecturer	Yes	
Dr Petr Kalous	Consultant Neonatologist	No	
Mrs Anna Lindahl	Lecturer	No	
Dr Benjamin McCormick	Research Fellow	No	
Mrs Kathryn McMullan	Retired Clinical Pharmacist	No	
Ms Vicky Ritchie	Healthcare Science Principal (GI Clinical Physiologist)	Yes	
Miss Gemma Robb	Medical Secretary	Yes	
Mrs Megala Thiruvothiyur	Research Assistant In Medical Statistics	Yes	
Mrs Bensita Thottakam	PhD Student	Yes	
Mrs Hilary Young	Family Nurse Partnership Lead	Yes	

Also in attendance:

Name	*Position (or reason for attending)*
Miss Karen Gauld	Ethics Administrator
Mrs Carol Irvine	Senior Ethics Co-ordinator
Dr Sally Kilburn	Scientific Officer

32 Market Place
Burgess Hill
West Sussex
RH15 9NP
Tel: 01444 239123
Fax: 01444 244978
Email: info@thedtgroup.org

Dr Brian O'Neill
Graham Anderson House
1161 Springburn Road
G21 1UU

5th December 2017

Dear Dr O'Neill,

THE DISABILITIES TRUST RESEARCH ETHICS COMMITTEE (DTREC) APPROVAL

Study Title: Technology Evaluating And Measuring Emotional Dysregulation (TEAMED).

We are pleased to inform you that the DTREC has APPROVED an extension of the abovementioned project, and the addition of Ms Julia Day as an investigator in the project.

The revised approval period is from **December 2017** to **July 2018**.

The following are to be observed upon DTREC approval:

1) The study will be conducted in accordance with Trust's relevant policies.
2) Service users who lack capacity to consent to take part in research may **NOT** be approached for recruitment into the study, and consent may **NOT** be given by a proxy (e. g. relative).
3) The Researcher should promptly report the DTREC of:
   i. Deviations from, or changes to the protocol.
   ii. New information that may affect adversely the risk to the participants or the conduct of the study.
   iii. Change in planned timeline of the study
   iv. Completion of the study.
3) A Study Status Report should be submitted for the following:
   i. Study status: a brief report is to be submitted within six months of commencement of the study.
   ii. Study completion or termination: the Final Report is to be submitted within three months of study completion or termination.
4) Any dissemination of the findings should acknowledge the support of the Brain Injury Rehabilitation Trust and The Disabilities Trust in the study.

On behalf of the DTREC, I would like to wish you the best with your study.

Yours sincerely,

p. p.

Dr Caroline Drugan
Chair of the DTREC
32 Market Place
Burgess Hill
RH15 9NP

32 Market Place
Burgess Hill
West Sussex
RH15 9NP
Tel: 01444 239123
Fax: 01444 244978
Email: info@thedtgroup.org

The Disabilities Trust
www.thedtgroup.org

Dr Brian O'Neill
Graham Anderson House
1161 Springburn Road
G21 1UU

19th March 2018

Dear Dr O'Neill,

THE DISABILITIES TRUST RESEARCH ETHICS COMMITTEE (DTREC) APPROVAL

Study Title: Technology Evaluating And Measuring Emotional Dysregulation (TEAMED).

We are pleased to inform you that the DTREC has APPROVED an extension of the abovementioned project, and the addition of Ms Julia Day as an investigator in the project.

The revised approval period is from **6th December 2017** to **18th September 2018**.

The following are to be observed upon DTREC approval:

1) The study will be conducted in accordance with Trust's relevant policies.
2) Service users who lack capacity to consent to take part in research may **NOT** be approached for recruitment into the study, and consent may **NOT** be given by a proxy (e. g. relative).
3) The Researcher should promptly report the DTREC of:
   i. Deviations from, or changes to the protocol.
   ii. New information that may affect adversely the risk to the participants or the conduct of the study.
   iii. Change in planned timeline of the study
   iv. Completion of the study.
3) A Study Status Report should be submitted for the following:
   i. Study status: a brief report is to be submitted within six months of commencement of the study.
   ii. Study completion or termination: the Final Report is to be submitted within three months of study completion or termination.
4) Any dissemination of the findings should acknowledge the support of the Brain Injury Rehabilitation Trust and The Disabilities Trust in the study.

On behalf of the DTREC, I would like to wish you the best with your study.

Yours sincerely,

p. p.

Dr Caroline Drugan
Chair of the DTREC
32 Market Place
Burgess Hill
RH15 9NP

North of Scotland Research Ethics Service
Summerfield House
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Aberdeen
AB15 6RE

Telephone: 01224 558458
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Email: nosres@nhs.net

29 May 2018

Miss Julia Day
Institute of Health and Wellbeing
University of Glasgow
1st Floor, Admin Building
Gartnavel Royal Hospital
GLASGOW
G12 0XH

Dear Miss Day

Study title:	**Technology Evaluating and Measuring Emotional Dysregulation (TEAMED)**
REC reference:	**18/NS/0030**
Amendment number:	**2.0**
Amendment date:	**25 May 2018**
IRAS project ID:	**243255**

Approval was sought for the following changes:

Substantial Amendment:

Due to technical difficulties, the electronic devices would not have collected sufficient data within the previously defined 8 week period for statistical analysis. Therefore the study team would like to extend the data collection period to 12 weeks, if consented to by participants via the amended consent form, in order to provide further opportunity to obtain sufficient data for analysis.

Non-Substantial Amendments:

The following amendments were also included in the amended documents for information, and were not deemed to be substantial by the NHS sponsor, who had approved these.

1. Participant Information Sheet:

Amended to include storage of data at the Brain Injury Rehabilitation Trust (BIRT)

2. Proposal:

Data handling clarified re: server managed by University of Stirling and analysis completed at BIRT

Inclusion of Professor Ken Turner for advice regarding analysis

3. REC form:

Storage and use of personal data during the study amended to include storage on a private company computer (BIRT)

Other key investigators/collaborators amended to include Professor Ken Turner and Rebekah McLoughlin (Assistant Psychologist)

The above amendment was reviewed by the Sub-Committee in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	*Version*	*Date*
Letter from sponsor [Confirmation from Sponsor]		21 May 2018
Notice of Substantial Amendment (non-CTIMP)	2.0	25 May 2018
Participant consent form	1.1	7 May 2018
Participant information sheet (PIS)	1.1	7 May 2018
Research protocol or project proposal	2.0	25 May 2018

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

Working with NHS Care Organisations

Sponsors should ensure that they notify the R&D office for the relevant NHS care organisation of this amendment in line with the terms detailed in the categorisation email issued by the lead nation for the study.

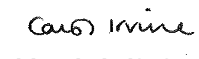
Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

We are pleased to welcome researchers and R & D staff at our Research Ethics Committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

18/NS/0030:	Please quote this number on all correspondence

Yours sincerely



pp'd on behalf of
Dr Hanne Bruhn
Alternate Vice-Chair

Enclosures: List of names and professions of members who took part in the review

North of Scotland Research Ethics Committee (2)

Attendance at Sub-Committee of the REC meeting by correspondence

Committee Members:

Name	*Profession*	*Present*	*Notes*
Dr Hanne Bruhn	Alternate Vice-Chair & Research Fellow - Psychology	Yes	Chair
Ms Vicky Ritchie	Healthcare Science Principal (GI Clinical Physiologist)	Yes	

Also in attendance:

Name	*Position (or reason for attending)*
Mrs Carol Irvine	Senior Ethics Co-ordinator

RE: Ethics Application: 18/NS/0030 - IRAS Project ID: 243255

Sara da Silva Ramos <Sara.DaSilvaRamos@thedtgroup.org>

Mon 11/06/2018 15:35

To: Julia Day <j.day.1@research.gla.ac.uk>;

Cc: Brian O'Neill <Brian.ONeill@thedtgroup.org>; Jon Evans <Jonathan.Evans@glasgow.ac.uk>;

Hi Julia,

Thanks for these details. All I needed to confirm. I hope the study goes well, and look forward to hearing more in due course. Do not hesitate to contact me if there is anything I can help you with at any point.

Kind regards,

Sara

From: Julia Day <j.day.1@research.gla.ac.uk>
Sent: 05 June 2018 16:43
To: Sara da Silva Ramos <Sara.DaSilvaRamos@thedtgroup.org>
Cc: Brian O'Neill <Brian.ONeill@thedtgroup.org>; Jon Evans <Jonathan.Evans@glasgow.ac.uk>
Subject: Re: Ethics Application: 18/NS/0030 - IRAS Project ID: 243255

Dear Sara

Many thanks for your email.

It will be Brian's computer in his office where the data will be stored, and it will be on his personal desktop rather than the shared network. The analysis will also be carried out on Brian's computer, but may also be stored on the University of Glasgow computer for the purposes of my thesis write-up. The data will not have any personal identifiable information (e.g. name, age, gender, diagnosis) but will be linked via a patient identifier that only certain necessary members of the research term are aware of.

Personal data (e.g. consent forms, demographic information) is stored in a paper form in Brian's office.

As you're probably aware, Brian's office is accessible via a secure entry into reception, two key pads into the patient area where Brian's office is located, and a door with a door code into his office.

Let me know if you have any further questions, or there are any concerns about the above.

Kind regards

Julia

From: Sara da Silva Ramos <Sara.DaSilvaRamos@thedtgroup.org>
Sent: 05 June 2018 15:53:16
To: Julia Day
Cc: Brian O'Neill; Jon Evans
Subject: RE: Ethics Application: 18/NS/0030 - IRAS Project ID: 243255

Dear Julia,

Thanks for sending this information. I've kept a record of these changes, which do not require further formal internal approval.

I would only like to confirm the following with regards to storing data in BIRT computers:

Could you ensure that the BIRT computer storing the data is secure and the data is password protected? If possible, keep it in a drive with restricted access by members of the research team only, and keep any personal data separately from all other data you collect for the project (which you might already be planning to do anyway).

Do let me know if you have any questions, or need help from BIRT in ensuring you have access to the right equipment.

Kind regards,

Sara

From: Julia Day <j.day.1@research.gla.ac.uk>
Sent: 29 May 2018 16:09
To: Sara da Silva Ramos <Sara.DaSilvaRamos@thedtgroup.org>
Cc: Brian O'Neill <Brian.ONeill@thedtgroup.org>; Jon Evans <Jonathan.Evans@glasgow.ac.uk>
Subject: Fw: Ethics Application: 18/NS/0030 - IRAS Project ID: 243255

Dear Sara da Silva Ramos

I am emailing regarding an amendment to the TEAMED 2 research project.

Many of the changes were considered to be minor by the NHS sponsor, the email correspondence of which is attached with details of the minor amendments. I have also attached relevant documents with highlighted changes.

One of the amendments, extending the data collection period to 12 weeks, was considered to be a substantial amendment, and was submitted to the North of Scotland Research Ethics Committee for review. This amendment has been approved, and I have also attached the favourable opinion letter. Just

to note, as part of the data collection extension, all participants will be required to sign the new consent form, as their current informed consent relates to an 8 week data collection period.

Therefore, prior to going ahead with the changes, I am emailing yourself for BIRT approval, should all the above and attached be considered appropriate for approval.

Please let me know if there is any further information you need.

Kind Regards

Julia Day

Trainee Clinical Psychologist

From: RES, Nos (NHS GRAMPIAN) <nosres@nhs.net>
Sent: 29 May 2018 13:33
To: Julia Day
Cc: Jon Evans; Emma-Jane Gault
Subject: Ethics Application: 18/NS/0030 - IRAS Project ID: 243255

Dear Professor Evans

Study Title: Technology evaluating and measuring emotional dysregulation (TEAMED)

Please find attached the Favourable Opinion Letter for Substantial Amendment 2.0 25/05/18.

Kind regards

Carol

North of Scotland Research Ethics Service
Summerfield House
2 Eday Road
Aberdeen
AB15 6RE
Tel: 01224 558458

It is extremely important that the version numbers and dates of all documents recorded on the IRAS Checklist are accurate and reflect the version numbers/dates recorded on

the documents, as this may cause ongoing problems with other departments/agencies, eg R&D , MHRA etc.

The HRA is keen to know your views on the service you received – our short feedback form is available **here**

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RE: 18/NS/0030 Confirmation of amendment type AM01 (non-substantial: additional collaborator) Technology Evaluating and Measuring Emotional Dysregulation (TEAMED)

Emma-Jane Gault

Fri 04/05/2018 12:37

To:Julia Day <j.day.1@research.gla.ac.uk>;

Cc:Jon Evans <Jonathan.Evans@glasgow.ac.uk>; Brian.ONeill@thedtgroup.org <Brian.ONeill@thedtgroup.org>;

Dear Julia,

Study Title:	Technology Evaluating and Measuring Emotional Dysregulation (TEAMED)
Sponsor:	University of Glasgow
REC ref:	18/NS/0030
Chief Investigator:	Professor Jon Evans
Amendment number	AM01 (non-substantial: additional collaborator joining the research team - Professor Ken Turner, University of Stirling)

Thank you for your email submitting the above amendment.
It has been reviewed on behalf of the Sponsor. I confirm that it is non-substantial and does not require formal REC approval. However, you should notify REC of the amendment for information and you will need to confirm with BIRT that the amendment does not affect its management approval of the study.

Please revise any affected study documents and send them to me for review eg since the study protocol names specific collaborators, it will need to be updated accordingly with any changes highlighted (I suggest updating to v1.1 and a new date) and you should check if you need to update the PIS/Consent Form as well.
Please also confirm that any data shared will be fully anonymised before it leaves BIRT.
Once the amendment is ready for submission, I will issue formal approval on behalf of the Sponsor.

Please contact me if you have any queries.

Kind regards,
Emma-Jane

Emma-Jane Gault
Research Governance Officer
University of Glasgow
Email emmajane.gault@glasgow.ac.uk

Room 327
Wolfson Medical School Building
University Avenue
Glasgow
G12 8QQ
Tel. +44 (0)141 330 5519

Or

Clinical Research & Development
West Glasgow Ambulatory Care Hospital
Dalnair Street
Glasgow
G3 8SW
Tel. +44 (0)141 232 1819

Appendix 2.2 Participant Information Sheets

Version 1.1 07.05.18

Participant Information Sheet

Technology Evaluation and Measuring Emotional Dysregulation (TEAMED)

You have been invited to take part in a research study. Before you decide whether to take part, it is important to understand why we are doing the research and what it will involve. Please read this information carefully and take time to decide. Discuss it with someone if you would like. Please ask if you would like more information.

What is the purpose of the study?

The study aims to understand how body functions (e.g. temperature, heart rate) can influence people's ability to manage emotions and behaviour. Strong emotions can lead to behaviour that can harm us or others, such as hurting yourself and others, and damaging things. We are aiming to see whether our body functions help to predict harmful behaviour.

What is the procedure that is being tested?

We are testing whether a smartwatch with special software can predict harmful behaviour. The smartwatch collects information about heart rate, sweat, temperature and movement. The system will then create a calculation that can predict when this information will lead to harmful behaviour.

Why have I been invited?

You have been chosen to participate as you have experienced a severe brain injury and sometimes have difficulty with controlling emotions and behaviour.

Do I have to take part?

No. It is up to you whether you decide to take part or not. If you decide to take part, you are free to withdraw from the study at any time and you do not have to give a reason. If you decide not to take part, this will not affect the care you receive.

What will happen to me if I take part?

A member of the research team will ask you to wear a watch for up to 12 weeks. During this time, the watch will collect information about your heart rate, sweat, temperature and movement. You will also be given a phone, which will store this information. You will be asked to take off the watch when you shower, and the medical staff can help remind you to do this. You will not be asked to do anything else. Information from your medical record such as your age, gender and medical information will also be collected.

What are the alternatives for treatment?

If you chose not to take part, you will not be asked to wear the watch and your care will continue as usual.

What are the possible disadvantages and risks of taking part?

There is a small chance that you might have a skin reaction to the watchstrap. If this happens, please let a medical staff member know and they can treat the skin reaction. You will not be asked to continue wearing the watch and your participation in the study will end.

What are the possible benefits of taking part?

There are no known benefits.

What happens when the research stops?

At the end of the research, you will not be asked to continue wearing the watch.

Will my taking part in this study be kept confidential?

All information collected during the study will be strictly confidential, including information gathered from your medical file. You will not be identifiable from the information gathered about you. This information will be anonymised and stored on Brain Injury Rehabilitation Trust, University of Stirling and University of Glasgow computers, accessible by the research team.

What will happen to the results and data of the study?

The data from the study will be stored anonymously and securely on Brain Injury Rehabilitation Trust, University of Stirling and University of Glasgow computers for up to 10 years and may be used in future approved studies if you agree to this. The results of the study will form part of an educational qualification and may be published in a specialist journal within two years of the study finishing. You will not be identifiable in any report. The care team may inform you of any results if you wish.

Complaints

If you have any complaints about the study, please speak to Sandra Wylie (Service Manager, Brain Injury Rehabilitation Trust), Graham Anderson House, 1161 Springburn Road, Glasgow, G21 1UU. Tel: 0141 4046060.

Who is organising and funding the research?

University of Glasgow and the Brain Injury Rehabilitation Trust is organising and funding the research.

Who has reviewed the study?

Independent researchers at the University of Glasgow have reviewed the study. The NHS North of Scotland (2) Research Ethics Committee approved the study.

Contacts for Further Information

Julia Day (Trainee Clinical Psychologist) j.day.1@research.gla.ac.uk

Brian O'Neill (Consultant in Neuropsychology and Rehabilitation)
Brian.ONeill@thedtgroup.org

Thank you for taking the time to read this information.

Participant Information Sheet (Easy Read)

Technology Evaluating and Measuring Emotional Dysregulation (TEAMED)

You have been invited to take part in a study. Before you choose whether to take part, please read this information. Please talk about it to the person who has given you this information.

What is the study for?

The study is to help our understanding of difficulty controlling emotions and behaviour after a brain injury.

Difficulty controlling emotions can lead to situations where you may hurt yourself or others, damage things, or do things that make it difficult for others to support you.

Why have I been invited?

You have been chosen as you have injured your brain and have difficulty with managing emotions after your brain injury.

Do I have to take part?

No. It is up to you whether you decide to take part. You can stop taking part at any time and you do not have to give a reason. This will not affect the care you receive.

What will happen to me if I take part?

You will be asked to wear a watch for 8 weeks. During this time the watch will collect information about your heartbeat, temperature, sweat and movement. You will also be given a phone, which will store the information.

You will be asked to take off the watch when you shower, and the medical staff can help remind you to do this. You will not be asked to do anything else. Information from your medical record such as your age, gender and medical information will also be collected.

What is being tested?

We are finding out whether information collected on the watch helps predict people's behaviours.

What if I don't take part?

No. If you choose not to take part, the staff team will help you in the same way as normal.

What are the possible risks of taking part?

There is a small chance that you may have a skin reaction to the watchstrap. If this happens, please let your medical staff know. You will then stop taking part in the study.

What are the possible benefits of taking part?

There are no known benefits.

What happens when the research stops?

You will not be asked to keep using the watch.

Who will know about me taking part?

All information collected during the study will be strictly confidential. You will not be identifiable from the information gathered about you.

What will happen to the results and data of the study?

The data from the study will be stored securely for up to 10 years and may be used in future studies if you agree to this.

The results of the study will be used for an educational degree and may be published in a specialist journal within two years of the study finishing. You will not be identifiable in any report.

Complaints

If you have any complaints about the study, your staff team will help you speak to Sandra Wylie (Service Manager, Brain Injury Rehabilitation Trust).

Who is organising and funding the research?

University of Glasgow and the Brain Injury Rehabilitation Trust is organising and funding the research.

Who has reviewed the study?

The University of Glasgow have reviewed the study. The NHS North of Scotland (2) Research Ethics Committee approved the study.

Contacts for Further Information

If you would like more information, your staff team will help you speak to Brian O'Neill (Consultant in Neuropsychology and Rehabilitation).

Thank you for taking the time to read this information.

Appendix 2.3 Participant Consent Form

Technology Evaluating And Measuring Emotional Dysregulation (TEAMED)

	Please Initial
1. I confirm that I have read and understand the information leaflet dated 07.05.18 (version 1.1), or easy-read information leaflet dated 28.02.18 (version 1), for the above study.	☐
2. I confirm that the researcher has answered any queries to my satisfaction.	☐
3. I understand that my participation is voluntary and that I am free to withdraw from the project at any time, without having to give a reason and that if I withdraw my medical care will not be affected.	☐
4. I understand that any information collected about me in the study will remain confidential, and that no information which identifies me will be made publicly available.	☐
5. I give permission for the research team to access my medical records at Graham Anderson House to obtain information which is relevant to this study.	☐
6. I understand that my data (including personal information) may be accessed by authorised representatives of the University of Glasgow (the Sponsor) for the purposes of audit only.	☐
7. I consent to taking part in this study.	☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature

Appendix 2.4 Example of Challenging Behaviour Tool Incorporating Overt Aggression Scale-Modified for Neurorehabilitation (OAS-MNR)

Behaviour Recording for

Name	

Salutogenic Behaviours

	Date / Time / How often? (Best guess)	**How good did it appear to feel?** (Bigger the smiley, the better the feeling)
Helped someone out		☺ ☺ ☺
Appeared angry, or aggressive, but got over it		☺ ☺ ☺
Enjoyed the moment / Engaged in relaxation		☺ ☺ ☺
Finished a task or job		☺ ☺ ☺
Cooked a meal for themselves		☺ ☺ ☺
Cooked a meal for others		☺ ☺ ☺
Phoned/met a friend		☺ ☺ ☺
Solved a problem		☺ ☺ ☺
Did some exercise		☺ ☺ ☺
Spent time outdoors		☺ ☺ ☺
Lost themselves in something fun		☺ ☺ ☺
…		☺ ☺ ☺

Challenging Behaviours

Date / Time	**Staff Initials**	**Antecedents**			**Behaviour (type, rating)**	**Interventions (A-I)**	**Multiple Recordings (✓ when multiple identical incidents take place in quick succession < 2 second interval)**
		Contributing Factors		**Observed directly beforehand (1-25)**			
		Structured activity	**Noisy environment**				

***NB each separate incident recorded in this way must be separated by at least 2 seconds**

1. Aggressive Behaviours (From the *Modified Overt Aggression Scale – MOAS)*

	Verbal aggression - *VA*	Physical aggression against objects - *PO*	Physical aggression against self- *PS*	Physical aggression against other people - *PP*
1	Makes loud noises, shouts angrily, is not person directed e.g *'bloody hell'*	Slams doors, scatters clothing, makes a mess in response to clear antecedent (without others being at risk of being hit).	Picks/scratches skin, hits self, pulls hair (with no/minor injury).	Threatening gesture clearly person directed, swings at people, grabs clothes, spitting at people.
2	Mild personal insults clearly directed at some other person, not including swearing/offensive sexual comments e.g *'you are a stupid idiot'*.	Throws objects down, kicks furniture without breaking it, marks the wall.	Bangs head, hits fist into object, throws self onto floor or into objects (hurts self without serious injury).	Strikes, kicks, pushes, pulls hair (without significant injury).
3	Swearing, moderate threats clearly person directed at others or self e.g *'fuck off you bastard'*.	Breaks objects, smashes windows.	Inflicts small cuts, bruises, minor burns to self.	Attacks others causing mild-moderate physical injury, (bruises, sprains, welts).
4	Clear threats of violence directed at others or self e.g *'I'm going to kill you'*.	Sets fire, throws objects dangerously (some other person is at risk of being hit, regardless of intention).	Mutilates self, causes deep cuts, bites that bleed, internal injury, fracture, loss of consciousness.	Causes severe physical injury (broken bones, internal injury) to person aggression directed.

2. Sexualised Behaviours (From the *Saint Andrews-Swansea Sexualized Behaviour Assessment – SASBA)*

	Verbal Comments *VC*	Non Contact *NC*	Exposure *E*	Touching Others *TO*
1	Intimate personal comments of mild severity, e.g 'have you got a girlfriend?', *'I love you', You're gorgeous'*.	Blowing kisses, kissing self or staring at another persons groin, female breasts or buttocks, or makes obscene gesture.	Appears unaware that is exposing genitals, female breasts or buttocks in a public setting.	Touches for a prolonged period (excess of 2 seconds) or strokes another person – does not include groin, female breasts or buttocks.
2	Comments of a sexual nature, clearly not person directed, e.g *'I've got a big dick'*.	Touches own groin, female breasts or buttocks over or under clothes (no exposure).	Wearing no clothes in a public setting, clearly not person directed.	Kissing another person.
3	Descriptions of another persons groin, female breasts or buttocks clearly directed to another person e.g *'You have a nice bottom'. 'She's got lovely breasts'*.	Masturbates in a non shared setting where staff are present (e.g begins when staff enter bedroom or in bath).	Intentionally expose genitals, female breasts or buttocks to another person (appears to be a deliberate premeditated behaviour).	Lifting skirts, pinching or touching buttocks, sitting on other's knee.
4	Explicit accounts of sexual intent, rquests or activity e.g. *'show me your knickers', 'I want to shag you'*.	Masturbates without genitals being exposed in a public setting, including ward shared areas (e.g dining room).	Masturbates with genitals being clearly exposed in a public setting, including ward shared areas.	Touching others groin, female breasts, or rubbing own genitals or female's breast against another person.

3. Antecedents

	Set One: Contributing Factors (Code 1-3)		Set Two: Observed directly before (Coded 11-25)
1	Structured activity.	11	Given direct verbal prompt to comply with instruction.
2	Noisy environment.	12	Given verbal guidance/advice to assist completion of task/activity.
3	Had epileptic fit in last 24 hours.	13	Given verbal/visual feedback about performance e.g token feedback.
4	In dining room.	14	Direct response to other clients verbal behaviour.
		15	Request specifically denied by other person.
		16	Any other verbal interaction.
		17	Physical guidance/facilitation including TA.
		18	Direct response to other clients physically aggression (directed at them).
		19	Direct response to other clients physically aggression (**not** directed at them).
		20	During restraint/whilst being assisted to seclusion.
		21	Given item e.g food.
		22	Purposeful behaviour is TOOTS by person to whom it is directed at.
		23	Obviously agitated or distressed.
		24	No obvious antecedent.
		25	Other (Please specify)

4. Interventions

A	B	C	D	E	F	G
Aggression ignored. TOOTS	Talking to patient including prompts	Closer observation.	Holding patient (MOVA).	*PRN* medication given by mouth.	*PRN* medication given by injection.	Isolation (no seclusion).
H	**I**	**J**	**K**	**L**	**M**	**N**
Seclusion	Use of other restraints.	Injury requires immediate medical treatment.	Injury requires immediate medical treatment for other.	Special programme.	Physical distraction (leading the patient away).	Other.

Appendix 2.5 Summary of Means and Standard Deviations (SDs)

Microsoft Health ***Physiological***			**AvHR**		**AvHRDiff**		**AvHRDiff Mean**		**PeakHR**		**PeakHRDiff**		**PeakHRDiff Mean**	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	16	80.75	6.20	-0.79	4.18	1.77	6.08	101.75	19.16	-0.21	9.51	7.39	18.95
	No	973	78.99	7.08	-0.10	7.24	-0.03	7.07	94.36	14.93	-0.67	16.58	-0.13	14.84
2	Yes	24	77.29	4.21	1.71	4.96	2.08	4.25	90.42	10.65	2.81	9.57	-6.18	14.15
	No	757	74.96	7.19	-0.33	6.45	-0.17	7.66	88.00	12.11	-0.59	13.54	-6.10	16.10
3	Yes	5	74.20	4.45	1.50	4.97	-1.04	4.45	85.60	4.67	-2.75	3.90	-7.01	4.67
	No	619	75.18	6.86	-0.13	5.91	0.25	6.85	92.78	13.70	-0.37	15.2	0.15	13.70
4	Yes	38	77.95	4.58	-0.11	4.4	4.14	4.50	89.45	8.48	-3.84	17.3	3.83	8.43
	No	899	73.68	6.62	0.01	4.55	-0.09	6.58	85.54	10.93	0.11	11.86	-0.06	10.92
5	Yes[a]	1	72.00	0.00	-9.00	0.00	1.97	0.00	83.00	0.00	-14.00	0.00	-5.09	0.00
	No	364	71.13	7.78	-0.22	5.18	-0.20	7.67	88.29	12.56	-0.34	14.53	-0.23	12.54

			MinHR		**MinHRDiff HrBefore**		**MinHRDiff Mean**		**StepCount**		**StepCountDiffHr Before**		**StepCountDiff Mean**	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	16	67.00	5.51	0.50	5.14	0.68	5.55	396.63	322.38	-67.29	372.43	33.91	321.67
	No	973	66.30	6.33	-0.01	7.97	-0.01	6.32	364.36	433.44	-5.23	473.12	-0.56	432.54
2	Yes	24	65.96	4.44	2.00	7.86	1.84	4.41	276.25	255.91	23.33	338.00	62.98	269.38
	No	575	63.99	7.03	-0.10	8.17	-0.23	7.77	205.16	239.59	-0.2	252.46	-2.00	237.74
3	Yes	5	65.80	1.72	2.75	2.49	1.91	1.72	342.40	240.72	125	422.70	-6.39	240.72
	No	619	63.55	5.97	-0.05	7.51	0.19	5.95	417.54	533.78	-5.29	605.00	1.43	527.98
4	Yes	38	69.29	4.29	0.61	5.71	3.33	4.19	198.58	233.76	-99.32	333.01	34.08	234.97
	No	899	65.87	6.60	0.09	7.33	-0.06	6.57	162.77	297.38	4.66	358.25	-1.25	297.16
5	Yes[a]	1	64.00	0.00	-4.00	0.00	4.20	0.00	494.00	0.00	378	0.00	-159.01	0.00
	No	364	60.88	7.53	-0.12	5.47	-0.18	7.43	769.57	905.06	-20.05	998.3	-1.36	899.68

N = total number of aggressive episodes captured, [a]*Value derived from one aggressive episode,* [b]*No aggressive episodes for collected data*

continued

Sleep			**Duration**		**DurationDiff**		**DurationDiffMean**		**Awake**	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	11	28778.73	6858.88	1569.50	10.251.27	2994.55	6716.47	2333.73	916.83
	No	23	25572.78	8509.12	7146.13	12206.58	-163.87	8548.02	2571.74	1417.57
2	Yes	15	30619.00	12770.16	-2095.25	18884.10	2137.77	11604.45	10765.27	13559.44
	No	22	26276.23	13395.78	-3955.90	17372.13	-1457.57	13856.34	6040.36	6179.17
3	Yes	2	26343.50	5436.50	-2726.00	5212.00	650.43	5436.50	3036.50	793.50
	No	20	25369.30	3429.63	1320.20	4414.69	-65.04	3419.88	3244.65	1430.87
4	Yes	16	28931.81	10553.42	-6783.88	11314.57	593.36	10373.87	9040.13	2258.22
	No	14	29218.14	11137.48	5847.67	7403.74	-678.13	10427.28	7845.36	3596.63
5	Yes[b]	0								
	No	35	22648.76	7548.72	-367.60	9898.46	0.00	7548.72	5319.35	2460.68

			AwakeDiff		**AwakeDiffMean**		**LightSleep**		**LightSleepDiff**	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	11	419.17	1473.59	-48.28	855.88	12102.27	3135.69	1061.83	6167.10
	No	23	771.25	2020.40	202.60	1392.36	10487.3	4339.51	1851.88	6239.47
2	Yes	15	-624.75	6316.12	1935.52	10915.63	7579.53	3926.36	-1191.00	9718.79
	No	22	-1791.30	8273.45	-1319.67	7167.93	7477.59	4772.79	-926.10	5092.76
3	Yes	2	-1107.50	389.50	284.00	793.50	13751.50	2652.50	-959.00	5689.00
	No	20	173.20	1420.83	-28.40	1269.39	13902.90	2596.97	590.80	3762.57
4	Yes	16	-293.00	4084.64	412.11	2183.57	17530.44	8476.47	-5948.38	8955.38
	No	14	1828.67	2935.08	-470.99	3592.76	18844.86	8823.05	4392.50	3777.42
5	Yes[b]	0								
	No	35	62.90	3157.42	0.00	2460.68	12555.47	4958.75	-26.00	6307.33

continued

Sleep			LightSleepDiffMean		WakeUpsDiff		WakeUps		WakeUpsDiffMean	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	11	1574.59	2727.64	-0.33	1.80	3.09	0.90	-0.27	0.86
	No	23	-6.28	4424.61	1.00	3.67	3.78	2.23	0.43	2.20
2	Yes	15	113.73	3946.22	1.25	2.28	3.73	2.64	0.61	2.52
	No	22	-77.54	4746.63	-0.80	3.22	2.5	2.35	-0.42	2.34
3	Yes	2	142.57	2652.5	-3.00	1.00	3.5	0.50	-1.29	0.50
	No	20	-14.26	2567.67	0.40	1.56	5.8	2.23	0.13	2.00
4	Yes	16	-38156.82	80814.41	-5.25	7.08	11.06	5.3	0.83	5.26
	No	14	-87599.35	100598.26	2.33	2.98	9.64	4.55	-0.95	4.41
5	Yes[b]	0								
	No	35	0.00	4958.75	-0.20	5.34	7.65	3.56	0.00	3.56

			SleepEffDiff		SleepEff		SleepEffDiffMean	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD
1	Yes	11	-1.67	2.21	93.00	3.07	3.40	3.54
	No	23	-0.38	5.65	91.74	4.76	2.20	5.14
2	Yes	15	-9.25	7.15	77.73	21.72	-5.45	18.11
	No	22	5.80	14.30	89.00	10.68	3.72	12.52
3	Yes	2	5.00	2.00	92.50	2.50	0.43	2.50
	No	20	-0.60	4.74	89.65	4.94	-0.04	4.02
4	Yes	16	-6.00	11.83	70.19	12.32	-1.23	11.52
	No	14	-2.83	6.91	75.79	12.58	1.40	11.16
5	Yes[b]	0						
	No	35	-1.00	4.54	77.00	9.92	0.00	9.92

N = total number of aggressive episodes captured, [a]Value derived from one aggressive episode, [b]No aggressive episodes for collected data

continued

TEAMED Patient *Physiological*			**HRSD**		**HRTrend**		**HRPeaks**		**HRVSD**		**HRVTrend**		**HRVPeaks**		**SkinResist-anceSD**		**SkinResist-anceTrend**	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	4	1.80	2.06	3.00	0.00	0.44	0.65	2.31	1.08	4.88	0.99	6.78	4.85	2.93	4.34	4.40	1.59
	No	518	2.01	3.61	3.10	0.30	0.32	0.57	2.44	1.64	5.24	1.40	8.48	4.32	2.80	6.65	5.72	2.71
2	Yes	5	3.83	1.69	-[c]	-[c]	0.40	0.49	2.48	0.17	4.50	0.87	5.20	4.17	2.47	0.01	5.75	1.79
	No	130	1.82	2.21	3.16	0.46	0.18	0.42	2.53	1.60	5.40	1.43	7.43	4.99	2.25	3.80	6.04	3.46
3	Yes[b]	0																
	No	92	2.76	4.83	3.53	0.82	0.35	0.62	2.44	1.80	4.83	1.34	7.08	4.60	2.93	3.75	6.07	5.32
4	Yes	6	1.56	1.22	3.00	0.00	0.17	0.37	2.79	1.23	6.00	0.58	7.00	1.15	2.57	2.32	5.50	2.29
	No	258	2.62	3.57	3.00	0.00	0.10	0.32	2.48	1.73	5.43	1.35	9.34	4.31	3.30	5.13	5.42	2.25
5	Yes[b]	0																
	No	20	3.23	1.97	3.00	0.00	0.05	0.22	0.58	1.30	4.56	1.42	2.05	1.83	-0.39	1.43	3.80	1.17

			SkinResistanceTrough		**SkinTemp SD**		**SkinTemp Trend**		**SkinTemp Peaks**		**StepCountSD**		**StepCount Trend**		**StepCount Peaks**	
Participant		*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Yes	4	0.56	0.65	1.74	1.56	8.86	2.42	1.11	0.30	4.74	4.73	4.00	0.00	3.22	2.82
	No	518	0.52	0.88	2.33	4.09	11.14	6.80	0.63	0.73	2.48	3.54	3.13	0.33	2.57	2.88
2	Yes	5	0.20	0.40	0.78	2.35	6.75	1.30	0.20	0.40	2.20	0.49	-[c]	-[c]	2.80	1.83
	No	130	0.47	0.65	1.43	4.83	9.76	5.87	0.56	0.64	3.23	4.09	3.13	0.48	2.76	2.85
3	Yes[b]	0														
	No	92	0.47	0.91	2.19	3.04	14.45	8.61	0.60	0.64	2.81	4.73	3.00	0.00	1.71	2.21
4	Yes	6	0.00	0.00	1.47	1.30	11.83	2.79	0.67	0.75	2.11	2.82			2.00	1.91
	No	258	0.28	0.63	2.61	3.91	11.22	5.42	0.54	0.59	2.66	4.67	3.30	0.46	1.56	2.12
5	Yes[b]	0														
	No	20	1.45	1.43	2.29	1.71	6.10	2.70	0.50	0.67	17.61	22.25	3.00	0.00	1.58	2.16

N = total number of aggressive episodes captured, [a]*Value derived from one aggressive episode,* [b]*No aggressive episodes for collected data* [c]*Not enough values for calculation of feature*

Appendix 2.6 Algorithm Search Results

Note: *Unless otherwise stated, the Cost-Sensitive Classification (cost) is placed on 'Yes'*
Only results of Validation set are presented for algorithms with SMOTE
It was not possible to use SMOTE for TEAMED Application data due to the small number of aggressive episodes captured by the data

Participant 1

Microsoft Application

Physiological

1. Cost-Sensitive Classification with Cross-Validation
Yes = 9, No = 585

J48

		No			Yes		
Cost	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
65	**60**	435	0.99	0.74	4	0.03	0.44
65	**40**	463	0.99	0.79	4	0.03	0.44
65	**20**	523	0.98	0.89	0	0.00	0.00
55	**80**	457	0.99	0.78	4	0.03	0.44
55	**60**	473	0.99	0.81	4	0.03	0.44
55	**40**	477	0.99	0.82	3	0.03	0.33
55	**20**	521	0.99	0.89	1	0.02	0.11
45	**80**	457	0.99	0.78	4	0.03	0.44
45	**60**	488	0.99	0.83	4	0.04	0.11
45	**40**	475	0.99	0.81	3	0.03	0.33
45	**20**	532	0.99	0.91	1	0.02	0.11
35	**80**	458	0.99	0.78	4	0.03	0.44
35	**60**	488	0.99	0.83	4	0.04	0.44
35	**40**	482	0.98	0.82	1	0.01	0.11
35	**20**	529	0.99	0.90	1	0.02	0.11
25	**40**	539	0.98	0.92	0	0.00	0.00
25	**20**	548	0.98	0.94	0	0.00	0.00
25	**10**	541	0.98	0.93	0	0.00	0.00

Logistic Regression

	No			Yes		
Cost	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
85	333	0.98	0.57	3	0.01	0.33
75	357	0.98	0.61	2	0.01	0.22
65	392	0.98	0.67	1	0.01	0.11
55	439	0.98	0.75	0	0.00	0.00
45	476	0.98	0.81	0	0.00	0.00

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
65.5	**13**	487	0.99	0.83	3	0.03	0.33
65.5	**11**	403	0.99	0.69	5	0.31	0.03
55.5	**17**	482	0.99	0.82	3	0.03	0.33
55.5	**15**	484	0.99	0.83	3	0.03	0.33
55.5	**13**	525	0.99	0.90	2	0.03	0.22
55.5	**11**	491	0.99	0.84	2	0.02	0.22
45.5	**13**	498	0.98	0.85	0	0.00	0.00
45.5	**11**	514	0.99	0.88	1	0.01	0.11

2. SMOTE with Percentage Split
Training Set – Yes = 4, No = 412
Validation Set – Yes = 5, No = 173

J48

		No			Yes		
SMOTE (%)	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
14300	**60**	146	0.99	0.84	3	0.10	0.60
14300	**40**	144	0.99	0.83	3	0.09	0.60
14300	**20**	165	0.98	0.95	2	0.20	0.40
12300	**60**	145	0.98	0.84	2	0.07	0.40
12300	**40**	152	0.99	0.88	3	0.13	0.60
12300	**20**	166	0.98	0.96	2	0.22	0.40
10300	**60**	146	0.98	0.84	2	0.07	0.40
10300	**40**	147	0.99	0.85	3	0.10	0.60
10300	**20**	170	0.98	0.98	1	0.25	0.20
8300	**60**	158	0.98	0.91	2	0.12	0.40
8300	**40**	155	0.99	0.90	3	0.14	0.60
8300	**20**	170	0.98	0.98	1	0.25	0.20
6300	**40**	167	0.97	0.97	0	0.00	0.00
6300	**20**	171	0.97	0.09	0	0.00	0.00

Logistic Regression

	No			Yes		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
16300	94	0.96	0.54	1	0.01	0.20
14300	97	0.96	0.56	1	0.01	0.20
12300	108	0.96	0.62	0	0.00	0.00
10300	120	0.96	0.69	0	0.00	0.00
8300	136	0.99	0.79	0	0.00	0.00
6300	154	0.97	0.89	0	0.00	0.00

Multilayer Perceptron

		No			Yes		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
12300	**19**	168	0.98	0.97	1	0.17	0.20
12300	**17**	166	0.97	0.96	1	0.12	2.20
12300	**15**	166	0.98	0.96	1	0.13	0.20
12300	**13**	166	0.98	0.96	1	0.13	0.20
12300	**11**	163	0.98	0.94	1	0.09	0.20
10300	**19**	166	0.98	0.96	1	0.13	0.20
10300	**17**	166	0.98	0.96	1	0.13	0.20
10300	**15**	163	0.98	0.94	1	0.09	0.20
10300	**13**	163	0.98	0.94	1	0.09	0.20
10300	**11**	160	0.98	0.93	1	0.07	0.10

Sleep

1. Cost-Sensitive Classification with Cross-Validation
Yes = 7, No = 15

J48

		No			Yes		
Cost	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
4	**6**	0	0.00	0.00	6	0.27	0.86
4	**4**	2	0.67	0.13	6	0.32	0.86
4	**2**	1	0.50	0.07	6	0.30	0.86
3	**6**	2	0.33	0.13	3	0.87	0.19
3	**4**	3	0.60	0.20	5	0.29	0.71
3	**2**	0	0.00	0.00	6	0.29	0.86
2	**6**	5	0.42	0.33	0	0.00	0.00
2	**4**	9	0.56	0.60	0	0.00	0.00
2	**2**	11	0.73	0.73	3	0.27	0.43

Logistic Regression

	No			Yes		
Cost	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
8	10	0.71	0.67	3	0.38	0.43
7	10	0.71	0.67	3	0.38	0.43
6	10	0.71	0.67	3	0.38	0.43
5	10	0.71	0.67	3	0.38	0.43
4	10	0.71	0.67	3	0.38	0.43
3	9	0.64	0.60	2	0.25	0.29
2	10	0.67	0.67	2	0.29	0.29

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
4	**20**	7	0.58	0.47	2	0.20	0.29
4	**18**	6	0.55	0.40	2	0.18	0.29
4	**16**	8	0.62	0.53	2	0.22	0.29
4	**14**	6	0.55	0.40	2	0.18	0.29
3	**20**	7	0.58	0.47	2	0.20	0.29
3	**18**	6	0.55	0.40	2	0.18	0.29
3	**16**	7	0.58	0.47	2	0.20	0.29
3	**14**	6	0.55	0.40	2	0.18	0.29
2	**20**	7	0.58	0.47	2	0.20	0.29
2	**18**	7	0.58	0.47	2	0.20	0.29
2	**16**	7	0.58	0.47	2	0.20	0.29
2	**14**	7	0.58	0.47	2	0.20	0.29

2. SMOTE with Percentage Split
Training Set – Yes = 3, No = 10
Validation Set – Yes – 4, No = 5

J48

		No			Yes		
SMOTE (%)	**MinNum Obj**	N Correct	Precision	Recall	N Correct	Precision	Recall
300	**4**	0	0.00	0.00	3	0.46	0.75
300	**2**	5	0.56	1.00	0	0.00	0.00
200	**6**	5	0.56	1.00	0	0.00	0.00
200	**4**	5	0.63	1.00	1	1.00	0.25
200	**2**	5	0.63	1.00	1	1.00	0.25
100	**6**	5	0.56	1.00	0	0.00	0.00
100	**4**	5	0.63	1.00	1	1.00	0.25
100	**2**	4	0.67	0.80	2	0.67	0.50
50	**6**	5	0.56	1.00	0	0.00	0.00
50	**4**	5	0.63	1.00	1	1.00	0.25
50	**2**	5	0.56	1.00	0	0.00	0.00

Logistic Regression

	No			Yes		
SMOTE (%)	N Correct	Precision	Recall	N Correct	Precision	Recall
600	3	0.75	0.60	3	0.60	0.75
500	4	1.00	0.80	4	0.80	1.00
400	4	1.00	0.80	4	0.80	1.00
300	3	0.75	0.60	3	0.60	0.75
200	2	0.50	0.40	2	0.50	0.40
100	4	0.67	0.80	2	0.67	0.50
50	4	0.67	0.80	2	0.67	0.50
0	4	0.67	0.80	2	0.67	0.50

Multilayer Perceptron

		No			Yes		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
500	**20**	4	0.57	0.80	1	0.50	0.25
500	**18**	4	0.57	0.80	1	0.50	0.25
500	**16**	4	0.57	0.80	1	0.50	0.25
500	**14**	4	0.57	0.80	1	0.50	0.25
400	**18**	5	0.63	1.00	1	1.00	0.25
400	**16**	5	0.63	1.00	1	1.00	0.25
400	**14**	5	0.63	1.00	1	1.00	0.25
300	**18**	5	0.63	1.00	1	1.00	0.25
300	**16**	5	0.63	1.00	1	1.00	0.25
300	**14**	5	0.63	1.00	1	1.00	0.25
200	**18**	5	0.63	1.00	1	1.00	0.25
200	**16**	5	0.63	1.00	1	1.00	0.25
200	**14**	5	0.63	1.00	1	1.00	0.25
100	**22**	5	0.71	1.00	2	1.00	0.50
100	**20**	5	0.71	1.00	2	1.00	0.50
100	**18**	4	0.67	0.80	2	0.67	0.50
100	**16**	4	0.67	0.80	2	0.67	0.50
100	**14**	5	0.63	1.00	1	1.00	0.25

TEAMED Application

Physiological

1. Cost-Sensitive Classification with Cross-Validation
Yes = 4, No = 251

J48

		No			Yes		
Cost	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
140	**40**	166	0.98	0.66	0	0.00	0.00
140	**30**	150	0.98	0.60	1	0.01	0.25
140	**20**	212	0.98	0.85	0	0.00	0.00
120	**40**	158	0.99	0.63	3	0.03	0.75
120	**30**	156	0.98	0.62	0	0.00	0.00
120	**20**	212	0.98	0.86	0	0.00	0.00
100	**50**	166	0.98	0.66	0	0.00	0.00
100	**40**	125	0.98	0.50	0	0.00	0.00
100	**30**	209	0.98	0.83	0	0.00	0.00
100	**20**	212	0.98	0.85	0	0.00	0.00
80	**60**	164	0.99	0.65	0	0.00	0.00
80	**50**	186	0.98	0.74	0	0.00	0.00
80	**40**	160	0.98	0.64	0	0.00	0.00
80	**30**	210	0.98	0.84	0	0.00	0.00
80	**20**	213	0.98	0.85	0	0.00	0.00
60	**70**	182	0.98	0.73	0	0.00	0.00
60	**60**	178	0.98	0.71	1	0.01	0.25
60	**50**	151	0.97	0.60	0	0.00	0.00
60	**40**	211	0.99	0.84	1	0.02	0.25
60	**30**	209	0.98	0.83	0	0.00	0.00
60	**20**	219	0.98	0.87	0	0.00	0.00

Logistic Regression

	No			Yes		
Cost	N Correct	Precision	Recall	N Correct	Precision	Recall
200	237	0.98	0.94	0	0.00	0.00
180	238	0.98	0.95	0	0.00	0.00
160	237	0.98	0.94	0	0.00	0.00
140	235	0.98	0.96	0	0.00	0.00
120	234	0.98	0.93	0	0.00	0.00
100	235	0.98	0.94	0	0.00	0.00
80	236	0.98	0.94	0	0.00	0.00
60	238	0.98	0.95	0	0.00	0.00

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	N Correct	Precision	Recall	N Correct	Precision	Recall
130	**22**	140	0.99	0.56	2	0.02	0.50
130	**20**	206	0.99	0.82	1	0.02	0.25
130	**18**	209	0.99	0.83	1	0.02	0.25
130	**14**	235	0.98	0.94	0	0.00	0.00
120	**24**	140	0.99	0.56	2	0.02	0.50
120	**22**	176	0.99	0.70	2	0.03	0.50
120	**20**	210	0.99	0.84	1	0.02	0.25
120	**18**	233	0.98	0.93	0	0.00	0.00
120	**16**	235	0.98	0.94	0	0.00	0.00
120	**14**	233	0.98	928	0	0.00	0.00
100	**22**	210	0.99	0.84	0	0.00	0.00
100	**20**	234	0.98	0.93	0	0.00	0.00
100	**18**	236	0.98	0.94	0	0.00	0.00
100	**16**	235	0.98	0.94	0	0.00	0.00
100	**14**	235	0.98	0.94	0	0.00	0.00
80	**22**	236	0.98	0.94	0	0.00	0.00
80	**18**	234	0.98	0.93	0	0.00	0.00
80	**14**	237	0.98	0.94	0	0.00	0.00
60	**22**	234	0.98	0.95	0	0.00	0.00
60	**18**	235	0.98	0.94	0	0.00	0.00
60	**14**	239	0.98	0.95	0	0.00	0.00

Participant 2

Microsoft Application
Physiological

1. Weight with Cross Validation
Yes = 16, No = 581

J48

		No			Yes		
Cost	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
55	**80**	295	0.98	0.51	10	0.03	0.63
55	**60**	308	0.98	0.53	9	0.03	0.56
55	**40**	400	0.98	0.31	7	0.04	0.44
45	**60**	400	0.97	0.69	4	0.02	0.25
45	**40**	416	0.98	0.72	8	0.05	0.50
45	**20**	430	0.98	0.74	5	0.03	0.31
35	**80**	389	0.97	0.67	4	0.02	0.25
35	**60**	436	0.97	0.75	4	0.03	0.25
35	**40**	450	0.97	0.78	4	0.03	0.25

Logistic Regression

	No			Yes		
Cost	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
45	362	0.98	0.62	8	0.04	0.50
35	388	0.98	0.67	6	0.03	0.38

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
55	**13**	349	0.98	0.60	7	0.03	0.44
55	**11**	371	0.97	0.64	4	0.02	0.25
45	**13**	401	0.97	0.69	5	0.03	0.31
45	**11**	449	0.98	0.77	6	0.04	0.38
35	**19**	434	0.98	0.75	5	0.25	0.31
35	**17**	449	0.98	0.77	6	0.04	0.38
35	**15**	464	0.97	0.80	3	0.03	0.19
35	**13**	462	0.97	0.80	3	0.03	0.19
35	**11**	488	0.97	0.84	1	0.01	0.06

2. SMOTE with Percentage Split
Note: *Only results of Validation set are presented*

Training Set – Yes = 10, No = 347
Validation Set – Yes = 6, No = 234

J48

		No			Yes		
SMOTE (%)	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
4200	**100**	*209*	0.97	0.89	*0*	0.00	0.00
4200	**80**	*183*	0.97	0.78	*1*	0.02	0.17
4200	**60**	*183*	0.97	0.78	*1*	0.02	0.17
4200	**40**	183	0.97	0.78	*1*	0.02	0.17
4200	**20**	209	0.97	0.89			
4000	**60**	181	0.98	0.77	2	0.04	0.33
4000	**40**	181	0.98	0.77	2	0.04	0.33
4000	**20**	209	0.97	0.89	0	0.00	0.00
3800	**80**	192	0.97	0.82	0	0.00	0.00
3800	**60**	183	0.97	0.78	1	0.02	0.17
3800	**40**	183	0.98	0.78	1	0.02	0.17
3800	**20**	209	0.97	0.89	0	0.00	0.00
3600	**80**	198	0.97	0.82	0	0.00	0.00
3600	**60**	181	0.98	0.77	2	0.04	0.33
3600	**40**	183	0.97	0.78	1	0.02	0.17
3600	**20**	209	0.97	0.89	0	0.00	0.00

3400	**80**	190	0.97	0.81	1	0.02	0.17
3400	**60**	181	0.98	0.77	2	0.23	0.04
3400	**40**	194	0.98	0.83	1	0.02	0.17
3400	**20**	208	0.97	0.89	0	0.00	0.00
3200	**80**	202	0.98	0.86	1	0.03	0.17
3200	**60**	188	0.98	0.80	2	0.20	0.33
3200	**40**	201	0.98	0.87	1	0.03	0.17
3200	**20**	198	0.98	0.85	1	0.03	0.17
3000	**60**	192	0.98	0.82	1	0.02	0.17
3000	**40**	202	0.98	0.86	1	0.03	0.17
3000	**20**	199	0.98	0.85	1	0.03	0.17

Logistic Regression

	No			**Yes**		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
4200	180	0.97	0.77	1	0.02	0.17
4000	181	0.97	0.77	1	0.02	0.17
3800	182	0.97	0.78	1	0.02	0.17
3600	183	0.97	0.78	1	0.02	0.17
3400	187	0.97	0.80	1	0.02	0.17
3200	189	0.97	0.81	1	0.02	0.17
3000	190	0.97	0.81	1	0.02	0.17
2000	203	0.98	0.87	1	0.03	0.17

Multilayer Perceptron

		No			**Yes**		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
3600	**15**	219	0.97	0.94	0	0.00	0.00
3600	**13**	216	0.98	0.92	1	0.05	0.95
3600	**11**	220	0.97	0.94	0	0.00	0.00
3400	**13**	217	0.97	0.93	0	0.00	0.00
3400	**11**	217	0.98	0.93	1	0.06	0.17
3200	**17**	223	0.97	0.95	0	0.00	0.00
3200	**15**	219	0.98	0.94	1	0.06	0.17
3200	**13**	221	0.98	0.94	1	0.07	0.17
3200	**11**	223	0.97	0.95	0	0.00	0.00

Sleep

1. Cost-Sensitive Classification with Cross-Validation
Yes = 12, No = 20

J48

		No			Yes		
Cost	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
2	**4**	2	0.40	1.00	12	1.00	0.10
2	**3**	6	0.75	0.30	10	0.42	0.83
2	**2**	6	0.60	0.30	8	0.36	0.67
1.5	**4**	14	0.58	0.70	2	0.25	0.17
1.5	**3**	16	0.64	0.80	3	0.43	0.25
1.5	**2**	17	0.59	0.85	0	0.00	0.00
1	**4**	19	0.61	0.95	0	0.00	0.00
1	**3**	18	0.62	0.90	1	0.33	0.08
1	**2**	20	0.63	0.10	0	0.00	0.00

Logistic Regression

	No			Yes		
Cost	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
7	6	0.55	0.30	7	0.33	0.58
6	6	0.55	0.30	7	0.33	0.58
5	7	0.58	0.35	7	0.35	0.58
4	7	0.54	0.35	6	0.32	0.50
3	7	0.50	0.35	5	0.28	0.42
2	7	0.47	0.35	4	0.24	0.33
1	8	0.53	0.40	5	0.29	0.42

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
4	**18**	7	0.47	0.35	4	0.24	0.33
4	**16**	5	0.38	0.25	4	0.21	0.33
4	**14**	7	0.47	0.35	4	0.24	0.33
3	**18**	7	0.44	0.35	3	0.19	0.25
3	**16**	8	0.47	0.40	3	0.20	0.25
3	**14**	8	0.47	0.40	3	0.20	0.25
2	**18**	7	0.44	0.35	3	0.19	0.25
2	**16**	7	0.44	0.35	3	0.19	0.25
2	**14**	7	0.44	0.35	3	0.19	0.25
1	**18**	10	0.50	0.50	2	0.17	0.17
1	**16**	9	0.47	0.45	2	0.15	0.17
1	**14**	8	0.44	0.40	2	0.14	0.17

2. SMOTE with Percentage Split

Training Set – Yes = 7, No = 11
Validation Set – Yes = 5, No = 9

J48

		No			Yes		
SMOTE (%)	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
200	**8**	3	0.43	0.33	1	0.14	0.20
200	**6**	3	0.60	0.33	3	0.33	0.60
200	**4**	2	0.67	0.22	4	0.67	0.22
200	**2**	2	0.67	0.22	4	0.67	0.22
100	**8**	3	0.43	0.33	1	0.14	0.20
100	**6**	3	0.60	0.33	3	0.33	0.60
100	**4**	2	0.67	0.22	4	0.36	0.80
100	**2**	2	0.67	0.22	4	0.36	0.80
50	**8**	2	0.40	0.22	2	0.22	0.40
50	**6**	3	0.60	0.33	3	0.33	0.60
50	**4**	6	0.60	0.67	1	0.25	0.20
50	**2**	7	0.64	0.78	1	0.33	0.20

Logistic Regression

	No			Yes		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
300	3	0.60	0.33	3	0.33	0.60
200	3	0.60	0.33	3	0.33	0.60
100	5	0.62	0.56	2	0.33	0.40
50	5	0.62	0.56	2	0.33	0.40

Multilayer Perceptron

		No			Yes		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
300	**18**	3	0.50	0.33	2	0.25	0.40
300	**16**	3	0.50	0.33	2	0.25	0.40
300	**14**	3	0.50	0.33	2	0.25	0.40
200	**18**	5	0.83	0.56	4	0.50	0.80
200	**16**	4	0.80	0.44	4	0.44	0.80
200	**14**	4	0.80	0.44	4	0.44	0.80
100	**18**	4	0.50	0.44	1	0.17	0.20
100	**16**	4	0.50	0.44	1	0.17	0.20
100	**14**	4	0.50	0.44	1	0.17	0.20
50	**18**	4	0.67	0.44	3	0.38	0.60
50	**16**	5	0.63	0.56	2	0.33	0.40
50	**14**	4	0.67	0.44	3	0.38	0.60

TEAMED Application

Physiological

1. Cost-Sensitive Classification with Cross-Validation
Yes = 3, No = 80

J48

		No			Yes		
Cost	**MinNum Obj**	N Correct	Precision	Recall	N Correct	Precision	Recall
125	**10**	6	0.86	0.08	2	0.03	0.67
125	**8**	15	0.88	19	1	0.02	0.33
125	**6**	31	0.94	0.39	1	0.02	0.33
125	**4**	51	0.94	0.64	0	0.00	0.00
125	**2**	58	0.95	0.73	0	0.00	0.00
105	**10**	6	0.86	0.08	2	0.03	0.67
105	**8**	14	0.88	0.18	1	0.02	0.33
105	**6**	42	0.93	0.53	0	0.00	0.00
105	**4**	60	0.95	0.75	0	0.00	0.00
105	**2**	60	0.95	0.75	0	0.00	0.00
105	**10**	14	0.88	0.18	1	0.02	0.33
105	**8**	40	0.95	0.50	1	0.02	0.33
85	**6**	43	0.95	0.38	0	0.00	0.00
85	**4**	55	0.95	0.69	0	0.00	0.00
85	**2**	64	0.96	0.80	0	0.00	0.00
85	**10**	31	0.94	0.39	0	0.00	0.00
85	**8**	43	0.94	0.54	0	0.00	0.00
65	**6**	63	0.96	0.79	0	0.00	0.00
65	**2**	65	0.96	0.81	0	0.00	0.00
45	**10**	57	0.95	0.71	0	0.00	0.00
45	**8**	57	0.95	0.71	0	0.00	0.00
45	**6**	56	0.95	0.70	0	0.00	0.00
45	**4**	59	0.95	0.74	0	0.00	0.00
45	**2**	68	0.96	0.9	0	0.00	0.00
25	**12**	55	0.96	0.69	0	0.00	0.00
25	**8**	54	0.95	0.68	0	0.00	0.00
25	**6**	59	0.95	0.74	0	0.00	0.00
25	**4**	66	0.96	0.83	0	0.00	0.00
25	**2**	68	0.96	0.85	0	0.00	0.00

Logistic Regression

	No			Yes		
Cost	N Correct	Precision	Recall	N Correct	Precision	Recall
125	64	0.97	0.80	1	0.06	0.33
105	66	0.97	0.83	1	0.07	0.33
85	64	0.97	0.06	1	0.059	0.33
65	65	0.97	0.81	1	0.188	0.06
45	64	0.97	0.06	1	0.059	0.33
25	64	0.96	0.80	0	0.00	0.00

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	N Correct	Precision	Recall	N Correct	Precision	Recall
125	**20**	65	0.96	0.81	0	0	0
125	**18**	65	0.96	0.81	0	0	0
125	**16**	65	0.96	0.81	0	0	0
125	**14**	63	0.96	0.79	0	0	0
105	**20**	65	0.96	0.81	0	0	0
105	**18**	65	0.96	0.81	0	0	0
105	**16**	65	0.96	0.81	0	0	0
105	**14**	63	0.96	0.79	0	0	0
85	**20**	65	0.96	0.81	0	0	0
85	**18**	65	0.96	0.81	0	0	0
85	**16**	65	0.96	0.81	0	0	0
85	**14**	63	0.96	0.79	0	0	0
65	**20**	63	0.96	0.79	0	0	0
65	**18**	65	0.96	0.81	0	0	0
65	**16**	63	0.96	0.79	0	0	0
65	**14**	63	0.96	0.79	0	0	0
45	**18**	63	0.96	0.79	0	0	0
45	**16**	64	0.96	0.80	0	0	0
45	**14**	63	0.96	0.79	0	0	0
25	**16**	61	0.95	0.76	0	0	0
25	**14**	65	0.96	0.81	0	0	0

Participant 4

Microsoft Application
Physiological

1. Cost-Sensitive Classification with Cross Validation
Yes = 20, No = 495

J48

		No			Yes		
Cost	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
35	**70**	283	0.983	0.572	15	0.066	0.75
35	**50**	336	0.971	0.679	10	0.059	0.5
25	**90**	300	0.971	0.606	11	0.053	0.55
25	**70**	314	0.984	0.634	15	0.077	0.75
25	**50**	357	0.967	0.721	8	0.055	0.4
15	**90**	364	0.96	0.73	5	0.037	0.25
15	**70**	378	0.967	0.764	7	0.056	0.35
15	**50**	391	0.958	0.79	3	0.028	0.15

Logistic Regression

	No			Yes		
Cost	N Correct	Precision	Recall	*N* Correct	Precision	Recall
35	279	0.982	0.564	15	0.065	0.75
25	334	0.979	0.675	13	0.075	0.65
20	374	0.974	0.756	10	0.076	**0.5**
15	415	0.972	0.838	8	0.091	0.4

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
35	**17**	325	0.973	0.657	11	0.061	0.55
35	**15**	325	0.976	0.657	12	0.066	0.6
35	**13**	323	0.973	0.653	11	0.06	0.55
35	**11**	307	0.978	0.62	13	0.065	0.65
25	**15**	373	0.969	0.754	8	0.062	0.4
25	**13**	389	0.97	0.786	8	0.07	0.4
25	**11**	377	0.969	0.762	8	0.063	0.4

2. SMOTE with Percentage Split
Training Set – Yes = 13, No = 295
Validation Set – Yes = 7, No = 200

J48

		No			Yes		
SMOTE (%)	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
2400	**90**	131	0.97	0.66	3	0.04	0.43
2400	**70**	110	0.99	0.55	6	0.06	0.86
2400	**50**	108	0.99	0.54	6	0.06	0.86
2200	**70**	110	0.99	0.55	6	0.06	0.86
2200	**50**	131	0.99	0.66	5	0.07	0.71
2000	**70**	110	0.99	0.55	6	0.06	0.86
2000	**50**	160	0.96	0.80	1	0.02	0.14

Logistic Regression

	No			Yes		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
2400	98	0.99	0.49	6	0.06	0.86
2200	96	1.00	0.48	7	0.06	1.00
2000	105	0.99	0.53	6	0.06	0.86
1800	117	0.99	0.07	6	0.07	0.86
1400	131	0.99	0.66	6	0.08	0.86
1200	144	0.99	0.72	5	0.08	0.71
1000	161	0.97	0.81	2	0.05	0.29

Multilayer Perceptron

		No			Yes		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
2600	**17**	164	0.97	0.82	1	0.03	0.14
2600	**15**	163	0.96	0.82	1	0.03	0.14
2600	**13**	154	0.96	0.77	1	0.02	0.14
2600	**11**	144	0.96	0.72	1	0.02	0.14
2400	**15**	117	0.98	0.59	5	0.06	0.71
2400	**13**	123	0.96	0.62	2	0.03	0.29
2400	**11**	119	0.96	0.60	2	0.02	0.29
2200	**13**	140	0.96	0.70	1	0.02	0.14
2200	**11**	150	0.96	0.75	1	0.02	0.14

Sleep

1. Cost-Sensitive Classification with Cross Validation
Note: *Cost-Sensitive Classification placed on 'No' values*

Yes = 13, No = 8

J48

		No			Yes		
Cost	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
1	**6**	0	0.00	0.00	10	0.56	0.77
1	**4**	0	0.00	0.00	10	0.56	0.77
1	**2**	0	0.00	0.00	10	0.56	0.77
1.5	**6**	2	0.22	0.25	6	0.50	0.46
1.5	**4**	1	0.17	0.13	8	0.53	0.62
1.5	**2**	4	0.50	0.50	9	0.69	0.69
2	**6**	6	0.33	0.75	1	0.33	0.08
2	**4**	3	0.23	0.38	3	0.38	0.23
2	**2**	5	0.42	0.63	6	0.67	0.46

Logistic Regression

	No			Yes		
Cost	N Correct	Precision	Recall	N Correct	Precision	Recall
1	1	0.11	0.13	5	0.42	0.39
2	2	0.25	0.25	7	0.54	0.54
3	2	0.22	0.25	6	0.50	0.46

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
1	**18**	1	0.17	0.13	8	0.53	0.62
1	**16**	1	0.14	0.13	7	0.50	0.54
1	**14**	0	0.00	0.00	6	0.43	0.46
2	**18**	3	0.25	0.38	4	0.44	0.31
2	**16**	3	0.25	0.38	4	0.44	0.31
2	**14**	3	0.38	0.23	3	0.23	0.38

2. SMOTE with Percentage Split
Note: *Oversampling placed on 'No' values as it is the minority class*
Training set – Yes = 8, No = 4
Validation set – Yes = 8, No = 4

J48

		No			Yes		
SMOTE (%)	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
100	**6**	0	0.00	0.00	4	0.50	0.80
100	**4**	0	0.00	0.00	4	0.50	0.80
100	**2**	0	0.00	0.00	4	0.50	0.80
200	**6**	0	0.00	0.00	4	0.50	0.80
200	**4**	0	0.00	0.00	4	0.50	0.80
200	**2**	0	0.00	0.00	4	0.50	0.80
300	**6**	0	0.00	0.00	4	0.50	0.80
300	**4**	0	0.00	0.00	4	0.50	0.80
300	**2**	0	0.00	0.00	4	0.50	0.80
400	**6**	0	0.00	0.00	4	0.50	0.80
400	**4**	0	0.00	0.00	4	0.50	0.80
400	**2**	0	0.00	0.00	4	0.50	0.80

Logistic Regression

	No			Yes		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
100	1	0.20	0.25	1	0.20	0.25
200	1	0.20	0.25	1	0.20	0.25
300	1	0.25	0.25	2	0.40	0.40
400	0	0.00	0.00	2	0.33	0.40

Multilayer Perceptron

		No			Yes		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
0	**18**	1	0.20	0.25	1	0.20	0.25
0	**16**	1	0.20	0.25	1	0.20	0.25
0	**14**	1	0.20	0.25	1	0.20	0.25
100	**18**	1	0.20	0.25	1	0.20	0.25
100	**16**	1	0.20	0.25	1	0.20	0.25
100	**14**	1	0.20	0.25	1	0.20	0.25
200	**18**	1	0.20	0.25	1	0.20	0.25
200	**16**	1	0.20	0.25	1	0.20	0.25
200	**14**	1	0.20	0.25	1	0.20	0.25

TEAMED Application

Physiological

1. Cost-Sensitive Classification with Cross-Validation
Yes = 4, No = 178

J48

		No			Yes		
Cost	**MinNumObj**	N Correct	Precision	Recall	N Correct	Precision	Recall
55	**50**	126	0.98	0.71	1	0.02	0.25
55	**40**	113	0.99	0.64	3	0.37	0.75
55	**30**	113	0.99	0.64	3	0.37	0.75
55	**20**	113	0.99	0.64	3	0.37	0.75
55	**10**	152	0.98	0.85	1	0.04	0.25
45	**60**	131	0.97	0.74	0	0.00	0.00
45	**50**	121	0.99	0.68	3	0.05	0.75
45	**40**	113	0.99	0.64	3	0.04	0.75
45	**30**	125	0.98	0.70	1	0.02	0.25
45	**20**	128	0.98	0.72	1	0.02	0.25
35	**80**	145	0.97	0.82	0	0.00	0.00
35	**70**	134	0.99	0.75	2	0.04	0.50
35	**60**	124	0.98	0.70	2	0.04	0.50
35	**50**	113	0.99	0.64	3	0.04	0.75
35	**40**	113	0.99	0.64	3	0.04	0.75
35	**30**	125	0.98	0.70	1	0.02	0.25
35	**20**	157	0.98	0.88	1	0.05	0.25
35	**10**	158	0.98	0.89	1	0.05	0.25

Logistic Regression

	No			Yes		
Cost	N Correct	Precision	Recall	N Correct	Precision	Recall
135	144	0.97	0.81	0	0.00	0.00
125	144	0.97	0.81	0	0.00	0.00
115	145	0.97	0.82	0	0.00	0.00
105	145	0.97	0.82	0	0.00	0.00
95	145	0.97	0.82	0	0.00	0.00
85	145	0.97	0.82	0	0.00	0.00
75	146	0.97	0.82	0	0.00	0.00
65	146	0.97	0.82	0	0.00	0.00
55	147	0.97	0.83	0	0.00	0.00
45	148	0.97	0.83	0	0.00	0.00
35	152	0.97	0.85	0	0.00	0.00

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	N Correct	Precision	Recall	N Correct	Precision	Recall
115	**20**	152	0.97	0.85	0	0.00	0.00
115	**18**	135	0.97	0.76	0	0.00	0.00
115	**16**	120	0.98	0.67	2	0.03	0.50
115	**14**	145	0.98	0.82	1	0.03	0.25
105	**20**	152	0.98	0.85	1	0.04	0.25
105	**18**	137	0.99	0.77	2	0.05	0.50
105	**16**	134	0.99	0.75	2	0.25	0.04
105	**14**	153	0.98	0.86	0	0.00	0.00
95	**22**	141	0.98	0.79	1	0.03	0.03
95	**20**	154	0.98	0.87	1	0.04	0.25
95	**18**	152	0.97	0.85	0	0.00	0.00
95	**16**	156	0.96	0.88	0	0.00	0.00
95	**14**	152	0.97	0.85	0	0.00	0.00
85	**20**	141	0.98	0.86	0	0.00	0.00
85	**18**	153	0.98	0.86	0	0.00	0.00
85	**16**	153	0.98	0.86	0	0.00	0.00
85	**14**	157	0.98	0.88	0	0.00	0.00
75	**22**	153	0.98	0.86	0	0.00	0.00
75	**20**	153	0.98	0.86	0	0.00	0.00
75	**18**	154	0.96	0.87	0	0.00	0.00
75	**16**	156	0.96	0.88	0	0.00	0.00
75	**14**	156	0.96	0.88	0	0.00	0.00
65	**20**	158	0.98	0.89	0	0.00	0.00
65	**18**	159	0.98	0.89	0	0.00	0.00
65	**16**	160	0.98	0.90	0	0.00	0.00
65	**14**	158	0.96	0.89	0	0.00	0.00
55	**20**	161	0.98	0.90	0	0.00	0.00
55	**18**	161	0.98	0.90	0	0.00	0.00
55	**16**	161	0.98	0.90	0	0.00	0.00
55	**14**	162	0.98	0.91	0	0.00	0.00
45	**22**	161	0.98	0.90	0	0.00	0.00
45	**20**	163	0.98	0.92	0	0.00	0.00
45	**18**	163	0.98	0.92	0	0.00	0.00
45	**16**	166	0.98	0.93	0	0.00	0.00
45	**14**	166	0.98	0.93	0	0.00	0.00

Participant 1-5

Microsoft Application
Physiological

1. Cost-Sensitive Classification with Cross Validation
Yes = 50, No = 2233

J48

		No			Yes		
Cost	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
55	**230**	1325	0.99	0.59	34	0.04	0.68
55	**210**	1409	0.99	0.63	29	0.03	0.58
55	**190**	1510	0.99	0.68	28	0.04	0.56
55	**170**	1527	0.99	0.68	27	0.04	0.54
55	**150**	1503	0.98	0.67	22	0.03	0.44
45	**250**	1431	0.99	0.64	28	0.03	0.56
45	**230**	1489	0.99	0.67	29	0.04	0.58
45	**210**	1526	0.99	0.68	27	0.04	0.54
45	**190**	1567	0.98	0.70	25	0.04	0.50
45	**170**	1604	0.98	0.72	24	0.04	0.48
35	**250**	1675	0.98	0.76	14	0.02	0.28
35	**230**	1650	0.98	0.74	24	0.04	0.48
35	**210**	1713	0.99	0.77	24	0.04	0.48
35	**190**	1662	0.98	0.74	23	0.04	0.46
25	**250**	1745	0.98	0.78	12	0.02	0.24
25	**230**	1789	0.98	0.80	13	0.03	0.26
25	**210**	1805	0.98	0.81	18	0.04	0.36
25	**190**	1848	0.98	0.83	15	0.04	0.30

Logistic Regression

	No			Yes		
Cost	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
55	1263	0.99	0.57	34	0.03	0.68
45	1395	0.99	0.63	30	0.04	0.60
35	1601	0.98	0.72	21	0.03	0.42
25	1848	0.98	0.83	15	0.04	0.30

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
55	**17**	1417	0.99	0.64	34	0.04	0.68
55	**15**	1462	0.99	0.66	30	0.04	0.60
55	**13**	1440	0.99	0.65	30	0.04	0.60
55	**11**	1306	0.99	0.59	34	0.04	0.68
45	**21**	1554	0.99	0.70	32	0.05	0.06
45	**19**	1575	0.99	0.71	30	0.04	0.60
45	**17**	1590	0.99	0.71	29	0.04	0.58
45	**15**	1549	0.99	0.69	29	0.04	0.58
45	**13**	1519	0.98	0.68	25	0.03	0.50
45	**11**	1507	0.99	0.68	34	0.05	0.68
35	**21**	1706	0.98	0.76	23	0.04	0.46
35	**19**	1693	0.99	0.76	27	0.05	0.54
35	**17**	1725	0.99	0.77	24	0.05	0.48
35	**15**	1663	0.99	0.75	32	0.05	0.64
35	**13**	1708	0.99	0.77	27	0.05	0.54
35	**11**	1633	0.99	0.73	29	0.05	0.58
25	**19**	1883	0.98	0.84	18	0.05	0.36
25	**15**	1823	0.99	0.82	22	0.05	0.44
25	**11**	1845	0.99	0.83	21	0.05	0.42

2. SMOTE with Percentage Split

Training Data – Yes = 28, No = 1507
Validation Data – Yes = 22, No = 837

J48

		No			Yes		
SMOTE (%)	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
5500	**230**	672	0.98	0.80	7	0.04	0.32
5500	**190**	650	0.98	0.78	8	0.04	0.36
5500	**150**	603	0.98	0.72	8	0.03	0.36
5500	**110**	661	0.99	0.79	7	0.04	0.32
5300	**210**	690	0.98	0.82	5	0.03	0.23
5300	**190**	593	0.98	0.71	11	0.04	0.50
5300	**150**	633	0.98	0.76	8	0.04	0.36
5300	**110**	654	0.98	0.78	8	0.04	0.36
5100	**290**	595	0.98	0.71	9	0.04	0.41
5100	**270**	664	0.98	0.79	9	0.05	0.41
5100	**250**	610	0.98	0.73	12	0.05	0.55
5100	**210**	690	0.98	0.82	5	0.03	0.23
5100	**190**	657	0.98	0.79	5	0.03	0.23
5100	**150**	676	0.97	0.81	4	0.02	0.18

4900	190	683	0.98	0.82	7	0.04	0.32
4900	150	663	0.98	0.79	8	0.04	0.36
4900	110	663	0.98	0.79	8	0.04	0.36
4900	70	636	0.98	0.76	9	0.04	0.41
4900	30	720	0.98	0.86	4	0.03	0.18

Logistic Regression

	No			**Yes**		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
5500	468	0.98	0.56	14	0.04	0.64
5300	575	0.98	0.57	12	0.03	0.55
5100	481	0.98	0.58	12	0.03	0.55
4900	497	0.98	0.59	12	0.03	0.55
4700	468	0.98	0.56	14	0.04	0.64

Multilayer Perceptron

		No			**Yes**		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
5500	**19**	468	0.98	0.60	14	0.04	0.64
5500	**17**	722	0.98	0.86	6	0.05	0.27
5500	**15**	755	0.98	0.90	4	0.05	0.18
5500	**11**	725	0.97	0.87	3	0.03	0.14
5300	**19**	691	0.98	0.83	8	0.05	0.36
5300	**15**	674	0.98	0.81	9	0.05	0.41
5300	**11**	658	0.98	0.79	8	0.04	0.36
5100	**15**	670	0.98	0.81	6	0.27	0.27
5100	**11**	679	0.98	0.81	9	0.05	0.41
4900	**19**	706	0.98	0.84	5	0.04	0.23
4900	**15**	710	0.98	0.85	6	0.05	0.27
4900	**11**	679	0.98	0.81	6	0.04	0.27

Sleep

1. Cost-Sensitive Classification with Cost-Validation
Yes = 34, No = 65

J48

		No			Yes		
Cost	**MinNumObj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
3	**20**	16	0.67	0.25	26	0.35	0.77
3	**15**	23	0.66	0.35	22	0.34	0.65
3	**10**	23	0.70	0.35	24	0.36	0.71
3	**5**	18	0.64	0.28	24	0.34	0.71
2	**20**	25	0.74	0.39	25	0.39	0.75
2	**15**	26	0.67	0.40	21	0.35	0.62
2	**10**	43	0.71	0.66	16	0.47	0.44
2	**5**	39	0.69	0.60	15	0.37	0.44
1	**20**	58	0.64	0.89	2	0.22	0.06
1	**15**	55	0.64	0.85	3	0.23	0.09
1	**10**	57	0.66	0.88	5	0.39	0.15
1	**5**	58	0.68	0.89	7	0.50	0.21

Logistic Regression

	No			Yes		
Cost	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
3	32	0.74	0.49	23	0.41	0.68
2	39	0.71	0.60	18	0.41	0.53
1	52	0.68	0.80	10	0.44	0.29

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
3	**20**	39	0.63	0.60	11	0.30	0.32
3	**18**	38	0.64	0.59	13	0.33	0.38
3	**16**	35	0.65	0.54	15	0.33	0.44
3	**14**	37	0.69	0.57	17	0.38	0.50
2	**20**	40	0.67	0.62	14	0.36	0.41
2	**18**	39	0.66	0.60	14	0.35	0.41
2	**16**	39	0.65	0.60	13	0.33	0.38
2	**14**	41	0.66	0.63	13	0.35	0.38
1	**20**	44	0.66	0.68	11	0.34	0.32
1	**18**	47	0.67	0.72	11	0.38	0.32
1	**16**	47	0.68	0.72	12	0.40	0.35
1	**14**	46	0.67	0.71	11	0.37	0.32

2. SMOTE with Percentage Split
Training set - Yes = 20, No = 36
Validation set - Yes = 14, No = 29
J48

		No			Yes		
SMOTE (%)	**MinNum Obj**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
150	**15**	5	0.56	0.17	10	0.29	0.71
150	**10**	16	0.73	0.55	8	0.38	0.57
150	**5**	8	0.62	0.28	9	0.30	0.64
150	**2**	8	0.62	0.28	9	0.30	0.64
100	**15**	10	0.56	0.35	6	0.24	0.43
100	**10**	10	0.71	0.35	10	0.35	0.71
100	**5**	10	0.71	0.35	10	0.35	0.71
100	**2**	15	0.71	0.52	8	0.36	0.57
50	**15**	6	0.50	0.21	8	0.26	0.57
50	**10**	14	0.74	0.48	9	0.38	0.64
50	**5**	21	0.70	0.72	5	0.39	0.36
50	**2**	21	0.70	0.72	5	0.39	0.36

Logistic Regression

	No			Yes		
SMOTE (%)	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
150	18	0.72	0.62	7	0.39	0.50
100	19	0.73	0.66	7	0.41	0.50
50	20	0.74	0.69	7	0.44	0.50

Multilayer Perceptron

		No			Yes		
SMOTE (%)	**Hidden Layers**	*N* Correct	Precision	Recall	*N* Correct	Precision	Recall
150	**22**	19	0.79	0.66	9	0.47	0.64
150	**20**	19	0.76	0.66	8	0.44	0.57
150	**18**	19	0.79	0.66	9	0.47	0.64
150	**16**	17	0.81	0.59	10	0.46	0.71
150	**14**	18	0.86	0.62	11	0.50	0.77
100	**22**	17	0.74	0.59	8	0.40	0.57
100	**20**	20	0.80	0.69	9	0.50	0.64
100	**18**	20	0.77	0.69	8	0.47	0.57
100	**16**	18	0.75	0.62	8	0.42	0.57
100	**14**	19	0.83	0.66	10	0.50	0.71
50	**22**	19	0.79	0.66	9	0.47	0.64
50	**20**	18	0.78	0.62	9	0.45	0.64
50	**18**	17	0.71	0.59	7	0.37	0.50
50	**16**	18	0.72	0.62	7	0.39	0.50
50	**14**	17	0.77	0.59	9	0.43	0.64

TEAMED Application

Physiological

1. Cost-Sensitive Classification with Cross-Validation

Yes = 11, No = 586

J48

		No			Yes		
Cost	**MinNumObj**	N Correct	Precision	Recall	N Correct	Precision	Recall
60	**90**	388	0.98	0.66	2	0.01	0.18
60	**80**	385	0.98	0.66	3	0.02	0.27
60	**70**	435	0.98	0.74	1	0.01	0.09
60	**60**	443	0.98	0.76	0	0.00	0.00
60	**50**	432	0.98	0.74	0	0.00	0.00
50	**70**	442	0.98	0.75	0	0.00	0.00
50	**60**	451	0.98	0.77	0	0.00	0.00
50	**50**	414	0.98	0.71	3	0.02	0.27
50	**40**	462	0.98	0.73	2	0.01	0.18
40	**70**	454	0.98	0.78	0	0.00	0.00
40	**60**	441	0.98	0.75	0	0.00	0.00
40	**50**	423	0.98	0.72	1	0.01	0.09
40	**40**	441	0.98	0.75	2	0.01	0.18
40	**30**	469	0.98	0.80	2	0.02	0.18
40	**20**	482	0.98	0.82	0	0.00	0.00

Logistic Regression

	No			Yes		
Cost	N Correct	Precision	Recall	N Correct	Precision	Recall
70	377	0.98	0.64	4	0.02	0.36
60	406	0.98	0.69	3	0.02	0.27
50	426	0.98	0.73	2	0.01	0.18

Multilayer Perceptron

		No			Yes		
Cost	**Hidden Layers**	N Correct	Precision	Recall	N Correct	Precision	Recall
70	**18**	530	0.98	0.90	1	0.02	0.09
70	**16**	479	0.98	0.82	3	0.03	0.27
70	**14**	439	0.98	0.75	3	0.02	0.27
60	**16**	542	0.98	0.93	1	0.02	0.09
60	**14**	489	0.98	0.83	3	0.03	0.27
50	**22**	546	0.98	0.93	0	0.00	0.00
50	**20**	516	0.98	0.88	1	0.01	0.09
50	**18**	535	0.98	0.91	0	0.00	0.00
50	**16**	556	0.98	0.95	0	0.00	0.00
50	**14**	554	0.98	0.95	0	0.00	0.00

Appendix 2.7 Major Research Project Proposal

Technology Evaluating and Measuring Emotional Dysregulation (TEAMED)

Background:

Challenging behaviour is a significant issue for people with an acquired brain injury (ABI), and can impact everyday functioning. Research has explored medication, psychological and environmental interventions. The development of portable wearable devices that measure real-time physiological states opens avenues for assessing the predictability of challenging behaviour for future prevention via biofeedback intervention.

Aims:

To explore whether a physical monitoring device (electronic watch) can accurately predict challenging behaviour in individuals with an ABI.

Method:

A prospective case series design will be used. Participants will be recruited from Graham Anderson House. Participants will have sustained a severe brain injury, be ≥16 years old, and present with challenging behaviour. Patients with severe cognitive impairment will be excluded. Written consent will be sought from participants. Participants will wear an electronic watch that monitors heart rate, galvanic skin response, skin temperature and movement for up to 12 weeks. NHS Ethical approval for the project will be sought from the West of Scotland Research Ethics Committee. Approval via the MHRA and NHS R&D is not required.

Applications:

Identification of a tool that can predict challenging behaviour would be valuable for patients and staff by opening avenues for its prevention via proactive strategies.

Introduction

Challenging behaviour following acquired brain injury (ABI) is a significant issue for both patients and care providers (Tateno et al, 2003). These behaviours, if poorly controlled, can lead to difficulties with educational, vocational, and social pursuits, and family re-integration (Morton and Wehman, 1995; Ylvisaker et al, 2005). A study of 507 patients with severe ABI reported 54% to display challenging behaviour; inappropriate social behaviour was most commonly reported (33%; Sabaz et al, 2014). Difficulty identifying emotions, empathy, emotion regulation, social cognition and alexithymia are also found to be more prevalent following an ABI than the general population (McDonald, 2013; Wood and Williams, 2007).

Warden et al (2006) reviewed 33 pharmacological studies, and found supportive evidence for the use of medication for the treatment of aggression in people with a ABI; these included betablockers, methylphenidate, serotonin reuptake inhibitors, lithium, and tricyclic antidepressants. They also summarised evidence supporting cranial electrical stimulation and homeopathy, despite only one study identified for either intervention. They did not support the use of carbamazepine, pyritinol, valproate, estrogen and amantadine. Ylvisaker et al (2007) systematically reviewed 65 non-pharmacological studies (n = 172) for children or adults with behaviour disorders following an ABI; all studies reported an improvement in behavioural functioning. Interventions included contingency management, applied behavioural analysis and positive behavioural support. However, conclusions are restricted by methodological limitations: only two of the 65 studies were randomised controlled trials, with small sample sizes that did not record challenging behaviour frequency; the majority were uncontrolled single-cases or a series of cases. Other limitations include the lack of standardised intervention procedures, failure to report previously attempted failed interventions, and failure to record long-term outcomes (Ylvisaker et al, 2007). Psychological and behavioural interventions have also been recommended to treat the clinical correlates of aggressive behaviour following an ABI e.g. mood disorders, substance abuse, poor social support (Tateno, 2003). However research is limited, highlighting the need to explore further intervention options.

The evidence for the role of biofeedback, using physiological data, to improve emotion regulation is limited in the brain injury population; although there is some evidence for its role in improving cognitive functioning (Thatcher, 2000). Interventions have mainly provided neurofeedback to participants via the operant conditioning of preferable brain wave

patterns recorded via electroencephalography (Thatcher, 2000). In other populations supportive evidence has explored the use of biofeedback from skin temperature, muscle tension and brain waves for the treatment of chronic pain, urinary incontinence, high blood pressure and headaches (e.g. Cvjetičanin and Bašic, 2016; Dannecker et al, 2005). There is some evidence supporting the relationship between physical recordings and antisocial and violent behaviour in non-brain injured individuals (e.g. heart rate; Raine, 2002), but both correlation and intervention research is limited in the brain injury population. With the emergence of portable physiological monitoring systems this can broaden research opportunities, which have previously relied on patients being wired into large computer equipment, by allowing patients to wear the devices throughout the day.

The Graham Anderson House is a brain injury rehabilitation unit provided by the Brain Injury Rehabilitation Trust (BIRT) for people with complex needs that require residential care and support. Many patients resident at the Graham Anderson House require staff intervention to help manage challenging behaviours (i.e. harm to the patient or staff) as the patient is unable to identify and/or self-manage difficult emotions appropriately. With the developments in technology leading to the creation of Smart Watches, individuals can now accurately record and review their own physiological data (e.g. heart rate variability, sleep, movement). Developments in machine learning have also opened avenues for identifying useful patterns in data. It would be clinically relevant to be able to use machine learning techniques to find patterns in patients physiological data that would help predict future challenging events; this would provide opportunities for intervention that could then prevent future harmful behaviours. Therefore the current study aims to complete an exploratory investigation into whether a machine-learning algorithm can be used to predict challenging behaviour using physiological data.

Aims

To investigate whether a machine learning algorithm can be used to predict challenging behaviour episodes, using physiological data.

Research Questions

Can a machine learning algorithm be used to predict challenging behaviour using physiological data?

What levels of precision (positive predictive value) and recall (sensitivity) are obtained when machine learning algorithms are applied to physiological data?

Hypothesis

A machine learning algorithm can be used to predict challenging behaviour using physiological data.

Plan of Investigation

Participants

Patients with a brain injury, who are resident in a BIRT unit and present with challenging behaviour during the recruitment period.

Inclusion Criteria

- Patients who have sustained a severe injury to the brain, as determined by length of unconsciousness (greater than 6 hours) and a Glasgow Coma Scale of 3 to 8.
- Participants who have the capacity to consent to participation in research defined as understanding:
    - the type of physiological data the watch is collecting (sweat, heart rate, movement, sleep, temperature)
    - what the data is being used for (i.e. whether the data can predict episodes of physical or verbal violence)
    - that their participation involves wearing the watch for 8 weeks
    - that they can withdraw from the study at any time
    - that their data will be anonymised
- Patients who are resident in the Graham Anderson House BIRT Unit throughout the duration of the study.
- Patients ≥16 years old
- Patients presenting with challenging behaviour, during the recruitment period
- Patients will not be excluded on the basis of comorbid psychiatric disorders or histories of drug/alcohol misuse, in order to provide conclusions representative of the clinical population

Exclusion Criteria

- Patients without the capacity to consent to participation in research.

Recruitment Procedures

Patients will be recruited from the Graham Anderson House BIRT unit and approached by their clinical care team regarding participation in the study. Informed consent will be sought from the individual, after providing information about the study, by a member of the research team. They will be given at least 24 hours to decide whether to participate in the study. Patients that cannot provide consent will not be eligible to participate in the study.

Measures

The primary outcome of accuracy of prediction of challenging behaviour episodes will be determined through the predictive ability of the machine learning algorithm. This involves collecting physiological data using an electronic watch, and collecting challenging behaviour events using a clinical tool. Challenging behaviour episodes will be recorded via an adapted OAS-MNR (Alderman et al, 1997). The OAS-MNR is routinely used at the Graham Anderson House to record challenging behaviour and therefore this information will be collected from the patients' medical notes and anonymised for analysis procedures. As the staff at Graham Anderson House reporting this information are not involved in the study and have no conflict of interest, and the monitoring devices are commercially available and in similar appearance to a variety of Smart Watches, they are considered blind and independent raters of challenging behaviour. All types of behaviour recorded on the OAS-MNR will be considered an event.

Participants will wear a portable physiological monitoring device, Microsoft Band 2, which will record heart rate variability, movement, galvanic skin response, skin temperature and sleep. Data will be collected over for up to 12 weeks. A WIFI connected phone will store the physiological data, which will then be sent to a secure server managed by the University of Stirling, before being extracted for storage on a password protected Brain Injury Rehabilitation Trust computer. No personal identifiable information will be recorded on the watch and therefore all physiological data will be anonymised and linked to the patient via a unique ID kept separately on a password protected NHS computer known only to the researcher cannot be linked to the patient.

Demographic and clinical characteristics (e.g. age, gender, brain injury severity) will be gathered from each participants' medical records.

Design

Due to the nature of the study, a case series design will be used.

Research Procedure

Following enrolment in the study, participants will wear the watch for up to 12 weeks. During this time, staff will complete the adapted OAS-MNR, as per standard clinical care, when a challenging behaviour event occurs; this will describe the situation in which the event occurred, participant and staff responses, and any resulting behaviours, including the occurrence of challenging behaviour. Following an initial period of data collection, this data will be used in the creation and validation phase of the machine learning algorithm. The second period of data collection will be used to test the machine learning algorithm (see Data Analysis Section). Throughout the study, staff will respond to challenging behaviour events as per standard care. During participation, data will be stored on a secure data server (see Data Handling below).

Data Handling

A WIFI connected phone will store the physiological data measured by the Watch. This data will then be sent to a University of Stirling managed secure server, before being extracted for storage on a password protected Brain Injury Rehabilitation Trust computer. No personal identifiable information will be recorded on the watch and therefore all physiological data will be anonymised confidential, with the identity known only to the researcher. The data will only be linked via a unique ID held separately from both the consent forms and the study data. Consent forms will be stored at Graham Anderson House in the participants' medical files, accessible by the clinical team; medical files will not be accessible to the research team more than 3 months after the study has ended.

Data Analysis

The machine-learning package WEKA (Waikato Environment for Knowledge Analysis) will be used to analyse the physiological and behavioural data. A proportion of the data sampled will be used to create and validate a machine-learning algorithm. As this is an exploratory study, if possible, multiple models may be created in order to determine the most

appropriate algorithm(s); this may mean the development of a generic model, a specific model adapted for each patient, or separate models of verbal or physical aggression events. As the data involves time series data, temporal dependencies in the data will be accounted for via machine learning methods (e.g. sliding window approach). Events will be determined via staff completion of the adapted OAS-MNR within an hour window, non-events will be determined via a one hour window of non-completion of the adapted OAS-MNR. This process will also involve exploring the most appropriate level of sensitivity (aka. recall) and positive predictive value (aka. precision); this will include exploring the clinical applicability. The remaining data collected will be used to test the final machine learning algorithm(s). Dr Kevin Swingler (Lecturer in Computing Science, University of Stirling) and Professor Ken Turner (Emeritus Professor, University of Stirling) will provide guidance regarding data analysis, where required.

Justification of sample size

The number of residents at the BIRT unit restricts the number of patients potentially eligible for inclusion. During the recruitment period, it was estimated that at least 8 patients were considered to be eligible. Considering this, alongside the novel nature and case series design, the timescale of the project deadline, and the number of watches available, four participants was suggested to be appropriate for inclusion for thesis submission. This was considered to be sufficient to provide preliminary findings as to the predictability of machine learning algorithm(s) in predicting challenging events occurring in people with ABI. Up to a further 4 participants may then be recruited, with the total 8 participants included for submission to a peer reviewed journal. An 12-week schedule was chosen to balance length of time participants needed to wear the watch, to account for any periods of missing data, and ensuring enough time had passed for enough occurrences of challenging behaviour episodes; the average occurrence of challenging behaviour episodes at BIRT, per patient, is approximately 25 events per week.

Health and Safety Issues

See Health and Safety Form (Appendix 2)

Researcher Safety Issues

Due to the patient population investigated, safety issues relating to challenging behaviour may be present. The researcher will have received adequate training and be aware of local policy procedures should a safety issue arise. Due to the specialist nature of the service, staff

will be adequately trained in supporting this population during episodes of challenging behaviour for the duration of the study.

Participant Safety Issues

Due to the patient population investigated, participants may find it difficult to understand the purpose of the study and that a watch is being used to predict future challenging behaviour events. This may lead to reluctance to engage with the study. As the participants are resident at the rehabilitation unit, if any participant becomes distressed at any time during the study they will have access to their clinical care team for support. Participants have the right to withdraw from the study at any time. There is also a noted safety issue regarding the possibility of a skin reaction to the watch itself. As the participants are resident at the rehabilitation unit, their mental and physical health is regularly assessed. If any participant indicates or appears to show signs of a skin reaction, the watch will be removed and appropriate treatment will be provided. The participant will no longer wear the watch and will be withdrawn from the study.

Ethical Issues

NHS Ethical approval for the project will be sought from an NHS Research Ethics Committee. Approval via the Medications and products Healthcare Regulatory Authority was not required, as the study involves no randomisation, change to standard treatment or aims to claim generalisation of findings. NHS Research and Development approval will not be sought as the research will be conducted at a non-NHS site.

Financial Issues

See Costs and Equipment Form (Appendix 3)

Financial costs include printing costs for consent forms and participant information sheets. Portable devices to record physiological measures will be provided by the Graham Anderson House.

Dissemination Plan

The research will be submitted as part of the thesis component of the Doctorate in Clinical Psychology academic programme. This will be accessible via the e-library at the University of Glasgow. Details of the results will be provided to participants via their care team. The

research team also plan to submit the research as a manuscript for publication in a peer reviewed journal.

Proposed Timetable

September 2017	Systematic Review Outline
Wednesday 17th January	Ethics Paperwork
Thursday 18th January 2018	Draft Proposal
Thursday 1st February 2018	Proposal
March 2018-May 2018	Data Collection
April-June 2018	Data Analysis
June 2018	Draft Thesis
27 July 2018	Final Thesis
September 2018	VIVAS

Practical Applications

The identification of physiological measures that predict behaviours that challenge services would provide important warning signs to indicate intervention by staff to prevent the behaviour from occurring. This would have significant implications as to the frequency and severity of behaviours that challenge services.

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