Technology and its role in rehabilitation for people with cognitive-communication disabilities following a Traumatic Brain Injury (TBI)

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ABSTRACT

Purpose: To review the literature on communication technologies in rehabilitation for people with a traumatic brain injury (TBI), to: (a) determine its application to cognitive-communicative rehabilitation, and b) develop a model to guide communication technology use with people after TBI.

Method: This integrative literature review of communication technology in TBI rehabilitation and cognitive-communication involved searching nine scientific databases and included 95 studies.

Results: Three major types of communication technologies (assistive technology, augmentative and alternative communication technology, and information communication technology) and multiple factors relating to use of technology by or with people after TBI were categorised according to: (i) individual needs, motivations, and goals; (ii) individual impairments, activities, participation, and environmental factors; and (iii) technologies. While there is substantial research relating to communication technologies and cognitive rehabilitation after TBI, little relates specifically to cognitive-communication rehabilitation.

Conclusions: Further investigation is needed into the experiences and views of people with TBI who use communication technologies, to provide the 'user' perspective and influence user-centred design. Research is necessary to investigate the training interventions that address factors fundamental for success, and any impact on communication. The proposed model provides an evidence-based framework for incorporating technology into speech pathology clinical practice and research.

Traumatic brain injury (TBI) is a significant public health issue, often with severe long-term consequences for the individual with a TBI, their immediate family, friends, and the wider community [1-4]. The impairments acquired by people with a TBI can include cognitive-communication impairments - communication difficulties resulting from changes in cognition commonly associated with TBI [5]. Cognitive-communication impairments are distinct from motor speech impairments or primary language impairments (e.g. aphasia), in that the impairments arise from the diffuse axonal injuries which occur in frontal and pre-frontal areas of the brain [6]. These impairments can be defined as any aspect of communication that result from underlying deficits in cognition [4,5,7].

Communication difficulties after a TBI can affect how a person hears, listens, understands, speaks, reads, writes, and how they engage in conversation and social communication [5]. The underlying deficits of cognition that affect these communicative functions can include slowed information processing; impaired working memory and attention; disorientation and disorganisation; executive function problems including rigidity, poor conceptualization, planning, and problem solving; and poor self-control or self-regulation of cognition or behaviour [4,5]. As a result of these changes in cognitive-communicative processes, people with TBI have been described as ‘overtalkative, inefficient, tangential or drifting from topic to topic, or lacking in language output.’ [4] (p.354). These cognitive-communication impairments can restrict a person’s ability to communicate, live independently, return to work or education, participate in society, and build or maintain relationships after their TBI [8].

The International Cognitive (INCOG) guidelines for the management of a person’s cognitive rehabilitation following TBI highlight that assessment of cognitive-communication skills should incorporate performance in everyday social activities [4]. Adolescents and young adults, the group most at risk of TBI, use digital and online communication

technologies from a young age [9] and, following TBI, involvement in social, academic, and societal situations may be reduced with difficulties using technology and social media [5]. As a result, people with cognitive-communication impairments resulting from a TBI face challenges in accessing information independently and engaging effectively in social networks [8]. However, little is known about how people with cognitive-communication impairments after TBI use and experience digital communication and the internet. Furthermore, clinical guidelines for the assessment of cognitive-communication skills following a TBI do not provide guidance on the use of social media, or of assistive technologies (AT) to support cognitive-communication rehabilitation [4,5].

In order to review the existing literature on technology it is essential to consider which types of technology appear in relation to TBI and cognitive-communication. In this study, we considered three major categories of technology: (i) Assistive Technology (AT), being 'any item, piece of equipment, or product, whether it is acquired commercially, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities' [10] (p.4); (ii) Augmentative and Alternative Communication (AAC) tools, systems, or strategies [11], being ATs that are used specifically to assist or support communication; and (iii) Information and Communications Technologies (ICT), defined as 'any device or application used for communications' [12] (p.130). ICT includes technology such as email, the internet, and mobile phones [13] which enable users to access, store, transmit, and manipulate information [14]. The multiple purposes of the different types of technology selected as a focus for this review are outlined in Table 1.

Insert Table 1 about here

Communication impairments, limitations, and disabilities following TBI are wide-ranging in scope and social isolation resulting from loss of friendships is common [4]. As for other members of society, social media interactions hold potential for increasing

communication and social participation for people with TBI by offering another way to connect with family, friends, and the community [15]. In commentary regarding the use of email and texts in psychological therapy after acquired brain injury (ABI), Newby and Coetzer (2013) noted the limited published evidence with regard to email and its use in rehabilitation with people who have a brain injury [16]. They documented the potential advantages and benefits of electronic communication and also extended this to include texting from a mobile phone. Notably, the advantages included the convenience, portability, accessibility, and the universal or 'normal' status that email and texting have in general society [16]. The authors observed from their clinical experiences that incorporating electronic communication into rehabilitation provided more personally meaningful communication opportunities [16]. Communication technologies can be used in rehabilitation to assist a person to work on their cognitive-communicative goals, as an adjunct to more traditional forms of cognitive-communication rehabilitation, or as stand-alone interventions. The use of communication technologies in rehabilitation is also wide-ranging in scope and could include using a mobile phone as a prompt to remember key points when having a conversation, practicing written communication in emails, or using Twitter to train providing key information in a smaller amount of words.

Newby and Coetzer (2013) noted that social networking platforms are becoming more important to be aware of in rehabilitation and that they have potential to reduce isolation and increase the sense of belonging in the community for people who have a TBI [16]. However, there are no studies to date investigating ways to support people with TBI in using social media to access information and engage socially online [15]. Therefore, the aim of this study was to review and synthesise the research on a range of relevant technologies that could be used in cognitive-communication rehabilitation (i.e. AT, AAC, and ICT) and to identify directions for future research.

METHOD

An integrative review was conducted to locate research relating to both TBI and the three types of technology – AT, AAC, and ICT – that are variously used in cognitive-communicative rehabilitation. In conducting this review, TBI was defined as a brain injury caused by an external force [17] including all levels of severity (i.e. concussion through to severe TBI); technologies included AT, AAC, and ICT; and rehabilitation referred to all phases of TBI rehabilitation (i.e. as an acute inpatient, an inpatient in a rehabilitation setting, and as a community outpatient). Articles that related to cognitive deficits and considered to have the potential to alter communication abilities, based on current international professional guidelines and definitions of cognitive-communication impairments, were included [4,5]. Only reports of studies in English were sought, but no limitations were placed on year of publication, study type (e.g. literature review, original research), or design (e.g. controlled trials or qualitative studies). A limit was placed on quality, being only peer-reviewed full text journal articles, theses/dissertations, and including participants aged over 14 years (i.e. adolescents and adults). The PRISMA statement and flow diagram for the reporting of systematic reviews was used without items relating to meta-analysis [18]. We excluded studies that were: not in English, not peer reviewed, not full text (e.g. conference abstracts), did not relate to TBI and technology used in cognitive-communicative rehabilitation, not about or including people with a TBI (e.g. instead related to stroke), or not relating to adults or adolescents with TBI.

Search strategy, study selection, and data extraction

In June 2015, nine electronic databases (CINAHL, Cochrane Reviews, EMBASE, Medline, PsycBITE, PsycINFO, PubMed, speechBITE, and Scopus) using the search terms: ‘TBI’ [traumatic brain injury OR TBI OR brain injury OR mTBI OR concussion], ‘rehabilitation’ [rehabilitation OR intervention OR therapy OR treatment], and ‘technology’

[assistive technology OR augmentative and alternative communication OR information and communications technology OR computer OR mobile technology OR email OR texting OR SMS OR internet OR telehealth OR telerehabilitation OR social media]. The truncation symbol (∗) was used to allow for different spellings and to detect variations on the endings of terms. The search was extended by using search alerts of new publications until January 2016, and these procedures located 10 286 potentially relevant titles which were imported into Endnote X7 [19] for consideration against the inclusion and exclusion criteria. The first and second authors read and consulted with one another over the titles and abstracts for inclusion keeping any uncertainties for review of the full text. In total, 175 papers were retrieved as full texts, and the first and second author agreed on excluding a further 80 articles that did not meet criteria for inclusion. In total, 95 articles published from 1993 to 2015 were included in the review [4,15,20-115]. Figure 1 summarises the search results and application of the inclusion/exclusion criteria to potentially relevant studies (PRISMA flow diagram [18]).

Insert Figure 1 about here

Data extraction. The following data was extracted from the 95 included studies into an Excel [116] spreadsheet: first author and year, study type, population characteristics, technology type, aims, methods, level of evidence, results and any recommendations, and directions for future research. The level of evidence of each of the included studies was determined as per the guidelines of the National Health and Medical Research Council of Australia (NHMRC) [117] where the design allowed. The authors discussed the findings of the included studies in the context of TBI rehabilitation for people with cognitive-communication disabilities, to inform the development of a descriptive model proposed to guide clinical management and future research.

RESULTS

Type and Level of Evidence

The 95 studies included in the review comprised: (i) 63 studies that were rated using NHMRC levels of evidence [117]: 13 Level I articles (systematic reviews), 27 Level II, III-1, III-2, III-3 (randomised and non-randomised controlled trials), 23 Level IV articles (case series); and (ii) 32 articles that described: single case experimental design studies (SCEDs, n = 19), clinical practice guidelines (CPGs, n = 1), qualitative studies (n = 10), and mixed methods designs (n = 3). A summary of the demographic and methodological characteristics of the included studies is provided in Table 2, showing: a) Assistive Technologies (AT) (n = 6), including Augmentative and Alternative Communication (AAC) (n = 27); and b) Information and Communications Technologies (ICT) (n = 69). Studies including ICT related to: computer program interventions (n = 8); internet interventions (n = 9); email and texting (n = 7); telerehabilitation (n = 35); mobile applications (apps) (n = 1); and social media (n = 9).

Insert Table 2 about here

Type of Technology: Assistive Technology (AT)

Assistive technology (AT) is often incorporated into rehabilitation to assist with cognitive aspects of everyday life, and the use of AT featured in eight of the included papers (see Table 2), including two systematic reviews [36,41], two SCEDs [48,57], one CPG [4], and one qualitative study [37] about cognitive support technologies. The AT featured included both low-tech and high-tech options, as well as specialised technologies and mainstream devices that are readily available [118]. Communication purposes of the AT included use of reminders via a personal digital assistant (PDA) or electronic organisers, paging systems, digital voice recorders, computers, cameras, mobile or smart phones, and alternative and augmentative communication (AAC) technologies [11,36,37,41]. There was clear evidence that AT can be multi-faceted in purpose – being assistive, adaptive, and

rehabilitative - to provide enhancement or improvements in the way people interact with technology to maintain their function and independence [11,118,119].

Although there is a growing body of research on cognitive rehabilitation, there is very little attention in the literature towards cognitive-communication rehabilitation. Charters et al. (2015) and de Joode et al. (2010) systematically reviewed 32 studies on use of AT for people with ABI and reported that there was insufficient evidence to recommend specific guidelines for using AT in rehabilitation [36,41]. Of the 32 studies considered by Charters et al. (2015), 18 evaluated use of a PDA or electronic organiser to assist cognitive function and 7 papers evaluated the use of mobile or smart phone devices [36]. Only two of the studies targeted cognitive-communication impairments or function [57,120], and only one of these included a participant with a TBI - who used a customised PDA as a conversation aid [57]. Nonetheless, the published evidence supports the notion that electronic systems can assist everyday function of people with TBI [36,48,121] and that successful use of technology rests upon tailoring interventions to the needs and abilities of the individual [41]. Studies investigating user experiences have found that both people with TBI and clinicians are optimistic about using AT [41], and expect favourable outcomes for both participant satisfaction and confidence [36]. Furthermore, consumer involvement and preferences in device selection, along with cognitive factors - particularly memory, insight, and executive function - were identified as important factors that affect a person with TBI's use of technology [36,41].

Of AT systems identified as being useful for cognitive support after TBI, mobile phones have been reported as the most important technology used, albeit for limited functions (e.g. phone calls, texting, and setting reminders) with more advanced features reportedly too complex [37]. In a study by Chu et al. (2014), one support person noted of an adult with TBI: 'He also has a smart phone. I mean, it's pretty sophisticated even for me to use. So I put in everybody's phone number. And then one day he deleted them all and he didn't know how he

did it. So it works, and it doesn't work' [37] (p.283). While noting the importance of aiming for independence in using AT for cognitive support, people with TBI and their families both reported that support of a family member or other person in using AT was vital for successful use [37].

Augmentative and Alternative Communication (AAC) technologies

Studies on the use of AAC in rehabilitation for people with TBI (n = 27) while relatively high in number, were small-scale, and comprised: two narrative reviews [26,34], five case series studies [29,31-33,112], 13 SCEDs [59-71], one CPG [4], five qualitative studies [46,47,53,75,81], and one mixed-methods study [54]. Two literature reviews provided a comprehensive overview of the use of AAC by people with TBI [34] and of AAC for adults with acquired neurological conditions [26]. In 2002, Campbell et al. [34] noted a shift in clinical practice towards the provision of AAC for communication support in acute settings even if severe communication impairments were considered transient or temporary. Most of the studies reviewed considered the relationship between AAC use and stages of recovery following a TBI. Early rehabilitation commonly focussed on addressing communication needs, and later rehabilitation targeted implementation of strategies, active participation, and improved quality of life [34]. Beukelman and colleagues [26] reported that access to funding and an effective support person are essential components for long-term successful use of AAC. Both Campbell et al. [34] and Beukelman et al. [26] highlighted the need for ongoing support and review of the individual's communication goals and needs to sustain successful use of AAC following TBI.

In the past decade, several papers have been published relating to the use of AAC by people with a TBI [29,31-33,59-71,75,112,122], comprising case series studies [29,31-33,112], single case experiments [59-71], and qualitative studies [47,75]; with a majority focus on device screen display [29,31-33,112], access [47,59-71], and emerging research into

user perspectives [46,75]. Research highlighting factors influencing use of AAC by individuals after TBI provides insight into how technology may facilitate increased independence and participation. Fager and colleagues (2014) reported that technology increased functional independence during inpatient rehabilitation and provided a way for people to practice beyond their therapy sessions [46]. User preferences were observed to include the desire for AAC systems and software to be consistent in access and performance, and easy to install and use [46].

Paterson et al. (2015) reported that people with acquired conditions who use AAC were often frustrated with AAC technologies, reporting that they had limited functional interactions using these systems. In contrast, they experienced mainstream technologies and digital communications, like social media, to be beneficial when communicating with other people [75]. Communicating in digital environments also appeared to assist in re-establishing self-identity in individuals with acquired communication impairments [75]. For example, one participant explained that 'his digital communication was the same as everyone else's and when he was online he felt "normal".' [75] (p.1528). A summary of the evidence found on the barriers and facilitators to successful use of AT devices, including AAC technologies, and the preferred device characteristics of people with a TBI is outlined in Table 3.

Literature to date supports the use of AT, including AAC, to assist cognitive-communicative function following TBI, with user preferences for technology being considered closely, particularly in supporting successful communication. Despite the lack of studies addressing cognitive-communicative rehabilitation directly, the factors identified in the current research provide insight into how using AT in rehabilitation may facilitate increased independence and participation in communication activities. Together, the findings suggest that is it feasible to use AT to support cognitive-communicative rehabilitation after TBI. Future research could investigate the efficacy of specific ATs in larger cohorts, and the

effectiveness of providing training in use of AT that addresses factors affecting successful use, and improves user involvement in decisions about use of AAC following TBI.

Insert Table 3 about here

Type of Technology: Information and Communications Technologies (ICT)

Computer program interventions

Computer program interventions have long been used in TBI rehabilitation for improving memory, attention, and visuospatial deficits [38,96,123]. The use of computer programs in cognitive-communicative rehabilitation for people with TBI appeared in eight of the included papers (see Table 2), consisting of three systematic reviews [38,91,96], three group comparison trials [42,43,90], and two case series studies [49,73]. Authors of systematic reviews recommend that computer programs be considered and used in conjunction with clinician-guided treatment [38,91,96]. However, current practice statements regarding effectiveness of computer program interventions for TBI draw upon one randomised controlled trial (RCT) conducted in 1994 as evidence [90], and the associated computer software is no longer available for scrutiny [123]. Recent research further supports the notion that computer programs for cognitive training may lead to better outcomes for people with cognitive-communicative difficulties after TBI - when used in conjunction with other methods [42,73]. Indeed, Fraas and colleagues (2008) noted positive patient-reported outcomes following an electronic journal-writing intervention, including improved communication, a new awareness of writing ability, personal fulfilment, and empowerment [49].

Internet interventions

The use of internet interventions in rehabilitation for people with TBI was examined in nine of the included studies (see Table 2), including one systematic review [55], one group comparison trial [51], and eight case series studies [44,45,49,85,92,95,97]. There is, as yet,

little evidence as to the effectiveness of internet interventions in cognitive-communicative rehabilitation following TBI, as studies so far focus on interventions targeting (i) use of internet chat-rooms [55]; (ii) internet training [44]; (iii) reintegration into school [97]; and (iv) telerehabilitation. Using the internet was reported to provide opportunities to practice in real-life tasks that may assist compensatory, navigational, and written language skills [44,55,95,97].

In a systematic review of 46 studies and 66 internet resources, Kilov et al. (2010) reported on 5 studies [44,45,85,95,124] investigating training of internet and email skills of people with TBI and other cognitive impairments. Kilov et al. (2010) concluded that internet training is feasible when specific instructions and a support person were incorporated into the person with TBI's training programs [55]. Little evidence was found on the use of internet chat-rooms by adolescents with TBI, despite the opportunities these communication environments might provide for engaging in social forums with reduced stigma [55]. Three case studies also provided useful clinical insights into the use of internet communication in rehabilitation for people with TBI. Verburg et al. (2003) presented a case where internet communication was used to facilitate reintegration into school for an adolescent following a moderate-severe TBI [121]. The authors reported that written messages, as opposed to live images and sound in online communication, allows young people with TBI time to compose messages, enabling communication without revealing the full extent of their difficulties post TBI [97]. The adolescent's mother commented, '<u>the internet connection was the best thing for J. It made the world of difference and kept him in touch</u>' [121] (p.119). The factors regarding function and social connection identified in this study further strengthen the argument that online communication may reduce stigma and communication challenges associated with TBI.

In 2007, Vaccaro and colleagues [94] surveyed 80 people with moderate-severe TBI in the United States about internet use and reported that less than 50% of respondents used the internet, a considerably lower rate of use than the general population (69%) [95]). People with TBI were interested in using the internet to get more information about brain injury and to communicate with other people [95]. All participants reported interest in receiving training to improve internet skills, and respondents with less experience in internet use reported greater interest in receiving training [95]. In 2005, Egan et al. evaluated an internet skills training intervention for people with a TBI [44]. The training materials used in the study were developed by the authors in collaboration with people with aphasia [124], and the authors aimed to determine if these materials could be used successfully with people who have cognitive-communicative impairments following a TBI [44]. 'Aphasia-friendly' principles were applied in the development of the training materials and utilised the ten text design guidelines outlined in Table 4.

Insert Table 4 about here

Egan et al.'s [44] intervention involved working through training modules that incorporated 12 internet tasks, including turning on the computer, connecting and using the internet, using email, printing, and shutting down the computer [44]. On completion of the training, one of the seven participants remarked 'Use of the internet has provided so many opportunities for communication and access to so many topics of interest to me. It has enhanced my lifestyle and widened my horizons' [44] (p.562). Study findings indicated that people with TBI are able to use the internet more independently using internet skills training materials; however, cognitive impairments that affect concentration, memory, and motivation present learning barriers.

Email and Texting

There is, as yet, only a small body of literature on the use a mobile phone for email and with a Short Messaging Service (SMS)) in the management of health conditions [125,126]. For people with TBI, the use of email and texting in rehabilitation was described in eight articles (see Table 2), being one systematic review [27], one RCT [87], two case series [85,92], and three SCEDs [40,56,86]. Thus, there is a paucity of research into the use of email and SMS for communication by people with TBI [27] and in health [27,126], with few experimental studies investigating the use of email during rehabilitation for people with TBI [27]. Borg et al. (2015) found only two studies that investigated the use of email for communication by people after TBI and none focused on the use of SMS. Using prompts containing ready-made sentences or phrases may facilitate email communication, and people with ABI benefitted socially and felt more connected with friends and family after training in the use of email [27,85,86]. Overall, the needs and preferences of people with TBI are diverse and guidelines for incorporating email communication into rehabilitation need to be tailored to the individual [27]. Furthermore, Borg and colleagues emphasised the need for further research in this area as '<u>accessibility to information and communication is a key to people with cognitive disabilities being able to enjoy their human rights and fundamental freedoms</u>' [27] (p.560) which include equal access to the computer, internet, and email communication afforded to others [127-129].

Treatment studies using SMS to improve rehabilitation progress in individuals with TBI have shown some success. In an RCT, Suffoletto et al. [87] evaluated the use of education and behavioural support via daily SMS for people with mild traumatic brain injury (mTBI) and concussion, reporting positive outcomes. In a single-blind within-subjects trial, Cully and Evans [40] tested the efficacy of sending SMS messages to people with a TBI in order to improve rehabilitation goal recall, and reported significant improvements in goal

recall. The results of these studies provide emerging evidence that SMS interventions might have a meaningful role in rehabilitation for people with TBI.

The use of email by people with TBI has also received some attention in the literature. Todis et al. (2005) asked participants with acquired cognitive-communication impairments to think about how technology, and email in particular, could be more user-friendly, and participants generating needs and suggested features [92]. Suggested features included improving the computer set-up and screen appearance, as well as the provision of adequate instructions and ongoing support [92]. Kim et al. (2010) documented participants' positive reports of benefit in using email after an intervention in the Goal-Plan-Do-Review format (as described by Ylvisaker & Feeney [130]). One participant reported: 'This is longest I have read since my accident… more than one page… long time ago. You motivated me.' [56] (p.25). These results suggest further investigation into the use of email as an intervention delivery method is warranted [56,92]. For people with TBI who used email every day prior to their injury, returning function via being able to access, read, and respond to emails from friends and family provided opportunities to practice communication in more natural contexts and for extended interactions [56]. These opportunities to practice communication in the community for work or social purposes may assist in the maintenance of relationships and reduce social isolation long-term following TBI [56,92].

Telerehabilitation

Recently, there has been a greater emphasis on increasing access for people who are unable to attend rehabilitation at in-person clinic services (e.g. due to physical impairments, cognitive impairments, or geographical location) via the use of telephone, internet, and video-teleconferencing platforms, known as tele-practice, tele-health, or tele-rehabilitation [39]. Cognitive-communication rehabilitation is now conducted via telerehabilitation with a substantial research interest in this area [28,39,79,84,89,93]. Indeed, telerehabilitation for

people with TBI featured in 38 of the included papers (see Table 2), comprising 2 systematic reviews [39,79], 22 group comparison trials [23-25,30,35,52,58,74,77,82,84,98-100,104-106,108-111,113], 9 case series [28,50,80,83,93,97,101,102,107], 1 SCEDs [89], and 1 CPG [4].

Two systematic reviews [39,79] included a total of 26 studies evaluating tele-practice in TBI, support for family members (n = 16), assessment (n = 8), and intervention for cognitive impairment (n = 2). None of the intervention studies provided communication training for participants with a TBI or their communication partners, and the two cognitive intervention studies included only participants with mild cognitive impairments [39,79]. The focus of the controlled trials in the reviews was impairment-based assessment and intervention rather than function, activity limitations, or participation restrictions [39,131]. Importantly, no statistically significant differences were found between the tele-practice and face-to-face intervention delivery methods [39,79].

Studies evaluating the use of tele-rehabilitation for cognitive-based difficulties after TBI (e.g. problem-solving and emotional dysregulation) noted minimal behavioural changes immediately post-intervention [58,93,98,100,104,105,107]. However there was high participant satisfaction with using tele-practice [93] and greater changes observed in outcome at follow-up [58,98,100,104,105,107]. Verburg et al. (2003) found that establishing internet connectivity and having a support person were both crucial to successful use of tele-practice with people after an ABI [97].

Mobile applications (apps)

Mobile health interventions include software applications (apps) that can be accessed on mobile devices such as a smartphone or tablet [72]. Apps (e.g. for games, social media, news, self-help, fitness) can be downloaded onto mobile devices (e.g. iPad, mobile phone). [132]. Although there are studies investigating the use of apps on mobile devices in

rehabilitation for other health conditions [133-135], there is limited research evaluating the use of these technologies with people after a TBI [72,136,137] - identified in one systematic review [72]. Lee et al. (2015) tested the use of mobile devices and apps in concussion management [72]. The authors highlighted the current lack of regulation and high variability of the apps available for concussion assessment, which led to development of a consumer checklist to assist in choosing an appropriate concussion assessment app [72]. Overall, there is limited empirical research dedicated to the design, development, and evaluation of TBI-related apps used in rehabilitation [72].

Social media and TBI

To date, there has been limited published peer-reviewed evidence of interventions using social media for people who have had a TBI [15]. The use of social media in rehabilitation for people with TBI appeared in two systematic reviews [15,55], one case series study [20], four qualitative studies [21,22,76,94], and two mixed-methods studies [88,114]. Brunner et al. (2015) identified that the majority of studies on the use of social media in TBI were descriptive and none investigated the effects of using social media on cognitive-communication skills [15]. Facilitators for social media use in people with TBI included training the person with TBI and their communication partners in using social media safely. The authors concluded that further investigation is needed into the potential benefits and facilitators of social media use for communication, social participation, and social support with the aim of reducing social isolation in people with TBI [15].

Currently, there is little guidance in the literature on ways to incorporate social media goals into rehabilitation plans for people after TBI. Use of online communication tools could give the person using them more time to consider information, comprehend that information, and respond to messages than is available in in face-to-face conversations [15,75,97]. Typically, networking sites support the use of short messages with little emphasis on correct

spelling and grammar [138,139]. Using social media has the potential to add to other methods of communication such as face-to-face conversations, telephone calls, written letters, or emails that inform functional goals in rehabilitation for people with TBI. The results of this review suggest that incorporating social media skills into rehabilitation for people with TBIs might increase their participation and facilitate social connection.

Despite a large number of included studies (n = 69) addressing ICT use in TBI rehabilitation, these studies have not yet tested the efficacy of using a broad range of ICT-based interventions for communication after TBI, and most studies on the use of social media are descriptive. As was the case in the AT studies reviewed, the majority of ICT-based studies focused on cognitive rehabilitation, with little attention to cognitive-communication rehabilitation. There is evidence in the studies reviewed that people with a TBI are interested in using ICT to communicate and are keen to receive training in order to use these tools more effectively to stay connected with family and friends. Despite the lack of studies specifically addressing cognitive-communicative rehabilitation, several factors were identified regarding how using ICT during rehabilitation may facilitate practice within naturally occurring contexts, return of function, and a greater sense of connection for people with TBI. Future research therefore needs to investigate these factors in the context of training in use of ICT during cognitive-communicative rehabilitation. Further investigation into online communication is therefore warranted in order to further explore the opportunities and experiences of people with a TBI when communicating with communication technologies.

DISCUSSION

This review provides substantial insights into the use of communication technologies to enhance cognitive-communicative function after TBI. There is a growing body of evidence supporting the notion that use of AT and ICT systems in cognitive-communicative rehabilitation is beneficial. The results can be used to improve guidance for clinicians and

family members on how AT, AAC, and ICT may be incorporated into cognitive-communicative rehabilitation for people with TBI. Use of a range of communication technologies may facilitate increased independence and participation with re-establishment of self-identity and engagement in online social interactions. Technology also featured in this review as an opportunity to extend therapeutic practice within every-day contexts that are naturally occurring and in use by the general public.

Our review also provides information on critical factors that affect outcomes for people after TBI, that need to be considered when various forms of technology are used in rehabilitation. However, of 35 telerehabilitation studies reviewed, none trialled an intervention where cognitive-communication training was provided, and all focused on training cognitive skills or providing family support. Telerehabilitation research for cognitive-communication skills training is emerging, with Rietdijk and colleagues (2015) identifying that the delivery of social communication skills training via Skype, for people after TBI and their communication partners, was feasible and effective, with a clinical trial now underway [78]. Despite growing academic commentary and discussion on the use of technology in TBI rehabilitation [136,140-142], there remain substantial gaps in the research in relation to new technologies (e.g. virtual reality, apps, social media, blogs, and micro-blogs). Indeed, there is little in the research literature relating to user perspectives or experiences of accessing the internet and using mobile devices and apps to improve their cognition or cognitive-communication skills following TBI. Further research is needed to determine (a) human computer interface factors pertaining to individuals with TBI, (b) how these factors impact on their use of new communication technologies (e.g. apps, social media, blogs), and (c) whether people with TBI are obtaining benefit or experiencing harms from the use of apps in their rehabilitation [136].

Including the individual with TBI in making decisions about technology, tailoring interventions to the person's individual goals and needs, and providing support and assistance, were identified as key factors influencing the successful use of technology in rehabilitation and everyday life after TBI. Wong et al. (2016) has since reported that direct instruction on how to use smartphone apps was important for people with TBI [143]. The importance of tailoring interventions to the individual is also consistent with the literature on technology interventions for people with aphasia, in that user acceptance and motivation are crucial when designing ICT systems and important for realising long-term engagement [144]. Practical considerations such as the need for the technology to be accessible, reliable, and durable were also important when introducing technologies for people with TBI. In addition, frequent re-evaluation of the person's needs and preferences for technology is critical for successful use and participation in online social communities.

A Proposed Model for successfully incorporating Technology into Cognitive-Communicative Rehabilitation for people after TBI

The factors affecting use of AT, AAC, and ICT in rehabilitation identified in this review can be modelled to inform how any technology could be used successfully in TBI rehabilitation. The factors were categorised according to three domains of evidence to inform decisions about incorporating technology into cognitive-communicative rehabilitation after TBI: (i) individual needs, motivations, and goals; (ii) the individual with the impairments undertaking activities and participating in the environment; and (iii) the technologies (see Table 5).

Insert Table 5 about here

It is important that an individual's desire or personal motivation to use technology in rehabilitation is taken into account in designing interventions. These personal motivations have the potential to significantly influence the other two domains, including what

technologies are selected and how each technology is used, as well as the training and assistance needed to enable successful use of the technologies. Identifying the person's needs and intended purposes of using the technology can inform functional goal development. The second domain identifies the individual's impairments, activities and participation, and environmental factors [131] that affect successful use of technology in TBI rehabilitation. As a result of their TBI, an individual may have cognitive-communicative impairments that alter the way in which they can learn and use technological systems, or undertake activities using technology. The third domain outlines the technological factors that influence successful use of technology in rehabilitation. These factors relate to the technology systems, particularly with respect to how the individual is able to use the technology long-term. Given that various factors can be considered as barriers or facilitators to successful use, it is important that interventions are not only designed to teach a person the use of technology, but also to reduce barriers and enhance facilitators for using technology in cognitive-communication rehabilitation following TBI.

Limitations and directions for future research

Findings of this review should be interpreted with caution, as the included studies covered a diverse range of technologies, and there has been limited attention to rehabilitation of cognitive-communication impairments specifically. Furthermore, the number of participants with a TBI in the included studies was relatively low. Nonetheless, the key results support the findings reported for other populations with acquired communication disabilities [144-147]. While two raters decided and agreed on exclusion of studies based on a reading of the titles and abstracts, all data extraction on the full text was completed only by the first author. Further trans-disciplinary and mixed methods research is needed to better capture both qualitative and qualitative data on the effect of using communication technologies in TBI cognitive-communication rehabilitation [15]. Quantitative studies

including participants with TBI using AT and ICT for cognitive-communication rehabilitation will need (a) a larger numbers of participants [36,41,89], (b) comparison conditions [36,41,88,97], and (c) rigorous outcome measures [36,41]. As people with TBI are a heterogeneous group [148-150] and recruitment to research is challenging [151], single case multiple-baseline experimental designs where participants serve as their own controls [152] are needed. Qualitative and mixed methods designs, including human computer interface studies, narrative inquiry, and network or content analysis of social media data, will help to understand the nature of social media use by people with TBI. Such diverse research methods (e.g., health, engineering, coding, and gaming) could more effectively capture the views, needs, and experiences of people with TBI on the use of communication technologies that are 'fit for purpose' and accessible to them. Future research needs to examine and address barriers to and facilitators for the use of communication technologies by people with TBI. Considering the absence of communication technology research including adolescents with TBI, future studies need to examine user design, accessibility, and implementation of communication technologies this group [44]. An important element of this would include the impact of training people with TBI and their supporters on using communication technologies in rehabilitation [36,37,55,56,136].

CONCLUSION

This review of research literature on a wide range of communication technologies considered the purposes, benefits, barriers, and facilitators for the successful use of technology in cognitive-communicative rehabilitation with adolescents and adults after TBI. While the diverse range of technologies reviewed (AT, AAC, and ICT) have been examined in relation to cognitive rehabilitation, there is as yet little attention in the research on the impact of these technologies on cognitive-communication rehabilitation. Studies determining the impact of technology to improve communication of people with TBI have included small

numbers of participants and none have yet rigorously examined the use of online communication systems with people who have cognitive-communication impairments. There is a need for further investigation of the views and experiences of people with TBI who use communication technologies, as well as the effect of providing training and support for using these technologies.

Life and rehabilitation after a TBI is complicated by the individual acquiring limitations in their organisational skills, ability to communicate, and maintain relationships with other people. The individual with TBI's recovery can be affected by many variables related to their injury, as well as other individual and contextual factors [131]. The proposed model of factors affecting the implementation of communication technologies into cognitive-communication rehabilitation provides an evidence-based framework for researchers and clinicians to consider when incorporating AT, AAC, or ICT into interventions. Using the model, researchers and clinicians might be able to better address the needs of people following a TBI in the use of technology and navigating online communities to increase communication, social participation, and social support. As society's development and use of technology increases over time, the expectation that technology will be incorporated into rehabilitation services for people with TBI is also likely to increase. A person-centred approach in clinical services will be needed support the use of multiple technological solutions tailored to the individual cognitive-communication needs of people with TBI.

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Declaration of Interest statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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Figure 1. **Search strategies and study selection (PRISMA flow diagram** [18]**).**

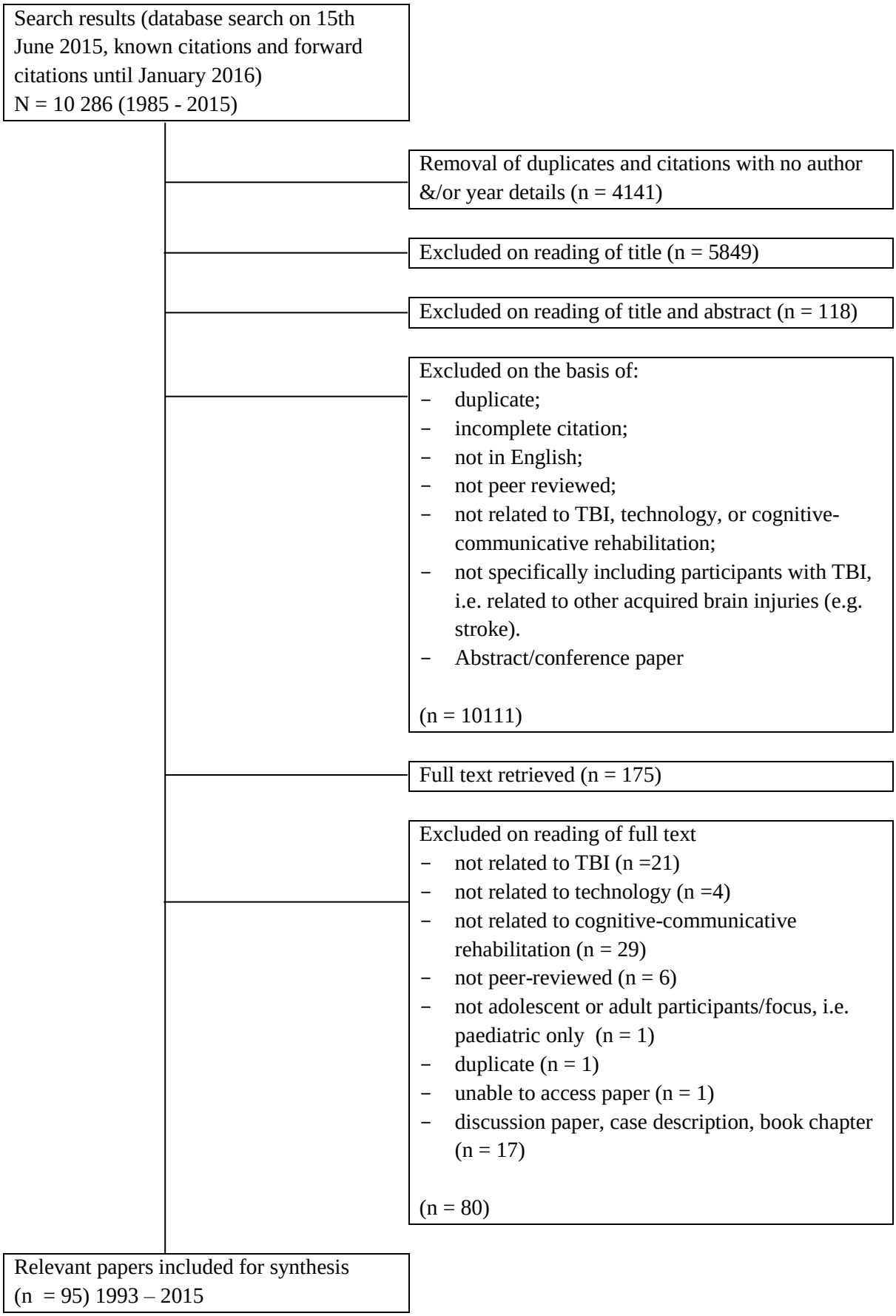

Table 1. Classification of AT, AAC, and ICT technologies to support communication and available evidence in TBI research

Technology	AT	AAC	ICT	Evidence in TBI research
AAC speech generating devices (high-tech)	YES[11]	YES[11]	YES (if on internet)[12]	YES[4]
AAC mobile devices (phones, tablets)	YES[11]	YES[11]	YES[12]	YES[141]
Alphabet / picture / writing board (low-tech)	YES[11]	YES[11]	NO	YES[4]
Unaided AAC (gestures, mime, facial expression, key word sign)	NO	YES[11]	NO	YES[4]
Adapted keyboards/ mouse	YES[11]	YES[11]	NO	YES[153]
Switch access for computer or speech generating device	YES[11]	YES[11]	NO	YES[153]
Eye gaze access for computer or speech generating device	YES[11]	YES[11]	NO	YES[153]
Computer programs	YES[11]	YES[11]	YES (if on internet)[12]	YES[38]
Internet Hardware & Software	NO	YES[11]	YES[12]	YES[15]
Video-teleconferencing	NO	NO	YES[12]	YES[15]
Online learning	NO	NO	YES[12]	YES[15]
Social Media	NO	YES[11]	YES[12]	YES[15]

Acronyms: AT = Assistive Technology; AAC = Augmentative and Alternative Communication; ICT = Information and Communications Technologies; TBI = Traumatic Brain Injury

Table 2. Methodological characteristics of the included studies (n = 95).

Note: * Denotes studies that were included in the systematic reviews (*).

Technology	NHMRC level I (systematic reviews)	NHMRC levels II, III-1, III-2, III-3 (randomised and non-randomised controlled trials)	NHMRC level IV (case series)	Single Case Experimental Design studies (SCEDs)	Clinical Practice Guidelines	Qualitative studies	Mixed methods studies
AT (n = 6)	[36] [41]			[48] [57]*	[4]	[37]	
AAC (n = 27)	[26] [34]		[29] [31] [32] [33] [112]	[59] [60] [61] [62] [63] [64] [65] [66] [67] [68] [69] [70] [71]	[4]	[46] [47]* [53]* [75] [81]*	[54]*
Computer program (n = 8)	[38] [91] [96]	[42] [43]* [90]*	[49] [73]				
Internet (n = 9)	[55]	[51]*	[44]* [45]* [49]* [85]* [92]* [95]* [97]*				
Email and Texting (n = 7)	[27]	[87]	[85]* [92]	[40] [56] [86]*			
Telerehabilitation (n = 35)	[39] [79]	[24]* [25]* [23]* [30]* [35]* [52]* [58] [74]* [77]* [82]* [84] [98]* [99]* [100] * [104]* [105] [106]* [108]* [109]* [110]* [111]* [113]* *	[28] [50]* [80]* [83]* [93] [97] [101]* [102]* [107]*	[89]	[4]		
Mobile technologies (n = 1)	[72]						

Social Media (n = 9)	[15] [55]*		[20]*			[22]* [94]* [21]* [76]*	[88]* [114]*

Acronyms: AT = Assistive Technology; AAC = Augmentative and Alternative Communication

Table 3. Factors influencing successful use of AT and AAC.

	Features	Examples from the literature
Barriers	Physical factors (e.g. vision and fine motor movement)[31,33,37,75]	'Adults with traumatic brain injury who need AAC technology must learn how to operate a device that is new to them while dealing with the unique pattern of cognitive, language, and learning limitations that resulted from their injury.' [31] (p.4)
	Cognitive-communication disability[31,33,75]	
	Cognitive factors (e.g. memory, insight, and executive function)[37]	'Also, the technology needs to be used consistently and constantly because "*the technology doesn't do you any good if you don't remember to turn it on*".' [37] (p.283)
	Psychosocial factors (e.g. anxiety)[37]	
	Access to device[36,41,75]	'All of our participants with TBI reported feeling isolated and experiencing low self-confidence because of their disabilities. "*And I've become anti-social with everybody. Because if I have a thought, I get anxious to say it because I think if I don't get it out I'll forget it, and that frustrates me. And if people around me don't understand my disability, then my patience is very short*".' [37] (p.283)
	Speed of device or internet connection[75]	
	Access to an appropriate support person[26,46,47]	'Without adequate and consistent caregiver or family support, individuals with TBI often cannot make decisions independently about which communication strategies may be most effective. They may also have difficulty advocating for themselves as they make the transition to new environments.' [47] (p.46)
	Reliability of device[36,41,46,75]	
	Access to funding[26,37,46,47,75]	
Facilitators	Motivation / active engagement[37]	'Pete also discussed the frustration he experienced in relation to the lack of reliability of the technologies he used and how vulnerable he felt without them: "…*and on the occasional time when both (device and call bell) aren't working I am frankly stuffed*."' [75] (p.1526)
	Training of the individual with TBI and their support person/s[4,34,47]	
	Consumer involvement in decisions about devices[4,34,75]	'Most participants expressed their concerns about the cost of obtaining the needed support. As a result, participants cannot afford a new device, such as a smart phone, an iPad, or a laptop, and the cost of its service. Neither were they able to meet the expense of human support.' [37] (p.283)
	Individualised approach with consideration of consumer needs and goals [4,34,75]	
	Repetition[37]	'Most of our participants strongly valued independence and wanted to use technology as much as possible to

	Good technical support and maintenance[37,75]	support independence: "*I would rather – the more independent I could be, the better I would feel about it*" (Martin).' [37] (p.283)
	Long-term funding for devices and support[37,75,154]	'Given the multiple contexts in which individuals with TBI may find themselves, the need for the identification, training, and monitoring of support personnel is a critical component to successful AAC use.' [47] (p.46)
	Ongoing assessment and re-evaluation of individual needs and preferences[4,34,75]	'It was clear that the choice of communication methods is a uniquely individual one and that professional interventions need to be tailored to meet the individual's specific goals.' [75] (p.1529)
	An appropriate support person is available for setting up access to and use of device[26,37,47,75]	'It [AAC provision] is characterised by the complex interaction between service user needs, the need for expert and independent assessment, user and carer training, timely reviews and on-going, life-long maintenance and user support.' [75] (p.1523)
	Confidence of caregivers and clinicians in using device[41]	'Consistent facilitator support appears to be critical to the success of AAC interventions.' [47] (p.45)
	Cost of device[37]	
	Speed and ease of internet connection/access[75]	'*When the iPad came on the scene it was a massive leap forward in communication skills and people could understand you much better and of course you have the various apps that come with it*' [75] (p.1525)
	Use of mainstream devices enables integration of different features, particularly if device is portable[75]	'*It's hard to keep up with conversations [face to face]. Conversely, when I'm using text-based media its fine. So Skype messages and Facebook or Twitter are perfectly useable* (Pete)' [75] (p.1525)
	Online communication resolves issues of timing and slow nature of using an AAC device in face-to-face communication[75]	'As John said (by email): "*I can express complex information better*".' [75] (p.1525)
	Online, text-based communication provides extra time to construct more meaningful and comprehensive messages[75]	'Pete said: "[my] *eye gaze isn't as precise as normal typing and it gives me a chance to correct things before I send them*".' [75] (p.1525)

	Online, text-based communication provides time to review messages before sending[75]	'Our participants told us that they would like technology that is "*smart*", "*simple*", and "*easy to use*".' [37] (p.283) 'They value many varied features of technology, but rated most highly good technical support, simple learning requirements, capacity to store information and long battery life.' [41] (p.710) 'People with TBI note that an important element in adopting new technology is good training in its use.' [37] (p.279) 'Individuals with disabilities, including TBI, are far more likely to experience financial hardship, which makes purchasing and using new devices burdensome. Connie stated that not only could she not afford new technologies, such as a smartphone or a replacement for her computer that is "*on life support*"; she also cannot afford the monthly internet or data plan service fees.' [37] (p.284) 'End-users (patients and families) identified a need for designs that are durable, reliable, intuitive, easy to consistently install and use.' [46] (p.121) 'The majority of the participants described the use of mainstream technologies prior to their injuries. Many brought these technologies with them throughout their rehabilitation stay and desired to be able to continue to use the devices that they were familiar with prior to their injuries.' [46] (p.126)
Preferred features of AT devices	Easy to use[37,41,75]	
	Good technical support[37,41]	
	Capacity to store information[41]	
	Durable[41,46,75]	
	Accessible[37,41,75]	
	Reliable[37,46,75]	
	Training in its use[37]	
	Affordable[37,75]	
	Easy to install and implement (i.e. does not require a high level of expertise)[37,46]	
	Use of mainstream, mobile devices (e.g. smartphones, tablets)[46]	
	Use of high-tech devices[75]	
	Helps to connect user and caregiver/others[37]	
	Desirable functions:	Keeping track of money spent[41], Calendar / Remembering things to do[36,41], Remembering conversations[41], Prompting functions[36], Auditory alerts[36], Social networking[75], Initiating activities[37], Performing complex tasks[37], Learning new tasks[37,75], Navigation and path finding[37,46], Phone calls / texting[37,46,155]

Table 4. Internet text design guidelines for people with communication disabilities [44] (p.557).

1	Simplify written instructions to short phrases and sentences
2	Use commonly occurring words with emphasis on simplicity
3	Use large font (size 14–18)
4	Use simplified font styles (e.g. Times New Roman, Comic Sans MS, Arial, Verdana)
5	Format with bulleting and numbering to clearly set out points
6	Break down instructions into clearly defined steps, then order steps in a logical sequence from simple to more complex
7	Use generous spacing between lines of text to maximize effect of white space
8	Use unambiguous graphics (e.g. clip-art, photos) to support meaning of text rather than replacing text altogether
9	Align text where possible from the left margin to simplify page layout presentation
10	Use different formatting techniques to make headings and important points stand out

Table 5. Proposed Theoretical Model for using Technology in Cognitive-Communicative Rehabilitation with people after TBI

Domain	Factor	Description
1. Personal drivers of Technology Use (Needs, Motivations, Goals, Activities)	Connection	Online communication facilitates social communication for the individual and may assist in the maintenance of relationships and reduction of social isolation.
	Leisure	Technology and online communication allows the individual to access leisure activities (e.g. social networking, watching videos).
	Everyday Life	Technology and online communication allows the individual to participate in everyday activities in daily life (e.g. having conversations, watching the news, shopping).
	Independence	Technology and online communication facilitates increased independence and participation of the individual, free from the control, influence, support, or aid of others.
	Learning	Technology and online communication provides opportunities for acquiring knowledge and skills.
	Access	Technology and online communication provides opportunities for accessing information and communication with others.
	Sharing	Communicating in digital environments provides opportunities for the individual to exchange information and share their experiences with others.
	Practice	Communicating in digital environments provides opportunities for communicative practice in real-life naturalistic contexts.
	Self-identity	Communicating in digital environments assists in re-establishing recognition of the individual's potential and qualities, especially in relation to social context.
2. Individual and Environmental Factors (Impairments, training, and supports)	Impairment	The underlying cognitive, psychosocial, and physical impairments affect the individual's ability to communicate and use technology effectively.
	Intervention approach	Intervention utilising technology need to be tailored to the needs and abilities of the individual.
	Consumer involvement	It is vital to consider user preferences and shared decision-making when designing or prescribing technology, to increase effectiveness along with consumer engagement and motivation.
	Support	Support needs of the individual may include technical support, maintenance of device/technology, or support personnel; includes short term and long-term support needs.
	Training	Training needs to be accessible, provide specific instructions and opportunities for repetition, and incorporate a support person.
3. Technological Factors (Technologies)	Type	The mode of technology system used by the individual, (e.g. the specific device, software, or online platform).
	Reliability	Reliability of the technology when being used by the individual (e.g. options to save user preferences, upgrades to software / online platforms)

	Durability	Ability of the technology to be long-lasting (e.g. durable to drops, duration of battery power, availability of software, consistency of online platforms)
	Accessibility	Accessibility of the technology for use by the individual (e.g. access to the internet, written language uses text design guidelines for people with communication disabilities).
	Affordability	Cost and access to funding for the technology, over short and long term.
	Capacity	Capacity of the technology to provide the required outcome for the individual, e.g. spoken output, storage of information, time for processing of information.
	Simplicity	The ease with which technology is installed, used, and maintained by the individual.