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SPECIAL COMMUNICATION

TBIBank: An International Shared Database to Enhance Research, Teaching and Automated Language Analysis for Traumatic Brain Injury Populations

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Abstract

Traumatic brain injury (TBI) has been established as a priority research area for public health, affecting an estimated 69 million individuals worldwide each year. Large-scale collaborative datasets may help to better understand this heterogenous and chronic health condition. In this paper, we present TBIBank; an innovative digital health resource that aims to establish a shared database for the study of communication disorders after TBI. We provide an overview of the current database, the standard discourse protocol used for the main TBIBank corpus, and the automated language analyses that can enable diagnostic profiling, comparative evaluation of treatment effects and profiling of recovery patterns. We also highlight the e-learning component of the digital health resource as a research translation tool. We conclude with a discussion of the potential research, clinical, and educational applications of TBIBank and future directions for expanding this digital resource.

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Traumatic brain injury as a public health priority

Traumatic brain injury (TBI) is considered a public health and research priority with an estimated 69 million cases each year across the globe.[1-3] TBI is a significant burden on health care systems in relation not only to mortality and morbidity but also to the many hidden costs associated with the long-term consequences of TBI. For example, persisting psychological, emotional, and communication changes can pose a barrier to employment, and TBI is a known risk factor for later neurodegenerative conditions.[4,5] An established body of research documenting these long-term consequences has led to the conceptualization of TBI as a chronic health condition requiring a long-term management approach.[6] Despite progress that has been made in identifying long-term consequences resulting from TBI, there are still significant gaps in understanding how to mitigate these long-term consequences, particularly as they relate to the treatment of communication behavior. For example, it remains unclear which active treatment ingredients support generalization of communication behavior and which measures best capture treatment effects.[7,8] Digital advances may offer a potential avenue for expanding and strengthening the evidence on this topic.

TBI Commission: recommendations

The Lancet Neurology Commission, established in 2017 and composed of international leaders in TBI research, aims to tackle the global health burden of TBI and provide recommendations for future research with a focus on influencing policy and enacting long-term investment into TBI research.[2,3] A key priority in the Commission's report was the need for large-scale, unified databases to support research efforts.[2] Large-scale databases can minimize Type II errors, particularly in populations such as TBI where there is significant clinical diversity. Similarly, unified approaches

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to measuring and recording outcomes through common data outcome sets can minimize methodological diversity, which is a current issue in TBI research.[9] A further critical need that was highlighted by the commission was for large-scale databases to include control comparison data with neurotypical populations.[2] Finally, improved consistency with clinical pathways, that is, the sequence of clinical interventions, timeframes, milestones and expected outcomes, and approaches toward care were also recommended.[10]

The origins of TBIBank: TalkBank as a digital resource

The need for large scale, unified and controlled datasets has also been identified for the study of language usage. One such initiative is the TalkBank project, which is a collective open-data sharing international repository for human communication.[11] TalkBank is a digitally-based platform that includes not only research databases but also software programs for transcription and automated analysis of language samples, a standard methodological discourse protocol for various clinical groups, and e-learning options. Since its inception, TalkBank has expanded across 14 research areas and 34 languages. AphasiaBank is an example of 1 research area, communication in aphasia, where the database has facilitated analyses of much bigger datasets than have ever previously been possible.[12] TBIBank is another, more recently developed, research area within the TalkBank project, specifically focusing on communication disorders after TBI. Other target clinical areas include FluencyBank for stuttering, RHDBank for right hemisphere disorder, and DementiaBank for dementia.

Advances in communication after TBI

Persisting cognitive-communication disorders are implicated in long-term psychosocial outcomes after TBI.[13] A cognitive-communication disorder refers to "difficulty with any aspect of communication (speaking, listening, reading, writing, and social interaction) due to underlying cognitive impairment (attention, information processing, memory, or executive functions)".[14,15] Cognitive-communication disorders can present variably thus, historically these disorders have been challenging to capture. However, measurement of these disorders has advanced considerably over the past 40 years, with discourse-level language analysis emerging as 1 of the most sensitive measures and demonstrating capacity to manage this inherent variability.[16,17] Discourse is a unit of language that conveys a message, such as a narrative or conversation, and requires a complex integration of cognitive, linguistic, and social skill for effective execution.[18] This inherent complexity enables discrete measurement of varied and nuanced communication behavior. Nuanced communication skills are required to effectively maintain and negotiate social relations, thus playing an important role in rehabilitation outcomes such as returning to work.[19] TBIBank integrates these advances in discourse measurement within an internationally ratified and unified protocol for adults with TBI. TBIBank has also expanded the capacity for discourse measurement in larger TBI population samples through the use of the freely downloadable automated language analysis program, computerized language analysis (CLAN) (https://dali.talkbank.org/clan/). Furthermore, TBIBank discourse data overlap with 2 other databases that include control data, further expanding the utility of this resource. The next section begins with a description of the current TBIBank database, which is followed by an overview of the protocol and an illustration of the automated analysis program. Finally, an e-learning component is discussed with a view to supporting research translation and promoting a common evidence-based approach to clinical care around communication disorders of TBI.

List of abbreviations:

CLAN **computerized language analysis**
EVAL **evaluation command**
TBI **traumatic brain injury**

TBIBank: digital health resource

Current database

Currently, TBIBank has 250 members from 19 different countries (as of October 10, 2022). Members of the consortium include individual researchers and clinicians who have registered interest in using and contributing to the TBIBank database and resources. The shared database comprises over 300 discourse samples from more than 130 participants with TBI and 359 discourse samples from 350 control participants (including control participants from AphasiaBank and RHDBank). An overview of the demographic details collected are outlined in table 1. To date, TBIBank data have been contributed by 5 clinical researchers and represent 7 distinct corpora, the largest of which are the Togher-Protocol (https://tbi.talkbank.org/access/English/Togher.html) and Coelho corpora (https://tbi.talkbank.org/access/English/Coelho.html). All corpora include spoken discourse with the exception of 1 that contains written narrative samples (https://tbi.talkbank.org/access/English/Stockbridge.html). Informed consent for open data sharing is required from all participants and participant anonymity is preserved. The database is password protected to prevent misuse of the data, with users (faculty and licensed clinicians) required to complete a free membership registration and agree to abide by the ground rules (https://talkbank.org/share/). Ethics approval for participant contributions to the database is obtained from relevant health service and university Human Research Ethics Committees, with informed consent or assent obtained from the person with TBI and/or their guardian. The discourse samples contain either a video or audio recording and a transcript of the recording, which is time-linked to the media file and coded (as explained below). Further details of the TBIBank corpora (as of May 2021) are presented in table 2.

The TBIBank protocol

International expert consensus was used to establish the TBIBank protocol for use with adults who have sustained a TBI. An overview of the full recommended outcome set, including demographic data, standardized communication tests, and the TBIBank discourse protocol is included in table 1. The TBIBank protocol aims to sample a range of discourse genres and has been established as a feasible assessment for individuals with moderate-severe TBI.[20] Emerging evidence supports the sensitivity of the selected tasks and stimuli for detection of cognitive-

Table 1 The TBIBank Protocol

Demographic Data*	Discourse Protocol†	Other Tests
Age	Free speech samples:	AphasiaBank Repetition Test
Sex	Brain injury story & coping	Verb Naming Test‡
Vision & hearing	Important event	Boston Naming Test—second Edition[27]
Languages spoken	Picture descriptions:	
Years of education	Broken window	Western Aphasia Battery-Revised[28]
Employment status	Refused umbrella	
Country of birth	Cat story	Conversation sample
Languages	Story narrative:	Optional:
TBI type, cause & severity PTA duration & GCS	Cinderella	Verbal Fluency
Medications & substance use	Procedural discourse:	(F,A,S)
Imaging results	Simple sandwich	RBANS[29]

Abbreviations: PTA, post-traumatic amnesia; GCS, initial Glasgow Coma Scale score; RBANS, Repeatable Battery for the Assessment of Neuropsychological Status.

* Further details regarding demographic data collection can be obtained through the contacts listed on https://tbi.talkbank.org/.

† All printed materials for the discourse protocol are available at: https://aphasia.talkbank.org/protocol/pictures/.

‡ Verb Naming Test from the Northwestern Assessment of Verbs and Sentences-Revised: Field Test Version.

communication disorders in a range of patient populations, including TBI. [21-26] All of the resources and stimuli for the TBIBank discourse protocol are freely available online (https://tbi.talkbank.org/).

Automated analysis: CLAN

The video- and audio-recorded language samples elicited with the TBIBank discourse protocol are transcribed in CHAT format and linked to the digitized media files. CHAT is designed to operate closely with the CLAN programs which permit computerized analysis of a wide range of linguistic and discourse structures. There is no need to do detailed coding of parts of speech or grammatical structures as this is automatically done by 1 basic CLAN command, MOR.A sample transcript is included in figure 1.

Once transcribed and linked, the language samples can be analyzed using the CLAN program. CLAN currently includes over 30 analysis commands that compute aspects of language production such as type token ratio (measure of linguistic diversity; calculated by dividing the total number of unique words by the total number

Table 2 Corpora Overview (October, 2022)

Corpus	Participants	Data Type	Location	DOI/URL	Other
Togher 1	58 participants; 5 data points (239 language samples) Mean age 35 years, 43M:11F, severe TBI	Audio & Video	Australia	doi:10.21415/T5R018	Longitudinal cohort study 5 data points over a 2-year period post-injury Discourse samples—TBIBank protocol and conversation with significant others
Togher 2	4 participants	Video	Australia	doi:10.21415/T52C74	Discourse samples—conversation
Armstrong	4 participants	Audio	Australia	doi:10.21415/T5CP6N	Discourse samples—conversation
Coelho	55 participants Mean age 28 years, 39M:16F, moderate-severe TBI	Audio	USA	doi:10.21415/T5Q01Z	Discourse—story retelling, story generation, conversation
Coelho	50 control participants Mean age 39 years, 34M:16F	Audio	USA	doi:10.21415/T5Q01Z	Discourse—story retelling, story generation, conversation
Marshfield (Turkstra)	12 participants Mean age 40 years, 7M:5F, moderate-severe TBI	Video	USA	doi:10.21415/T53W4G	Discourse—free speech (conversation), picture description, procedural discourse
Turkstra	3 participants	Video	USA	doi:10.21415/T52012	Short discourse samples
Stockbridge	91 control participants Mean age 27 years, 21M;70F	Written	USA	doi:10.21415/D70T-C409	Discourse—written samples from online surveys with expository prompts and a variety of other tasks
AphasiaBank Control database	277 control participants Mean age 55 years, 126M:151F	Audio & Video	USA	http://aphasia.talkbank.org	AphasiaBank discourse protocol and some additional story narratives
RHDBank Control database	24 control participants Mean age 47.4 years, 6M;18F	Video	USA	https://rhd.talkbank.org/	RHDBank discourse protocol (includes conversation)

Abbreviations: M, male; F, female.

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@Begin
@Languages:        eng
@Participants:     PAR Participant , INV Investigator
@ID:      eng|Togher|PAR|66;00.|female|TBI||Participant|12;00.||
@ID:      eng|Togher|INV|||||Investigator|||
@Media:   XX, video
%exp:     informed consent
@G:       Speech
@G:       Brain_Injury
*INV:     can you tell me what you remember about when you had your
          brain injury ?
%mor:     co|okay mod|can pro:per|you v|tell pro:obj|me pro:int|what
          pro:per|you v|remember adv|about conj|when pro:per|you v|have&PAST
          det:poss|your n|brain n|injury ?
%gra:     1|4|COM 2|4|AUX 3|4|SUBJ 4|0|ROOT 5|4|OBJ 6|8|LINK 7|8|SUBJ 8|4|COMP
          9|8|JCT 10|12|LINK 11|12|SUBJ 12|9|CPOBJ 13|15|DET 14|15|MOD 15|12|OBJ
          16|4|PUNCT
*PAR:     I get very confused with the results that I give at times .
%mor:     pro:sub|I aux|get adv|very part|confuse-PASTP prep|with det:art|the
          n|result-PL pro:rel|that pro:sub|I v|give prep|at n|time-PL .
%gra:     1|4|SUBJ 2|4|AUX 3|4|JCT 4|0|ROOT 5|4|JCT 6|7|DET 7|5|POBJ
          8|10|LINK 9|10|SUBJ 10|7|CMOD 11|10|JCT 12|11|POBJ 13|4|PUNCT
*PAR:     when I'm asked a quick , quick question the quick answer isn't very
          good .
%mor:     conj|when pro:sub|I~aux|be&1S part|ask-PASTP det:art|a adj|quick
          cm|cm adj|quick n|question det:art|the adj|quick n|answer
          cop|be&3S~neg|not adv|very adj|good .
%gra:     1|4|LINK 2|4|SUBJ 3|4|AUX 4|13|CJCT 5|9|DET 6|9|MOD 7|6|LP 8|9|MOD
          9|4|OBJ 10|12|DET 11|12|MOD 12|13|SUBJ 13|0|ROOT 14|13|NEG 15|16|JCT
          16|13|PRED 17|13|PUNCT
*PAR:     sometimes I think +"/.
%mor:     adv:tem|sometimes pro:sub|I v|think +"/.
%gra:     1|3|JCT 2|3|SUBJ 3|0|ROOT 4|3|PUNCT
*PAR:     +" why did I say such a silly thing ?
%mor:     pro:int|why mod|do&PAST pro:sub|I v|say qn|such det:art|a adjsilly
          n|thing ?
%gra:     1|4|JCT 2|4|AUX 3|4|SUBJ 4|0|ROOT 5|8|QUANT 6|8|DET 7|8|MOD 8|4|OBJ
          9|4|PUNCT
*PAR:     and I don't even believe it .
%mor:     coord|and pro:sub|I mod|do~neg|not adv|even v|believe pro:per|it .
%gra:     1|6|LINK 2|6|SUBJ 3|6|AUX 4|3|NEG 5|6|JCT 6|0|ROOT 7|6|OBJ 8|6|PUNCT
*PAR:     but for some reason that's what seems to come up first a_lot_of
          times which I'm even more concerned about now .
%mor:     conj|but prep|for qn|some n|reason pro:dem|that~cop|be&3S
          pro:int|what cop|seem-3S inf|to v|come adv|up adv|first qn|a_lot_of
          n|time-PL pro:rel|which pro:sub|I~aux|be&1S adv|even post|more
          part|concern-PASTP adv|about adv:tem|now .
%gra:     1|6|LINK 2|6|JCT 3|4|QUANT 4|2|POBJ 5|6|SUBJ 6|0|ROOT 7|8|DET
          8|6|CPRED 9|10|INF 10|8|COMP 11|10|JCT 12|10|JCT 13|14|QUANT
          14|8|JCT 15|20|LINK 16|20|SUBJ 17|20|AUX 18|19|JCT 19|20|JCT
          20|6|XJCT 21|20|JCT 22|20|JCT 23|6|PUNCT
*PAR:     whereas they <don't normally> [//] would've happened before .
%mor:     conj|whereas pro:sub|they mod|will&COND~aux|have part|happen-PASTP
          adv|before .
%gra:     1|5|LINK 2|5|SUBJ 3|5|AUX 4|5|AUX 5|0|ROOT 6|5|JCT 7|5|PUNCT
*PAR:     but these reasons they do .
%mor:     conj|but det:dem|these n|reason-PL pro:sub|they v|do .
%gra:     1|5|LINK 2|3|DET 3|4|APP 4|5|SUBJ 5|0|ROOT 6|5|PUNCT
*PAR:     some reason .
%mor:     qn|some n|reason .
%gra:     1|2|QUANT 2|0|INCROOT 3|2|PUNCT
*PAR:     perhaps because I have forgotten .
%mor:     adv|perhaps conj|because pro:sub|I aux|have part|forget&PASTP .
%gra:     1|2|JCT 2|5|LINK 3|5|SUBJ 4|5|AUX 5|0|ROOT 6|5|PUNCT
```

Fig 1 Example CHAT Transcript. The CLAN program automatically tags CHAT documents for morphological structures and parts-of-speech (%mor tier) as well as grammatical relations (% gra tier). This information is then used to compute outcome measures for EVAL and other CLAN commands.

of words produced), words per minute, verbs per utterance, and percentages of various parts of speech (eg, verbs vs nouns). The evaluation command (EVAL) is an example of 1 of the composite CLAN commands that computes an entire set of measures designed to make it easier and more efficient for researchers or clinicians new to language analysis. EVAL can compare the language sample of a single individual with the database (eg, controls, age- and sex-matched controls, other participants with TBI)

Table 3 Example EVAL Output

Case	Total_Utts	MLU_Morphemes	Words_Min	Verbs_Utt	%_Nouns	Retracing	Repetition
TBI 1 (23-year-old; man)	47	5·5	101	0·98	16·4	0	0
TBI 2 (54-year-old, man)	260	10·2	132	1·42	18·1	12	10
Control group (men, age range 20-60)	120	10·7	164	1·59	18·4	14·4	10·2

NOTE. This table presents 7 outcome measures out of a total 25 in the EVAL analysis. We show the results for 2 patients with TBI compared with a control group matched for sex and age range. TBI 1 is a 23-year-old man whose language could be described as impoverished after his severe TBI, which is reflected in the EVAL output. Compared with the control sample, this patient had reduced total number of utterances (Total_Utts), mean length of utterance in morphemes (MLU_Morphemes), words per minute (Words_Min), verbs per utterance (Verbs_Utt), and percentage of nouns in sample (%_Nouns). In contrast, TBI 2 is a 54-year-old man whose language could be described as excessive or verbose after his severe TBI, which is also reflected in his EVAL output. Compared with the control sample, TBI 2 has increased total utterances and words per minute. Despite the larger number of words per minute and utterances, he has comparatively similar verbs per utterance, percentage of nouns, and retracing and repetition, all of which reflect inefficiency in his language production.

or with that individual's repeat language samples over multiple time points. Table 3 shows a partial sample of the EVAL spreadsheet output.

An accompanying linked site (https://aphasia.talkbank.org) contains a manual and series of video tutorials that supports clinicians to use the automated language analysis tools in their clinical practice. The CLAN program can be downloaded to a personal device for clinical use and the language samples can be saved to a secured location on the personal device. No patient data are retained in the program or database without written permission.

E-learning: the TBIBank Grand Rounds

The TBIBank database is a rich and detailed resource that offers a unique opportunity to provide education about communication disorders after TBI. To provide examples of specific behavior types for instruction, the TBIBank Grand Rounds was established and modeled after the AphasiaBank Grand Rounds.[27] TBIBank Grand Rounds contains curated video samples illustrating the range of communication disorders that can result from a TBI. The samples are packaged into an easy-to-navigate, module-based online program that can be used flexibly. Presently, there are over 20 case examples and over 20 short video samples across 8 evidence-based learning modules (eg, *What is a cognitive communication disorder?, How do cognitive-communication disorders vary across different contexts?, How can we assess cognitive-communication disorders in spoken discourse?*). Similar to the research database, the TBIBank Grand Rounds is password protected, though students can gain access to these educational resources through their faculty members after discussing the ethical principles of shared databases.

Applications of TBIBank

TBIBank is a digital platform that can be used for research, clinical, and educational purposes. The current database offers the largest sample to-date of unified discourse-level language samples in TBI and control participants. Sample size, inconsistency of outcome measures, and lack of control data are key limitations identified in TBI research more broadly and communication disorders after TBI more specifically.[2,28] The TBIBank database has potential to address these issues, and there is already an emerging research body deriving from this shared database (https://tbi.talkbank.org/publications/) with a focus on moderate-severe TBI. Additionally, CLAN's computerized and automated EVAL program provides clinicians with an easy and efficient method for discourse analysis. Discourse analyses are recommended as 1 of the best practice tools in the assessment of communication disorders after TBI due to identified sensitivity for detecting subtle cognitive-communication difficulties.[21] Yet, lack of expertise and time constraints have been cited as key barriers to conducting discourse analyses in clinical settings.[29,30] The TBIBank protocol can be administered in 10-30 minutes and the EVAL analysis is available as a manualized program with online supporting tutorials. Hence, use of the TBIBank protocol and EVAL enables clinicians to implement best practice standards to maximize patient outcomes as part of a comprehensive cognitive-communication assessment. Finally, the TBIBank Grand Rounds is the first online, international, evidence-based, educational learning platform showcasing a wide range of communication disorders after TBI with multimedia samples.

Conclusions and future directions

TBIBank represents an advancement in initiatives to alleviate the global health burden of TBI through digital health. Initial development of the TBIBank database has focused on moderate-severe TBI. Potential future directions for TBIBank database include expansion of the database to represent a wider international population, evaluating suitability of the protocol for mild TBI,[31] increasing sample sizes and inclusion of long-term communication outcomes measured through discourse analysis. A database for pediatric TBI would also be a valuable future endeavor. Researchers, clinicians, or educators who are interested in using TBIBank or contributing toward the database are encouraged to refer to the guides and instructions provided at https://tbi.talkbank.org/.

Keywords

Communication disorders; Database; Language disorders; Rehabilitation; Traumatic brain injury

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