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Managing challenging behaviours in adults with traumatic brain injury: A scoping review of technology-based interventions

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Abstract

Challenging behaviours are one of the most serious sequelae after a traumatic brain injury (TBI). These chronic behaviours must be managed to reduce the associated burden for caregivers, and people with TBI. Though technology-based interventions have shown potential for managing challenging behaviours, no review has synthesised evidence of technology aided behaviour management in the TBI population. The objective of this scoping review was to explore what technology-based interventions are being used to manage challenging behaviours in people with TBI. Two independent reviewers analysed 3505 studies conducted between 2000 and 2023. Studies were selected from five databases using search strategies developed in collaboration with a university librarian. Sixteen studies were selected. Most studies used biofeedback and mobile applications, primarily targeting emotional dysregulation. These technologies were tested in a variety of settings. Two interventions involved both people with TBI and their family caregivers. This review found that technology-based interventions have the potential to support behavioural management, though research and technology development is at an early stage. Future research is needed to further develop technology-based interventions that target diverse challenging behaviours, and to document their effectiveness and acceptability for use by people with TBI and their families.

Keywords

Technology-based interventions, challenging behaviours, emotional dysregulation, brain injuries, mobile applications, biofeedback, MHealth

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Introduction

Challenging behaviours are one of the most serious chronic sequelae after a moderate-to-severe traumatic brain injury (TBI). Defined as actions deviating from sociocultural or developmental norms, these behaviours may present barriers to community participation and risks to individual and caregiver health and safety, all the while undermining dignity and quality of life.[1–3] More than half of survivors will exhibit challenging behaviours in the first two-years post-TBI, the most common being aggression (e.g., swearing, threatening violence, slamming doors), socially inappropriate behaviours (e.g., standing too close to strangers, excessive apologising, failing to pick up non-verbal clues), and apathy.[4] For more than two thirds of people with TBI, challenging behaviours go on to become chronic five-years post-injury.[4,5] These behaviours have significant detrimental effects on social participation[6–9] by restricting access to various support services, including housing, respite, and rehabilitation.[10,11] After hospital discharge, family caregivers have a drastic increase in responsibility and are often left alone to manage challenging behaviours.[12] These behaviours have a devastating impact on their mental health and care burden.[13–15] It is crucial to consider how these challenging behaviours are (self-) managed to meet the long-term needs of individuals with TBI and their caregivers[16] and support better quality of life.

Clinical practice guidelines recommend specialist behaviour services that undertake careful analysis of behaviour and educate families on how to manage challenging behaviours.[17] One such approach is the Positive Behaviour Support, which is recommended for the management of challenging behaviours in people with TBI.[18] Positive Behaviour Support-based models, which consist of a careful behavioural analysis of antecedents and consequences, have demonstrated feasibility and benefits in studies for individuals with TBI and their caregivers.[19–21] However, the implementation of such programs remains difficult. Stakeholders of Positive Behaviour Support programs raise potential issues such as lack of time, money, staff, or Positive Behaviour Support training in rehabilitation teams,[22] as well as the length or intensity of programs that may restrict the participation of family caregivers and individuals with TBI,[20] and hinder their engagement in those programs over the long-term.[23] Furthermore, challenging behaviours are context-specific and shaped or triggered by various internal (e.g., fatigue or stress levels) and external factors (e.g., punitive or avoidant responses from formal or informal caregivers, complex task demands),[24–26] and individuals vary in their ability to regulate behaviours from one situation to another.[24] Therefore, it is imperative to explore innovative service delivery methods[20] and ways to augment promising approaches, such as Positive Behaviour Support, that can address the above challenges.

The use of technology-based interventions is a growing trend that extends interventions beyond traditional practice as an alternative way for delivering interventions.[27] Technology-based interventions may include more accessible and readily available tools than traditional health services, provide users with an immersive and comprehensive experience,[28] and allow them to complete interventions at their own pace and convenience.[29] It could include educational (e.g., information sessions), behavioural (e.g., self-monitoring), or supportive (e.g., phone coaching) dimensions.[29] These tools are varied and may include mobile health support applications,[30,31] telerehabilitation,[32] online resources,[33] biofeedback,[34] or wearable sensors and machine learning.[35] Some of these technologies can also be smart by "*dynamically access[ing] information, connect[ing] people, materials […] in an intelligent manner*" (p. 62).[36] These smart technologies function in real-time, i.e., the actual time during which something takes place, which would be all the more relevant as technologies would provide feedback to the user, thus promoting behavioural self-management. For example, smart technologies may be wearable devices that include sensors, microprocessors and wireless modules to monitor physiological indicators of the user.[36] These technology-based interventions could therefore have a beneficial role in the cognitive rehabilitation of people with TBI,[37] and could particularly support self-management of chronic conditions, such as TBI, and improve patient and caregiver outcomes.[29]

Features that technology-based interventions offer include the ability to objectively collect data based on individual performance to provide real-time feedback to therapists or patients.[28] These technologies would allow users to better understand and regulate their behaviours in real time, and thus could play a uniquely beneficial role in clinical rehabilitation models, such as Positive Behaviour Support approaches.[38]

Some technologies have shown promise for detecting early warning signs of behaviour change in other populations. For example, Hong, Margines[39] used machine learning based on data collected from smartphones in a vehicle to understand and model car drivers' aggressive behaviours. Khan, Zhu[40] developed a framework to detect agitation and aggression in people with dementia by collecting data from various sources such as video cameras, wearable devices (for motion and physiological data), motion and door sensors, and pressure mats. More recently, Bosch, Chakhssi[41] focused on individuals with autism spectrum disorders and intellectual disabilities and their use of wearable technologies with sensors to monitor their physiological states and inform them to help manage aggressive behaviours.

At a regional Canadian panel discussion, new technologies to optimise long-term community integration for people with TBI were identified as a research priority, particularly because of technology's ability to expand care access.[42] Technology-based interventions have been shown to have the potential to support the (self-) management of challenging behaviours in other populations (e.g., Ref. 43–45). However, to our knowledge, there is no review of evidence pertaining to technology-based interventions used in the management of challenging behaviours with adults with a brain injury. It is important to identify and describe the nature of the evidence in the TBI context, including what technologies have been developed and assessed, and how technology has been used in managing challenging behaviours to identify promising interventions and gaps. Furthermore, recent Canadian clinical practice guidelines suggest that it would be useful to identify evidence of technological interventions supporting caregivers with emotional and behavioural management.[17]

In summary, the use of real-time technology-based interventions has the potential to help prevent and manage challenging behaviours by detecting and communicating the warning signs of these behaviours to individuals with TBI and/or their caregivers so that they can implement strategies to regulate behaviour, adapt to challenging situations and optimise participation in daily life. Given the lack of a comprehensive review of evidence for technology-based interventions studied with individuals with TBI, we conducted a scoping review to explore the potential of technology-based interventions in managing challenging behaviours and identify the available evidence in this area of research.

Methods

A scoping review enables the mapping of the available evidence in a given field of research, clarification of key concepts and definitions, and most importantly, the identification and analysis of knowledge gaps in the existing literature.[46] We followed the methodological framework proposed by Arksey and O'Malley[47] and subsequent updates.[48,49] Following this five-step framework further described below, the research team proceeded by (1) identifying the research questions, (2) identifying studies, (3) selecting relevant studies to be included in the scoping review, (4) charting the data, and (5) summarising and reporting data.[47] This review was conducted and reported using the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRIMSA-ScR) Checklist.[50]

Identifying the research questions

The main question of interest was: What technology-based interventions are used to enable the management of challenging behaviours in people with TBI? More specific questions were: (1) What technology-based interventions support people with TBI and their caregivers in the management of challenging behaviours?; (2) What are the specific context(s) of use and feedback modalities of the technology?; and (3) What is the level of maturity of the reported technology?

Identifying studies

A systematic search strategy was developed by the research team composed of experts in brain injury rehabilitation, challenging behaviours, technologies, and scoping reviews and an academic health science librarian. The search strategy was first conducted in December 2021 and updated in February 2023 using five databases: Medline, Embase, PsycInfo, CINAHL, and Web of Science. The final search strategy combined three key concepts: acquired brain injury, challenging behaviours, and technology-based interventions, as well as their database adaptations (see an example of the search strategy in Supplemental material 1). Our search was limited to evidence published from January 2000 to reflect technology-based interventions that are more likely to be recently used in the rehabilitation field. Finally, the reference lists of included articles were also manually searched.

Selecting relevant studies

The following inclusion criteria were used: (1) primary studies (all study designs), (2) written in French or in English, (3) with adults with a primary diagnosis of ABI and/or with secondary comorbidities, aged 18–64 years and identified as having challenging behaviours, (4) reporting on technology-based interventions that were thought to impact, directly or indirectly, a challenging behaviour, and (5) published in the form of articles and conference proceedings. French and English was chosen because they are the languages mastered by the authors of the manuscript. Age criterion was established to exclude older participants (<65 years old) which could represent very different profiles and technological needs.

This study was a mixed study scoping review, meaning that all study designs were eligible for inclusion. There were also no restrictions regarding the study settings to ensure coverage of the entire literature. The study selection process included four steps. First, several research team meetings were held to develop, validate, and refine the specific research questions, search terms, and inclusion criteria. Second, two reviewers (EL, ED) independently screened the titles and abstracts of ten articles to ensure that they both had the same understanding of the inclusion criteria and preliminary screening process. Next, the same reviewers independently screened all titles and abstracts and the selected full texts. When conflicts emerged, a third party (CH or EP) was consulted to reach an agreement. The entire research team validated the final results included in the review.

Charting the data

A data charting table was created on Excel (Microsoft Corp., Redmond, USA) to synthesise the data from all included studies and pilot tested by two independent reviewers (EL, ED) on five articles. The final data extraction table was developed with the consensus of all team members following two group discussions. Using this table, the same two reviewers independently extracted the following data from all included studies: authors, year of publication, study country, study design, research objectives and/or questions, sample size, methods, variables measured and tools used, and main findings. Participant characteristics with a short case description were also extracted and tabulated: ABI severity, secondary diagnosis, challenging behaviours targeted by the study, and caregiver inclusion in the intervention. Regarding the use of technology, the following information was extracted from each study: technology type, feedback modalities, setting in which the technology was used, and the maturity of the technology. Finally, intervention processes were described using the Template for Intervention Description and Replication framework (TIDieR).[51] All extracted data were validated by CH with assistance from EP.

Summarizing and reporting the data

Following the first extraction process, the reviewers met three times to compare findings, discuss discrepancies, and refine the data charting table. Then, the entire team met again to discuss frameworks to report the remaining data. To describe the level of technology maturity, the three-phase Framework for Accelerated and Systematic Technology-based intervention development and Evaluation Research (FASTER)[52] was chosen. The development phase, namely the first phase of FASTER, considers the design process innovation and intervention refinement following user feedback. Phase 2 consists of progressive usability and feasibility evaluation with users of the intervention prototype and further intervention refinement for implementation. Finally, Phase 3 is the scaled deployment and evaluation of the intervention with users in real-world contexts.[52] To report the challenging behaviours, the Overt Behaviour Scale (OBS)[53] was used as it was designed to assess the various types of challenging behaviours that can occur following an ABI and correctly inform and guide clinical interventions.[53] The 34-item OBS scale is divided into nine categories that measure verbal aggression, physical aggression against objects and others, inappropriate sexual behaviour, perseveration, wandering, inappropriate social behaviour, and lack of initiation.[53] Classifications of challenging behaviours were first made by EL and ED and then checked and refined through multiple discussions as a full team. Additional behaviours that did not directly align with OBS categories, but that were nevertheless considered as challenging by people with TBI or caregivers in the scientific literature (e.g., emotional dysregulation)[54,55] were defined and charted using an "Others" category.

Results

Search results

A summary of the search results is presented in Figure 1. The search identified 3505 articles for review. After reference screening and removal of duplicates, 16 articles met the inclusion criteria and were included for final analysis. All articles were published after 2010.

Study characteristics

Table 1 summarises the included articles. Across the 16 articles, case studies were the most common study design with samples ranging from 1 to 3 participants (n = 4;[56,57–59]), followed by randomised controlled trials (n = 3;[60–62]). Study samples varied widely, with two studies standing out by size (n = 112 and n = 461;[60,61]) and use of control groups. When the severity was specified, four studies included participants with mild TBI[57,58,60,63] and six studies included participants with moderate-to-severe TBI.[59,61,62,64–66] Most studies included samples having a majority of males, except for two female-only case studies.[56,58] The following results are organized per specific research questions.

What technology-based interventions are used to enable the management of challenging behaviours in people with TBI?

Technology-based interventions – Key features. Details of each intervention are presented according to the TIDieR framework[51] in Table 2. Six studies presented interventions based on biofeedback[58,59,62,65,66] and neurofeedback[57] technologies, and six others on mobile applications, which included smartphones,[38,60,64] iPod touch,[61] and smartwatches.[63,67] Two studies included semi-immersive[56] or complete virtual reality,[68] and another used a physiological monitoring system.[69]

Challenging behaviours and intervention aims. Studies targeted a variety of challenging behaviours when describing participant characteristics, specific intervention aims, and/or intervention measures, as presented in Table 1. A detailed categorisation of extracted challenging behaviours according

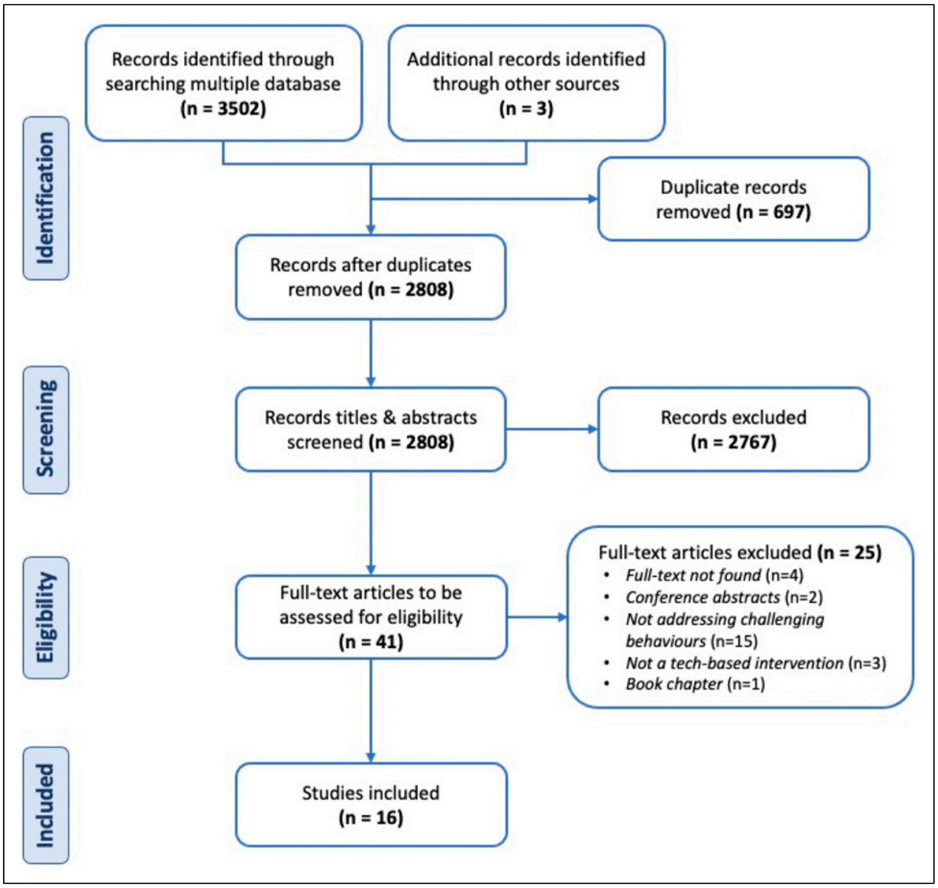

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for the scoping review process.

to the OBS is presented in Supplemental material 2. However, ten interventions targeted challenging behaviours that could not be readily categorised using the OBS.[56,58,60–66,70] These addressed emotional dysregulation and psychological distress (e.g., stress, anxiety, or depression). These studies also frequently integrated measures of other challenging behaviours, such as verbal/physical aggression,[58,61–63] but also lack of initiation and inappropriate social behaviours.[61]

Biofeedback studies aimed to increase participants' ability to regulate their breathing to achieve heart rate coherence (also called resonant frequency), and consequently addressed difficulties in emotional regulation, executive functioning, and psychological distress.[58,62,65,66] The included studies explored the association between behaviour and heart rate variability, and other related physiological measures (e.g., heart rate, respiration rate). Hammond[57] specifically targeted verbal and physical aggression management with the Low Energy Neurofeedback System, as well as O'Neill and Findlay[59] with their biofeedback intervention. They hypothesised that participants' challenging behaviours reduced in response to the biofeedback and allowed them to identify physiological signs of negative emotional states prior to them escalating.

Studies that used smartphone applications targeted a range of behavioural challenges, including post-concussion symptoms (e.g., irritability/frustration or psychological distress with Concussion coach application),[60] emotional dysregulation (e.g., BreatheWell application on smartwatch[63]) and/or impulsivity and maladaptive interpersonal behaviours (e.g. CALM intervention on iPod touch[61]). Jamieson, O'Neill[64] explored the use of the ForgetMeNot smartphone application that focuses on the effectiveness of unsolicited reminders to decrease prospective memory impairments. Here, the assistance provided by the reminders was seen by the authors as a potential intervention to decrease apathy.

Finally, De Luca, Torrisi[56] addressed severe anxiety and crying episodes by combining diaphragmatic breathing and relaxation techniques with a semi-immersive virtual reality environment (e.g., on-screen motion-based system for patient interaction with virtual reality scenarios in a traditional room setting).

The remaining four studies presented the preliminary steps of intervention development.[38,67–69] Rash, Helgason[68] elaborated a study protocol that targeted lack of

Table 1. Summary of included studies.

Studies	Sample (Males)	Study design and country	OBS category participant characteristics	OBS category measured/targeted by the intervention	Outcome measures	Major findings related to challenging behaviours
Belanger, Toyinbo[60]	$N_{intervention}$ = 231 (209) 42.1 ± 12.2 years $N_{control}$ = 230 (207) 41.0 ± 10.9 years Mild TBI PTSD (sec. Diagnosis)	RCT FASTER phase: 3 USA	-	Others (main target)	Self-report scales (NSI; BSI-18; Sesx) Total time spent on the app	No significant differences in global averages for the moderators, mediator and outcomes (*ps* > 0.05); Greater conditional probability of decreased PCS symptom severity (OR = 1.29) and smaller probability of progression of psychological distress symptoms of chronic concussion veterans compared to controls; Possible effect of self-efficacy as a mediator (p = 0.06); Correlation between the time spent on the app and decrease of PCS symptoms (r = 0.24)
De Luca, Torrisi[56]	*N* = 1 58 years Haemorrhagic stroke Anxiety (sec. Diagnosis)	Case study FASTER phase: 2 Italy	Others	Others (main target)	Neuropsychological evaluation (MoCA; AM Test) Coping strategies (Cope-NIV) Informant-report scale (HRS-A; HRS-D; FIM) Physiological parameters (blood pressure average value; heartbeat average value)	Significant improvement in cognitive functions (RCI = 3.1), anxiety (RCI = 3.0) and depression (RCI = 3.2) after the intervention; improvement in coping strategies (RCI = 3.1-3.2)
Elbogen, Dennis[61]	$N_{intervention}$ = 57 (53) 36.77 ± 8.60 years $N_{control}$ = 55 (50) 36.25 ± 8.30 years 64 moderate/severe TBI PTSD (sec. Diagnosis)	RCT FASTER phase: 3 USA	-	Others (main target) Verbal/Physical aggression Inappropriate social behaviour Lack of initiation	Neuropsychological evaluation (D-KEFS-Color-Word inhibition task) Self- & informant-report scales (BIS; DAR; HIBS; CAPS) Number of home visits completed	Significantly larger decreases in anger toward others in the intervention group (p = 0.008); Significant decrease of maladaptive behaviours as reported by family members in the intervention group (p = 0.016)
Hammond[57]	Case 1: 18 years (M, ADHD) Case 2: 30 years (M) Head injuries	Case study FASTER phase: 2 USA	Verbal/Physical aggression	Verbal/Physical aggression Physical aggression against other people	Interviews Self-report scales (homemade and STAI-2)	Noteworthy improvement in self-reports in both cases in a wide range of symptoms, including anger; Preliminary and uncontrolled results
Jamieson, O'Neill[64]	*N* = 3 (M) 45 years; 37 years; 55 years 1 severe TBI 2 TBI history (not reported), including 1 stroke	In situ field study FASTER phase: 2 UK	Inappropriate social behaviour Lack of initiation Others	-	Number of reminders Field observations	Markedly increase in the number of reminders when unsolicited prompts were introduced; Some barriers to use the app identified by participants (e.g., leaving the phone charging in his drawer; turning off the phone because it was annoying)
Kettlewell, Phillips[38]	*N* = 20 (15) 18-30 years (3) 31-50 years (9) >51 years (8) ABI	Mixed methods FASTER phase: 1 UK	-	Others (main target)	Focus groups & questionnaires	Overall interest of participants in using technology, but in a customisable format, easy to use and inexpensive/free; Some concerns identified, such as losing the phone, who had access to the data and losing the information if the phone was updated

(continued)

Table 1. (continued)

Studies	Sample (Males)	Study design and country	OBS category participant characteristics	OBS category measured/targeted by the intervention	Outcome measures	Major findings related to challenging behaviours
Kettlewell, Ward[70]	*N* = 11 (9) 43.45 ± 13.15 years 7 TBI (not reported) 4 ABI	Mixed methods A-B case design FASTER phase: 2 UK	Others	Others	Self-report scales (HADS; NEADL; MSNQ; EQ-5D-5L; CIQ; FAS; GAS) Audio-recorded semi-structured interviews	Significant increase of participants GAS scores between baseline and 6-months ($t(7) = 4.20$, $p = 0.004$); no significant changes in any other outcome measures; important additional perspectives of qualitative data, highlighting potential improvements of behavioural regulation not detected by the outcome measures
Kim, Zemon[65]	*N* = 13 (7) Median: 44 years 6 severe TBI 2 TBI (not reported) 5 ABI or degenerative disorders	Single treatment, non-randomised, unblinded quasi-experimental study FASTER phase: 2 USA	-	Others (main target)	Neuropsychological evaluation (Finger Tapping Test, Tactual Performance Test, Seashore Rhythm Test, Speech Sound Perception Test, the Halstead category Test, IVA+Plus CPT) Self and informant-report scales (BRIEF-A) HRV measures (LF/HF ratio; coherence ratio)	Non-significant improvement of emotional control in pre-post ($p > .05$); Significant correlation between families' rating of the participants' self-regulating ability (emotional control) and HRV indices (LF/HF ratio: $r_{(5)} = -0.98$, $p = 0.001$); coherence ratio; $r_{(5)} = -0.91$, $p = 0.005$); better concordance between participants' self-rating and how others (family members in particular) perceived their behaviour at post-treatment ($r_{(5)} = 0.86$, $p = 0.013$)
Kim, Zemon[66]	Same as Kim, Zemon[65] – secondary analyses performed				HRV indices (changes scores for the power of the LF band; changes scores of the LF/HF ratio) Neuropsychological measures (SSPT) Self-report and informant-report measures (BRIEF-A)	Significant correlation between change in LF and change in emotional control (5 min recordings: $r = -0.557$, $p = 0.048$; 10 min recordings: $r = -0.567$, $p = 0.044$); non-significant effects of LF/HF ratio as a predictor of emotional control; non-significant negative relation between HRV indices and emotional control
Lagos, Thompson[58]	*N* = 1 42 years Mild TBI	Case study FASTER phase: 2 USA	Others	Others (main target) Verbal/Physical aggression	Self-report scales (RPQ; HIT-6; POMS-SF) Physiological measures (HRV measures; RR)	Large short term and longer-term effects after HRV biofeedback on indices of autonomic control, decrease in mood disturbances and PCS, and improvements in headaches, according to visual observations on graphs

(continued)

Table 1. (continued)

Studies	Sample (Males)	Study design and country	OBS category participant characteristics	OBS category measured/targeted by the intervention	Outcome measures	Major findings related to challenging behaviours
McKeon, Terhorst[69]	*N* = 14 (10) 40.5 ± 3.28 years TBI (not reported)	Single group, cross-sectional, repeated measures study FASTER phase: 2 USA	-	Verbal/Physical aggression Perseveration	Behaviours filmed and coded (0 or 1) post-hoc by clinicians using the BDRS. Physiological measures (HR; RR; HRV)	Ability to initiate the presence of problematic events (mostly verbal dysregulation [54.5%]) with their behavioural tasks; reflection of the increase in behaviour through the measured physiological states including increase of HR (d_{av} = 0.0405, p = 0.03) and decrease of HRV (d_{av} = 0.502, p = 0.001), except for the RR; Preliminary evidence to further test physiology as a potential objective target for detecting behavioural dysregulation
O'Neill and Findlay[59]	Case 1: 33 years (M) Case 2: 18 years (M) Severe TBI	Case Study FASTER phase: 2 UK	Verbal/Physical aggression Others	Verbal/Physical aggression (main target) Others	Challenging behaviours score with the OASMNR scale by blind rehabilitation workers	Preliminary evidence of intervention effectiveness on challenging behaviours; non-significant effect of intervention for case 1 but self-injurious aggression eliminated; Significant effect size on verbal/physical aggression for case 2 (p = 0.001; d = 2.683)
Rash, Helgason[68]	*N*=30 (targeted) Stroke	Study protocol FASTER phase: 1 Canada	-	Lack of initiation (main target)	Feasibility indicators Self-report scales (HADS; Patient-reported measure of older adults' Sedentary Time; SIMS; Perceived Stress Scale; Subjective Happiness Scale)	-
Wallace, Morris[67]	*Part 1(a)* 2 healthcare providers(b) 5 TBI PTSD (sec. Diagnosis)	*Part 1* User-centred study FASTER phase: 1 USA	Others	Others (main target) Verbal/Physical aggression	*Part 1(a)* Not specified(b) Focus group	*Part 1 (a)* Input was used to inform the initial prototype of the apps(b) Recommendations on features, settings and display of the app. These steps resulted in eight "builds" of the app on Google © Glass and six on Android© Wear
	Part 2 *N*=14 (13) 26-42 years Range TBI (not reported) PTSD (sec. Diagnosis)	*Part 2* Not specified FASTER phase: 1			*Part 2* Sit-by and structured interviews Homemade Likert scale	*Part 2* Input provided on the display of information, ease of use, usefulness and other design preferences (wearable format, user customisation options, etc.), as well as experience of practice breathing. Feedback gathered through this process was incorporated into the beta version, the ninth build of the app on Google © Glass and seventh on Android© Wear

(continued)

Table 1. (continued)

Studies	Sample (Males)	Study design and country	OBS category participant characteristics	OBS category measured/targeted by the intervention	Outcome measures	Major findings related to challenging behaviours
Wallace, Morris[63]	$N_{intervention}$ = 15 (14) 37.47 ± 3.74 years $N_{control}$ = 15 (14) 37.87 ± 9.19 years Multiple mild TBIs PTSD (sec. Diagnosis)	Pilot pragmatic clinical trial FASTER phase: 2 USA	Others	Others (main target) Verbal/Physical aggression	Self-report standardised scales (GAS; BDI; BAI; PCL-5; Flourishing Scale; System Usability Scale) Self-rating homemade likert scales (Pre/post-session stress; Helpfulness of DB; DB technique knowledge; Difficulty remembering to practise DB; Difficulty remembering to use DB when stressed) Number of DB sessions	Improvements in both groups at all levels; Greater reduction in stress in the control group (p = 0.002). Significant improvements of health outcomes (PTSD, depression, anxiety, well-being) with no group differences
Wearne, Logan[62]	N = 50 (36) 44.6 ± 14.26 years Moderate-to-severe TBI	Single-centred RCT FASTER phase: 2 Australia	-	Others (main target) Verbal/Physical aggression	Self-report questionnaires (SAM; POMS-A; DASS-21; PSQI) Physiological measures (HR, skin conductance, RR, HRV)	No effects on objective/subjective responses to the mood induction procedure (ps > 0.05); Significant decrease of sleep disturbances (p < 0.05, η^2 = 0.114), greater resting state-positive mood (p < 0.005; η^2 = 0.161) and significantly fewer symptoms of depression (p < 0.05; η^2 = 0.114) at post-intervention for the intervention group

Notes. ABI = acquired brain injury; ADHD = attention deficit/hyperactivity disorder; AM Test = Attentive Matrices Test; app = application; BAI = Beck Anxiety Inventory; BDRS = Behavioral Dysregulation Rating Scale; BDI = Beck Depression Inventory; BIS = Barratt Impulsiveness Scale; BRIEF-A = Behavior Rating Inventory of Executive Function-Adult version; BSI-18 = 18-items Brief Symptom Inventory; CAPS = Clinician-Administered Posttraumatic Stress Disorder Scale; CIQ = Community Integration Questionnaire; Cope-NIV = Coping Orientation to Problems Experienced (Italian version); DAR = Dimensions of Anger Reactions; DASS-21 = 21-item Depression Anxiety Stress Scales; DB = Diaphragmatic Breathing; D-KEFS = Delis-Kaplan Executive Function System; EQ-5D-5L = EuroQol-5D-5L; FAS = Fatigue Assessment Scale; FIM = Functional Independence Measure; GAS= Goal Attainment Scaling; GMT = goal management training; HADS = Hospital Anxiety and Depression Scale; HF = High Frequency; HIBS = Head Injury Behavior Scale; HIT-6 = 6-item Headache Impact Test; HR = Heart rate; HRS-A = Hamilton Rating Scale for Anxiety; HRS-D = Hamilton Rating Scale for Depression; HRV = Heart Rate Variability; IVA+Plus CPT = the Integrated Visual and Auditory Continuous Performance Test; LF = Low Frequency; M = Male; MoCA = Montreal Cognitive Assessment; MSNQ = Multiple Sclerosis Neuropsychological Screening Questionnaire; η^2 = eta square; NEADL = Nottingham Extended Activities of Daily Living; NSI = Neurobehavioral Symptom Inventory; OASMNR = Overt Aggression Scale Modified for Neurorehabilitation; p = p-value; PCL-5 = Post-Traumatic Checklist-5; PCS = post-concussion syndrome; POMS-A = Profile of Mood States-Adolescent version; POMS-SF = Profile of Mood States–Short Form; PSQI = Pittsburgh Sleep Quality Index; PTSD = post-traumatic stress disorder; RCI = Reliable change index; RCT = randomised controlled trial; RPQ = Rivermead Postconcussion Questionnaire; RR = respiration rate; SAM = Self-Assessment Manikin; sec. = secondary; SESx = Self-Efficacy for Symptom Management Scale; SIMS = Situational Motivational Scale; SSPT = Speech Sounds Perception Test; STAI-2 = State-Trait Anger Expression Inventory-2; t = *t* test; TBI = traumatic brain injury; UK = United Kingdom; USA = United states of America.

Table 2. TIDieR framework summary.

Studies	Brief name	WHAT – Materials	What – Procedures	HOW	Where	WHEN and HOW much
Belanger, Toyinbo[60]	Concussion coach	Concussion coach smartphone application Smartphone	App includes: (1) psychoeducation on PCS symptoms following a mild TBI, (2) self-assessment using neurobehavioral Symptom Inventory, (3) identification and rating psychological distress	Virtual Individual Mobile	Living environment	3-month duration Reminders to engage with app sent on a weekly basis
De Luca, Torrisi[56]	Virtual rehabilitation	Breathing and relaxation techniques BTS nirvana (semi-immersive virtual environment)	Diaphragmatic breathing guided by instructions of the therapist, mediated by BTS nirvana System. This virtual rehabilitation system gives interactive series of exercises, interacting with the movements of the patient (two scenarios: One with audio-video and motor feedback). In the end, the participant was asked to tell physical and emotional feelings experienced during treatment. Compared with classical intervention in clinical environment realised before the target intervention	In-person Individual Stationary	Clinical environment	3 sessions weekly at least 40 min/sessions 2 month duration
Elbogen[61]	CALM (cognitive applications for life management)	iPod touch with only the functions necessary for the study CALM includes: GMT components Mind Jogger application IQ Boost application	GMT educational materials and didactic exercises given by clinical facilitators to teach veterans how to use this approach; home visits were planned to revise a new 2-month goal and promote engagement; Mind Jogger was a mobile app with content-free cues to prompt executive review (daily reminders; e.g., *what is my goal?*); IQ Boost was a mobile app to conduct n-back task exercises type (encouraged but not required); Family members engaged in the process to promote engagement in CALM intervention	In-person (home visits) Virtual (app use) Individual & dyad Mobile	Living environment	3 home visits (at least 60-90 min.) at 0, 2 and 4 months 6 months 4 daily random reminders through app (during waking hours)
Hammond[57]	LENS (Low energy neurofeedback System)	LENS	Weak EEG passive neurofeedback delivered at 1-sec intervals down electrode wires while the patient is motionless. Feedback is adjusted 16 times per second to remain a certain number of cycles per second faster than the dominant EEG frequency	In person Individual Stationary	Clinical environment	Case 1: 28 sessions Case 2: 26 sessions
Jamieson, O'Neill[64]	ForgetMeNot	Smartphone application Samsung Galaxy S3 mobile phone (Android© 4.3) Standard Samsung time selector widget	The participants were met 9-hour-long times by the experimenter to ensure understanding and interview participants. Participants received a one-hour demonstration session of how to use the app. The app allows: 1) the participant to set reminders for a specific time during the same day, 2) the participant to be alerted by audio-visual prompts, 3) the experimenter to plan unsolicited prompts (UPs; random prompt to set reminders), 4) to log every reminder. UPs were planned by the experimenter. The participants planned their own reminders when they wanted on the same day, according to a list of tasks that they often forget identified by the clinical team, the research team or the participants themselves	In person Virtual Mobile	Clinical environment	4 weeks duration 2 weeks with UPs – 2 weeks without (randomly assigned) UPs randomly 6 times/day
Kettlewell, Phillips[38]	Brain in Hand	Brain in Hand smartphone application	Reminder app to create a structured daily routine for difficult to remember tasks or problem situations; Traffic lights alarm system to record anxiety levels	Virtual Mobile	Living environment	N/A

(continued)

Table 2. (continued)

Studies	Brief name	WHAT – Materials	What – Procedures	HOW	Where	WHEN and HOW much
Kettlewell, Ward[70]	Brain in Hand	Brain in Hand smartphone application User smartphone Laptop/computer to edit diary online if needed	App personalised to specific needs. Workbook given before intervention and training book given during the training session and left with the participant; Two-hour training session was offered to each participant in time for questions. Each participant was then asked to demonstrate different features to the researcher before they could competently use the app. During the final part of the session, the researcher helped individuals personalise their diaries by adding daily events and changed the traffic light labels to suit their specific needs/goals. The researcher could give prompt or help to set up the app. After the face-to-face session, the app was intended for use by the individual in their daily life at home	In person Individual Mobile	Living or clinical environment (by choice)	2-hour training 12-months use 1 interview at 6-months post-intervention
Kim, Zemon[65]	HRV biofeedback	emWave device (HeartMath) Infrared plethysmograph sensor (earlobe or finger) Thought technology Ltd. BioGraph Infinit	Training in paced breathing to train participants to achieve resonance frequency (higher HRV and RSA); Participant receives feedback via a screen that provides a visualisation of the HRV in a game selected by the participant (Garden Game or Emotion Visualizer; the image changes on the screen depending on the achievement of resonance); cell-phone-size handheld devices for home practice (after 4 sessions)	In person Individual Mobile & stationary	Clinical & Living environments	10 sessions (60 min duration)
Kim, Zemon[66]	HRV biofeedback	—	Same intervention protocol as Kim, Zemon.[65]	—	—	—
Lagos, Thompson[58]	HRV biofeedback	ProComp Infiniti system Blood volume pulse sensor Respiration strain gauge Thought technology	Lehrer, Vaschillo[85] protocol. First taught to breathe at his resonant frequency; Session 1: Measures taken while the individual deeply breathes at specific frequencies determined by a light display that moves up and down on the computer screen; Subsequent sessions: The patient is directly given biofeedback for cardiac variability and instructed to increase the amplitude of heart rate fluctuations that occur in conjunction with respiration. The feedback can take several forms (beat-to-beat cardiotachometer, moving frequency analysis of heart rate within the past minute, light-bar display to illustrate the amplitude of RSA with each breath) but it is not specified which one has been used in the study; Homework: Participants must breathe slowly at resonance frequency using abdominal and pursed lip breathing techniques	In person Individual Stationary	Clinical & Living environments	10 weeks (45-60 minduration)/session 2 breathing practices/day (20 min duration, homework)
McKeon, Terhorst[69]	Naturalistic Physiological monitoring System	Bioharness-3 (Zephyr Technology Corporation) Fabric strap around the abdomen (Bluetooth tech) The Observer-XT package from noldus	Completion of 3 research tasks designed to elicit stress, while monitoring physiological measures. Videorecorded to allow coding of behavioural dysregulation by clinicians	In person Individual Wearable	Clinical environment	1 session (2 hours duration)

(continued)

Table 2. (continued)

Studies	Brief name	WHAT – Materials	What – Procedures	HOW	Where	WHEN and HOW much
O'Neill and Findlay[59]	HRV biofeedback	emWave2 device (HeartMath) Plethysmograph sensor (earlobe)	Participants were trained by the research team on how to achieve the heart rate coherence. They were asked to breathe in and out as the tracer lights rose and fell, maintain attentional focus in the heart region, and activate a memory or attitude of appreciation. During this exercise, they received feedback linked to the physiological measures recorded in real time to inform them of the quality of their heart rate coherence. Positive feedback on high coherence is in the form of a green light on the device (blue = medium; red=low) and a pleasant high-pitched tone sounds (medium or low tone in medium or low coherence)	In person Individual Mobile	Clinical environment	Supervision in the use for 10-20 min per day, Monday to Friday Individual independent use
Rash, Helgason[68]	VR entertainment program	Oculus Go system (Facebook Technologies)	Implementation one-on-one, face-to-face by a member of the research team. In a specific room for the VR program, participants select games/programs in areas related to relaxation, leisure, sport and activities or action/adventure. The interventionist will explain the program (i.e., putting on the VR goggles, how to control the game using the hand-held remote, game/program instruction). Can stop using the VR at any time and select another game/program or take a break. The participants will never be left alone while playing a game. They will be informed that they may invite friends/family to watch while they are using the VR entertainment program	In person Stakeholder support Stationary	Clinical environment	20-min info session 30-min/session; 3 sessions/week Inpatient rehabilitation duration
Wallace, Morris[67]	Breathewell app	Breathwell app – Google © Glass version Breathwell app – Android© wear smartwatch version	Interviews were completed with 14 participants (seven for Google © Glass version and seven for the Android© version); These two apps are presented as a breathing coach; both Android© Wear smartwatches and Google © Glass are wearable computers that use a smartphone-like format allowing users to download apps designed for brief interactions. Android© Wear smartwatches are worn on the wrist and have varying features. Google © Glass is a head mounted wearable with an optical display designed in the shape of a pair of eyeglasses; In both versions, users can customise the app according to their wishes (e.g., having a stress rating scale before/after the breathing exercise; setting reminders to practise, adjusting the rate of inhalation and exhalation, choosing the guide voice, selecting relaxing songs); both versions have an instructional video of a person with PTSD and TBI demonstrating the breathing technique; The app offers training for diaphragmatic breathing. It can show graphical elements to show the pace of inhalation/exhalation. The breathing pace bar on the Google © Glass version is light green and transparent so that the photo behind it can be viewed. The breathing pace bar on the Android© Wear version is blue and runs along the perimeter of the watch face. The Android© Wear device also vibrates at the end of each inhalation and exhalation to provide a tactile cue to the user	Individual Mobile	Living environment	N/A

(continued)

Table 2. (continued)

Studies	Brief name	WHAT – Materials	What – Procedures	HOW	Where	WHEN and HOW much
Wallace, Morris[63]	BreatheWell app with smartwatch	BreatheWell Wear app Companion app LG Urbane Android© Wear smartwatch Personal Android© devices or Android© tablet (when relevant, to use applications)	Two videos (2-min) demonstrating the diaphragmatic breathing and how to use the BreatheWell app; Instruction about diaphragmatic breathing given by a health provider in a calm atmosphere, before enrolment (part of intensive rehabilitation); The app displays the user's heart rate and guides performance of diaphragmatic breathing via visual, tactile, and auditory cues (e.g., voice guidance, calming sounds) that are customisable; Users pace their breathing by matching it to the movement of a blue circle running along the perimeter of the watch face. The watch vibrates at the end of each inhalation and exhalation as the visual pacing circle reverses direction for the next segment of the breathing cycle; Participants were asked to set alarm reminders through the app to help them remember to practise diaphragmatic breathing. Feedback on the app use is available through the companion app (e.g., frequency of use, changes in heart rate, and stress ratings)	Individual Mobile	Clinical environment	2 times/day during slow, calm periods Encouraged to use it when they experience stress or anxiety 4 weeks duration
Wearne, Logan[62]	HRV biofeedback	3 Ag/AgC1 sensors on the underside of wrists Sensors on third digits of the non-dominant hand Flexible respiration belt around the abdomen 10 channel FlexComp Infiniti encoder system Biograph Infiniti and CardioPro Infiniti software 6.0 (Thought Technology)	Seated in front of a PC laptop which displays physiological wave forms; Instructed to practise diaphragmatic breathing at their resonance frequency, following a visual pacer on computer; Positive feedback given by green light turned on, a static picture that became animated and a sound; breathing practice homework at their resonant frequency, by using the device of their choice (phone app, website or second-hand on a watch)	In person Individual Stationary	Clinical & Living environments	6 sessions over a 2-week period, with at least 1 day in between sessions 4 training blocks of 10 min/session Homework: 20 min/2x/day (or alternatively 10 min/4x/day)

Notes. App = application; EEG = electroencephalography; GMT = goal management training; HRV = heart rate variability; IQ = intellectual quotient; min = minute(s); N/A = not applicable; PCS = post-concussion syndrome; PTSD = post-traumatic syndrome disorder; RSA = respiratory sinus arrhythmia; TBI = traumatic brain injury; VR = virtual reality. The TIDieR framework was used to summarise each intervention and presented in Table 2. The *Why* category is discussed in the text. The following TIDieR categories were not included in the Table due to limited data available: Tailoring, Modifications, How well, and Who. All the studies that proposed a mobile application were conducted exclusively in English-speaking countries (i.e., USA & UK). This implies that the content of these studies can be assumed to be in English. It is worth noting that among these studies, only Belanger[60] and Wallace, Morris[63] explicitly mentioned English as part of their inclusion criteria.

initiation through a virtual reality program. McKeon, Terhorst[69] used a physiological monitoring system to measure behavioural dysregulation, including verbal aggression and perseveration. Kettlewell, Phillips[38] explored through focus groups and questionnaires completed by people with an ABI, caregivers, and clinicians, the barriers and facilitators of Brain in Hand, an application that was tested in another included study.[70] Finally, Wallace, Morris[67] conducted interviews and focus groups with clinicians and veterans with mild TBI and post-traumatic syndrome disorder to improve the prototypes of the BreatheWell application, which was also tested in a subsequent study.[63]

Main findings of selected studies. Table 1 summarises the main findings of each study that tested an intervention on the target population and presents the tools used to measure the main outcomes.

Using mobile applications, some studies found improvements in post-concussion syndrome severity and psychological distress (Concussion Coach app),[60] anger management, maladaptive interpersonal behaviours, and post-traumatic syndrome disorder symptoms (CALM app),[61] and emotional regulation.[63] Alternately, Kettlewell, Ward[70] found no objective quantitative improvement in behavioural regulation, although improvements were noted in subjective reports.

In the De Luca, Torrisi[56] semi-immersive intervention study, the participant showed a significant reduction in anxiety and increase in coping strategies, as well as a reduction in heart rate and blood pressure measures when performing relaxation techniques.

McKeon, Terhorst[69] preliminary study showed that the increase in challenging behaviours observed during the experimental tasks was reflected by a physiological increase in heart rate and decrease in heart rate variability. No change was observed with the respiration rate, suggesting that this specific physiological state may not be sensitive to the tasks studied.

Biofeedback studies provided preliminary evidence that heart rate variability training had a beneficial effect on emotional regulation,[58,65,66] as well as post-concussion syndrome and headaches,[58] and aggression.[59] Improved subjective well-being and continued use of the biofeedback device beyond the intervention phase were reported in one study,[59] while another study[62] showed no effect on either objective or subjective indicators of emotional regulation. However, positive effects on improved sleep and mood were noted, though these were not directly targeted by the intervention. Hammond[57] showed improvements in several symptoms (e.g., anger/explosiveness, anxiety, and impulsivity) but their results were preliminary and uncontrolled.

The included studies did not include a follow-up evaluation of their interventions, i.e. an evaluation able to report on the maintenance over time of the gains obtained after the intervention had been completed.

Caregiver involvement in the intervention. Two studies included caregivers. Elbogen, Dennis[61] included family members or friends to provide support and encourage veterans to engage in the CALM application. Kettlewell, Phillips[38] have planned for the Brain in Hand application to have a monitoring system portal that would allow a user, caregiver, mentor, or health care professional to track application usage and mentor support. This was further investigated in a consecutive study (e.g., family member, partner or carer).[70]

Stakeholders who provided the intervention. All mobile applications were intended to be ultimately used independently by participants with an ABI with no input from health care professionals,[60,61,63,64,70] except when specified otherwise (e.g., training, interviews, home visits;[61,63,64,70]).

Four biofeedback studies required training by clinical researchers,[59,62,65,66] whereas two other studies failed to report on training.[59,64] In one study, relaxation techniques were guided by a therapist[56] and in another, clinicians monitored the presence of challenging behaviours.[62] Finally, trainers' professional background was specified only in Kim, Wemon's (PhD candidate trained in neuropsychological assessments and HRV biofeedback)[65,66] and Kettlewell, Ward studie (PhD student trained to use Brain in Hand).[70]

What are the specific context(s) of use and feedback modalities of the technology?

A summary of technology-related contexts and feedback modalities are presented in Table 2 according to TIDieR framework.

Contexts of technology-based interventions. Mobile applications-based interventions were either offered in living environments,[60,61] clinical environments,[64] or both depending on the participant's choice.[70] All neurofeedback, biofeedback, or virtual reality interventions were implemented in clinical settings.[56–58,62,65,66] In addition to clinic-based interventions, the biofeedback intervention of Kim, Wemon's[65,66] also provided handheld devices to be used at home for further practice.

Feedback modalities of technology-based interventions. Limited information about the types of feedback modalities used in the interventions could be extracted. When the modality was specifically addressed in the article, feedback could be visual,[56,59,62–64] auditory,[56,59,63,64] motor,[56] and/or tactile.[63]

Smart nature of technologies. Mobile applications cannot be considered as smart technologies, as there is no adaptation of content or feedback provided to the user from the logs recorded by the application.[60,61,63,64] Brain in Hand is, however, presented as a smart application by the authors[70] because it allows recording of real-time information in a cloud and allows mentors to monitor and better understand the elements that cause distress.

Biofeedback studies are smart technologies as they record and analyse data and use it to provide real-time feedback during the intervention.[58,59,62,65,66] The neurofeedback technology can also be considered, to some extent, as being a smart technology, as it adapts the provided feedback based on the measured electroencephalography frequency during the intervention.[57]

The work of De Luca, Torrisi[56] can be considered as the one with the higher level of integration of smart technologies, because participants received direct audio-visual or motor feedback from the semi-immersive environment to adapt their behaviours during the intervention.

What is the level of maturity of the reported technology?

FASTER: Phase of intervention development. As described in Table 1, three studies were situated in Phase 1 (i.e., development and documentation[38,67,68]) and 11 studies were in Phase 2 (i.e., feasibility[56,57–59,62–66,70]). Overall, only two studies were in Phase 3 (i.e., implementation and effectiveness[60,61]).

Discussion

In this scoping review, we identified technology-based interventions that were investigated to promote or support the (self-) management of challenging behaviours in adults with TBI. Our results show that there is still little literature in this area and that existing technologies, primarily biofeedback techniques or mobile applications, mostly target emotional dysregulation.

Limited research in technology-based interventions for people with TBI

Technology in rehabilitation is an emerging field and few authors have investigated its relevance for the behavioural domain in people with TBI.[64,71] Challenging behaviours are complex issues to manage using technology, and technology solutions tend to require additional support to be optimally used. Technology development is often specific to a single population, as is the case with autism spectrum disorder (e.g., Ref. 72) or dementia (e.g., Ref. 45), and not tested with other populations. Conversely, clinicians, individuals with TBI, and families may be unaware of the existence of potentially useful technologies, thus limiting the development of a market and associated research.

Challenging behaviours targeted by technology-based interventions

Most studies focused on emotional dysregulation as the intervention target (e.g., post-traumatic syndrome disorder, post-concussion syndrome, stress/anxiety, depression). Few studies directly targeted common behaviours considered as challenging and burdensome for both the family and the person (e.g., aggression; lack of initiation; inappropriate social behaviours;[4]) although these were frequently included within more global outcome measures.

One reason can be that the concept of challenging behaviours is often poorly defined and only mentioned as broad participant characteristics. Also, emotional dysregulation likely constitutes a precursor to challenging behaviours rather than a challenging behaviour per se. Indeed, mental health difficulties (e.g., anxiety, depression, post-traumatic syndrome disorder, grief) or difficulty recognising/managing emotions have been linked to aggressive behaviours.[26,73] There are many risk factors for violent outbursts, both in hospital settings and in everyday life (e.g., overstimulation or disruptive noises, inconsistent daily routines or staff, interactions with others, lack of control over a situation, etc.[26,54,74]), which can lead the individual to feel overwhelmed and have difficulty coping with the demands of the environment.[26] Also, some physiological indices are known to be markers of negative emotional states such as anxiety, depression or even aggression (e.g., lowered heart rate variability and anger[75]). These same physiological markers are affected after TBI, with a heart rate variability being reduced in individuals with chronic TBI[76] and associated with deficits in social cognition.[77] O'Neill and Findlay[59] raised the hypothesis that their biofeedback technique reduced challenging behaviours by improving the early identification of physiological signs linked to negative emotional states, allowing for the prevention of emotional escalations and behavioural outbursts, thus facilitating behavioural control. Finally, some smartphone applications, such as ForgetMeNot,[64] target cognitive disorders that may act as triggers for anger or repetitive behaviours.[26]

Some challenging behaviours can also be complex targets for technology and intervention development. From a development perspective, challenging behaviours or their precursors first need to be clearly defined to identify parameters that are both detectable and measurable by sensors. Given that individuals with TBI have diverse presentations of challenging behaviours, such parameters may be difficult to specify. In this context, creating the appropriate interventions (e.g., alerts and feedback for change) for diverse individual profiles adds an important level of complexity. For example, providing technological feedback for inappropriate social behaviours requires much more advanced technology that simultaneously integrates individual and environmental data to analyse the corresponding social interactions and impacts the person's behaviours on others. Although not used in included studies, wearable cameras may be another potentially interesting technology to recognise socio-emotional contexts and facilitate such complex social interactions.[78]

Thus, current technologies show potential to identify precursors to challenging behaviours and act on them to prevent escalation towards even more complex challenging behaviours, though at present, technologies are insufficiently advanced to process and use real-time data to limit an escalation of behaviours. Beyond defining challenging behaviours, further exploration is required to identify pathways and precursors to challenging behaviours that may be realistically monitored using technology. This may include affective (e.g., anxiety), cognitive (e.g., apathy, overstimulation), and physical states (e.g., heart rate).

The involvement of family caregivers in the use of technology

Only two studies mentioned involvement of family caregivers, i.e., informal caregivers, to support participants with TBI in their use of an application[61,70] or simply to access data collected by the application, without their using this information to modify upcoming or current challenging behaviours.[70] However, literature on behavioural interventions for challenging behaviours, such as the Positive Behaviour Support, very often include family caregivers, given their major role in the daily life of individuals with an ABI.[79] Hence, future technologies could act as a caregiver strategy to manage adult challenging behaviours, such as wearable sensors and social robots developed for other specific paediatric populations to detect real time challenging behaviours and intervene early.[72]

Conversely, attention must be given not to over-involve family caregivers, as challenging behaviours may also present when individuals with TBI experience a lack of control.[26] In other words, individuals with TBI must remain at the centre of care, as encouraged by highly individualised clinical models.[79] Among others, biofeedback techniques may promote self-management and a greater sense of autonomy, as reported by O'Neill and Findlay.[59]

Settings, feedback, and technology measurement

In our review, mobile applications have been used both in clinical and living environments, while biofeedback has been largely used in clinical settings. Although biofeedback technologies measure real-time physiological variables to provide feedback during breathing technique training, they cannot be used in a real-world environment to detect the onset of a behavioural crisis and help prevent any form of escalation.

In comparison, wearable smartwatches show a great potential for use in healthcare. These technologies can be used to monitor, diagnose, or assist users in the management of treatment. They measure various physiological indices (e.g., blood pressure, oxygen saturation, heartbeat, sleep patterns, physical activities) and permit the programming of alarms for daily routines (e.g., taking medication[80]). The use of wearable technologies may represent an emerging direction in the TBI context and more specifically in the self-management of challenging behaviours.[81] Only one included study used Android© Wear smartwatches to deliver diaphragmatic breathing exercises in a veteran population with mild TBI and post-traumatic syndrome disorder.[63] However, this technology does not provide real-time feedback.

The feedback modalities used by each technology intervention were not always explicitly described in the retrieved studies, although overall a combination of feedback types (visual, tactile, and/or auditory) was used. Consequently, little is known about the feedback modalities used and the circumstances under which they appear to produce a beneficial effect. The reporting of such data would, however, help inform future work in this area.

Maturity of the technology

The FASTER phases provide an indication of the maturity of the technology-based intervention and is complementary to TIDieR-related extracted data. Our results suggest that most studies were in Phase 2 of the FASTER model which involves a first technology use with the target population.[52] However, the lack of detailed information describing interventions according to TIDieR requirements suggests poor reporting and the need to pay more attention to the early stages of technology development. This would allow for a better understanding of the underlying theoretical basis of interventions and how the latter should work prior to larger scale effectiveness testing.

However, as articles that met our inclusion criteria were mainly published in journals with a clinical focus, this may have limited the extent to which technologies were described. The few articles that specifically described the development of new technologies, still little was presented about how solutions emerged. As a result, it is unclear what technology design decisions were made and how the latter related to the clinical problems to be solved, including whether users were directly involved in specifying priorities, design requirements, and solutions. Such limited description of the technology hinders the reader's ability to evaluate the intervention's potential with regards to its intended purpose.

Strengths, limitations and future perspectives

To our knowledge, this is the first review to map and examine technology-based interventions that can support the (self-) management of challenging behaviours in individuals with TBI. This study identified important gaps in technology development that address challenging behaviours in individuals with TBI.

This review has limitations. A major issue in conducting this review was the lack of a standard definition of challenging behaviours, triggers, and related intervention targets. Future studies will need to better define the challenging behaviours targeted by the intervention, all the while better identifying the triggers that may be technologically monitored in the most beneficial way for users. This gap could be addressed by involving users in the ongoing development[82–84] of technology-based interventions to define and prioritise needs, or by promoting improved collaboration across domains (rehabilitation and technology). Indeed, stakeholders need to know what technologies exist or can be used with a given population, and technology developers need to know exactly what known behaviours to target and user needs to address.

This review identified the lack of exploitation of available technologies to address the management of challenging behaviours (e.g., artificial intelligence, smart technologies). Future studies may draw on commercialised technologies or existing research in other populations to gather additional ideas on the technologies that could be used and/or adapted for use with the ABI population.[83] Future studies would also need to explore technologies that provide real-time feedback and that can be easily integrated into users' real-world environments by adapting their behaviour to the feedback received. Indeed, real-time access to physiological measures (e.g., heart rate variability) has interesting potential in the self-management of challenging behaviours.[59] As the potential of wearable technologies to detect behavioural crises through the recording of physiological changes has been shown in some studies,[69] future studies should consider combining home biofeedback training to promote awareness of physiological signals and their interpretation,[59] with the daily use of wearable technology (e.g., smartwatch) to encourage self-regulation and real-time behaviour modification. Finally, it will be important for future studies on this topic to examine the usability and acceptability of these technology-based interventions to ensure that they are both easy to use, relevant to users and acceptable to them.

Conclusion

In this scoping review, we identified technology-based interventions that were scientifically investigated to promote or support the (self-)management of challenging behaviours in individuals with TBI. Our results show that there is little literature in this area and that existing technologies, mostly biofeedback techniques or mobile applications, are primarily intended to improve emotional dysregulation. Although this review shows that the field is still in its infancy, it supports the idea that technology-based interventions could play an important role in managing many challenging behaviours. Future research is needed to further develop technology-based interventions that target a variety of challenging behaviours, but also to document their effectiveness as well as their acceptability for use by individuals with TBI and their families in daily life.

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Author contributorship

EN and CB conceived the study. CH, EN, ED, EL, EP, and VPaquet developed the protocol and contributed to the development and refinement of the search strategy. VPaquet performed the search strategies in the appropriate databases. ED and EL screened the studies and wrote the first draft of the methods and results respectively. CH reviewed the results and drafted the first version of the manuscript. CH, EN, ED, EL, EP, CGV, RHW, and VPoulin participated in team meetings to refine the results and revise the manuscript. All authors reviewed, edited and approved the final version of the manuscript.

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Supplemental Material

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