

Journal Pre-proof

An attitude survey and assessment of the feasibility, acceptability, and usability of a traumatic brain injury decision support tool in Uganda

Cyrus Elahi, Charis A. Spears, Sarah Williams, Timothy Dunn, Josephine N. Najjuma, Catherine A. Staton, João Ricardo Nickenig Vissoci, Anthony Fuller, David Kitya, Michael M. Haglund

PII: S1878-8750(20)30903-7

DOI: <https://doi.org/10.1016/j.wneu.2020.04.193>

Reference: WNEU 14878

To appear in: *World Neurosurgery*

Received Date: 3 March 2020

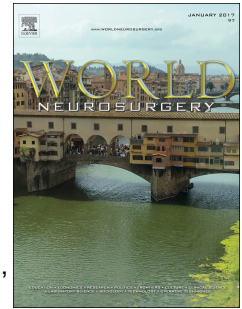
Revised Date: 23 April 2020

Accepted Date: 24 April 2020

Please cite this article as: Elahi C, Spears CA, Williams S, Dunn T, Najjuma JN, Staton CA, Nickenig Vissoci JR, Fuller A, Kitya D, Haglund MM, An attitude survey and assessment of the feasibility, acceptability, and usability of a traumatic brain injury decision support tool in Uganda, *World Neurosurgery* (2020), doi: <https://doi.org/10.1016/j.wneu.2020.04.193>.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2020 Published by Elsevier Inc.



Title: An attitude survey and assessment of the feasibility, acceptability, and usability of a traumatic brain injury decision support tool in Uganda

Author names and affiliations:

Cyrus Elahi^{a,1}, Charis A. Spears^c, Sarah Williams^a, Timothy Dunn^{b,f,g}, Josephine N. Najjuma^d, Catherine A. Staton^{a,e}, João Ricardo Nickenig Vissoci^{a,e}, Anthony Fuller^{a,b,c}, David Kitya^d, Michael M. Haglund^{a,b,c}

Affiliations

^aDuke Global Health Institute, 310 Trent Dr., Durham, North Carolina 27710, USA

^bDepartment of Neurosurgery, Division of Global Neurosurgery and Neurology, Duke University School of Medicine, 2301 Erwin Rd, Durham, North Carolina 27710, USA

^cDuke University School of Medicine, 40 Duke Medicine Cir., Durham, North Carolina 27710, USA

^dMbarara Regional Referral Hospital, Mbarara University of Science and Technology, P.O. Box 1410, Mbarara, Uganda

^eDepartment of Surgery, Division of Emergency Medicine, Duke University School of Medicine, 2301 Erwin Rd, Durham, North Carolina 27710, USA

^fDuke Forge, Duke University School of Medicine, 100 Trent Drive, Durham, North Carolina 27708, USA

^gDepartment of Statistical Science, Duke University, 214 Old Chemistry Bldg., Box 90251, Durham, North Carolina 27708, USA

¹Present address: Paul L. Foster School of Medicine, 5001 El Paso Dr., El Paso, TX 79905, USA

Corresponding author:

Michael M. Haglund, MD, PhD, MACM

Department of Neurosurgery

Duke University

4508 Hospital South

Durham, North Carolina 27710, USA

michael.haglund@dm.duke.edu

Authors' highest academic degrees and email addresses

Cyrus Elahi, MScGH: cyrusweal@gmail.com

Charis A. Spears, BA: charis.spears@duke.edu

Sarah Williams, MScGH: sarah.williams@duke.edu

Timothy Dunn, PhD: timothy.dunn@duke.edu

Josephine N. Najjuma: najjumajosephine@yahoo.co.uk

Catherine A. Staton, MD: catherine.lynch@duke.edu

João Ricardo Nickenig Vissoci, PhD: jnv4@duke.edu

Anthony Fuller, MD, MScGH: anthony.fuller@duke.edu

David Kitya, MD: dkitya1@hotmail.com

Michael M. Haglund, MD, PhD, MACM: michael.haglund@duke.edu

Key words: Acceptability, attitude survey, decision support, feasibility, neurosurgery, prognostic model, traumatic brain injury

Title: An attitude survey and assessment of the feasibility, acceptability, and usability of a traumatic brain injury decision support tool in Uganda

Abstract

Background

Traumatic brain injury (TBI) prognostic models are potential solutions to severe human and technical shortages. Although numerous TBI prognostic models have been developed, none are widely used in clinical practice, largely due to a lack of feasibility research to inform implementation. We previously developed a prognostic model and web-based application for in-hospital TBI care in low-resource settings. In this study, we tested the feasibility, acceptability, and usability of the application with potential end-users.

Methods

We performed our feasibility assessment with providers involved in TBI care at both a regional and national referral hospital in Uganda. We collected qualitative and quantitative data on decision support needs, application ease of use, and implementation design.

Results

We completed 25 questionnaires on potential uses of the app and 11 semi-structured feasibility interviews. Top-cited uses were informing the decision to operate, informing the decision to send the patient to intensive care, and counseling patients and relatives. Participants affirmed the application's potential to support difficult triage situations, particularly in the setting of limited access to diagnostics and interventions, but were hesitant to use this technology with end-of-life

1 decisions. While all participants were satisfied with the application and agreed it is easy to use,
2 several expressed a need for this technology to be accessible by smartphone and offline.

4 *Conclusions*

5 We elucidated several potential uses for our app and important contextual factors that will
6 support future implementation. This investigation helps address an unmet need to determine the
7 feasibility of TBI clinical decision support systems in low-resource settings.

8
9 **Key words:** Acceptability, attitude survey, decision support, feasibility, neurosurgery,
10 prognostic model, traumatic brain injury

11 **Short title:** Feasibility of TBI decision support tool

1 Introduction

2 Traumatic brain injury (TBI) is a burgeoning cause of death and disability that disproportionately
3 affects low- and middle-income countries (LMICs).¹ Health facilities in LMICs experience
4 severe technical and human shortages,² hindering the ability to accurately assess injury severity
5 and reduce the capacity to treat this high burden of disease.^{2,3} Prognostic models, algorithms that
6 combine clinical variables to calculate a risk of a prespecified outcome,⁴ are low-cost and highly
7 scalable compared to technologies like computed tomography (CT) scanners. However, despite
8 the potential for prognostic models to augment TBI risk assessment, there are no models
9 regularly used in clinical practice in LMICs.^{5,6}

10
11 One contributor to the poor uptake of prognostic models in clinical practice is the dearth of
12 feasibility and usability research. A comprehensive feasibility and usability study collects salient
13 information to inform the implementation of a tool, exploring its demand, acceptability, and
14 usability with intended end-users.⁷ This is necessary for any implementation, particularly in low-
15 resource settings like sub-Saharan Africa (SSA), where there are many potential barriers.
16 Previous feasibility testing in SSA has included mobile applications for pediatric mortality, non-
17 communicable diseases, and human immunodeficiency virus (HIV).^{8,9} To the best of our
18 knowledge, however, there have been no studies testing the feasibility of a TBI decision support
19 tool in SSA.

20
21 A risk calculator is a user-friendly interface for end-users to access the output from a prognostic
22 model. For TBI, prognostic models can support communication with patients and families,¹⁰ aid
23 in monitoring patients for deterioration, or reduce variability in prognostication between

providers with different levels of experience.¹⁰ While many TBI prognostic models are available,^{5,6} our team developed our own SSA-based TBI prognostic model and risk calculator.¹¹ This afforded the autonomy to leverage local datasets to increment model performance and adjust the risk calculator interface based on end-user testing.

The objective of this study was to evaluate the feasibility and acceptability of implementing an SSA-based TBI risk calculator (i.e., decision support tool) at two referral hospitals in Uganda. We also assessed the usability of our tool with potential end-users and their attitudes regarding the use of our application. These data provide context-specific information to inform the implementation of our tool but can apply to other decision support technology implementations in the region.

Material and Methods

Setting

This study included collected data from healthcare providers at two government-owned referral hospitals in Uganda: Mbarara Regional Referral Hospital (MRRH) and Mulago National Referral Hospital (MNRH).

MRRH is a 360-bed referral hospital located 250 kilometers southwest of the capital city, Kampala. The hospital serves an annual volume of 600 TBI patients from the surrounding 10 districts of Uganda and patients from neighboring Rwanda, Tanzania, and Democratic Republic of the Congo. Neurosurgical cases are managed by one neurosurgery-trained doctor, general surgery residents who have completed 6-week rotations in the neurosurgery department, and

interns, who rotate through the neurosurgery department; there are no neurosurgery residents. MNRH, a 1,500-bed national hospital located in Kampala, treats approximately 1,500 TBI cases annually. The hospital has a neurosurgery residency program staffed by 6 residents, 5 consultants, and 2 neurosurgery-trained providers in the casualty (emergency) department. Neurosurgery residents and consultants perform all the neurosurgical procedures at MNRH.

Study population

We used convenience sampling to recruit providers closely involved in the care of TBI patients. This definition included neurosurgeons, general surgeons, and an emergency medicine provider. To further increase our sample size, we recruited doctors at different levels of training, including interns, residents, and consultants (the equivalent to attending physicians), who are often involved in direct care of neurosurgical patients. Interns or general surgery residents must have completed a rotation in the neurosurgery department or casualty department to be included. Our target sample size for the feasibility and acceptability interview was 10, the size at which inductive thematic saturation (i.e., when no new themes emerge from the data) in qualitative interviews is typically reached.^{12,13} The target sample size for the usability testing and subsequent attitude survey was 7, the optimal number of test users for a project of this scope.¹⁴ We collected written informed consent from all participants and compensated each participant for their time.

Participant demographics

Demographics collected included provider age, gender, specialty, and level of experience (calculated by subtracting year of medical school graduation from 2018).

Study design

We implemented a mixed methods approach, collecting quantitative data by direct observation and surveys and qualitative data through semi-structured interviews. Our study design was based on *How We Design Feasibility Studies* by Bowen et al⁷ and a prior investigation of the feasibility of implementing a decision support tool in a similar setting.¹⁵ We followed the World Health Organization (WHO) Mobile Health Evidence Reporting and Assessment (mERA) Checklist in reporting results.¹⁶ From the mERA checklist, we investigated infrastructure, technology platform, intervention content, preliminary usability testing, user feedback, access of individual participants, cost assessment, adoption inputs, limitations for delivery, and contextual adaptability.

All participants were allowed to interact with the application during the study. As time permitted, participants completed a demographic questionnaire, a survey on potential uses of TBI prognostic models (i.e., use cases survey), a semi-structured interview investigating the demand and acceptability of our TBI decision support tool (i.e., feasibility and acceptability analysis), and/or usability testing with closing user experience attitude survey (see Table 1). The questionnaire and survey were considerably shorter than the interview and usability. Participants were allowed to decline completing any portion if they did not have time.

System design

In May 2018, we developed the original prototype of our TBI risk calculator as a mobile and web-based application.¹¹ The application displays the output of a Bayesian generalized linear

1 model, which we selected over several machine-learning based models. We then used the Shiny
2 package in R Programming Language (R Core Team, Vienna, Austria) to build the risk
3 calculator application. Early prototypes were tested by neurosurgeons and emergency medicine
4 physicians in the United States, Uganda, and Tanzania. The goals of these initial tests were to
5 identify major necessary changes and establish proof of concept; there was no systematic data
6 collection.

8 *Hardware specification*

9 Our application can be accessed on phone, tablet or computer with Internet access. For this
10 study, we tested the use of the application with end-users on both a tablet and a laptop. Internet
11 connection instability limited our ability to test this application on a phone.

13 *User interface*

14 Our application required end-users to enter 12 patient variables, including demographic data,
15 injury details, vital signs, and physical exam findings. From these data, the application presented
16 the patient risk for poor outcome both with and without surgery calculated from our model at the
17 top of the screen. Displayed below the risk output was an explanation of the output see (see
18 Figure 2 or Hernandez Rocha et al for a visual representation of the user interface).¹¹

20 *Use cases survey*

21 The use cases survey, adopted from an earlier study performed by Perel et al,¹⁷ asked providers
22 to rate the perceived importance of several pre-selected potential uses for the application,
23 including the decision to send a patient to the intensive care unit (ICU) or perform

decompressive craniotomy (detailed in Figure 1).

Acceptability and feasibility analysis, preliminary usability testing, and attitude survey

The acceptability and feasibility analysis explored participants' perceptions of the strengths, weaknesses, and implementation details of our decision support tool. The interview was conducted in English. With the participants' approval, the interviews were recorded and transcribed.

One author (C.E.) conducted the preliminary usability testing and semi-structured interviews with the participants in a controlled environment of a doctor's office or corridor. The examiner (C.E.) provided an introduction to the project and gave participants two hypothetical patient cases with different values for the patient data, but otherwise identical length and structure. Participants entered data from one case into a laptop and the other into a tablet. The order in which the participants used each device was alternated so that about half of the participants used the laptop first. Seated with the participant, the examiner captured the number of errors, comments, questions, and time of data entry as participants entered the patient information into the application and interpreted the output. We encouraged participants to think out loud while using the application and interpreting the output.¹⁵

For the attitude survey, participants completed a modified Computer System Usability Questionnaire (CSUQ)¹⁸ at the end of the second hypothetical case. The CSUQ asked providers to quantify their agreement with several statements regarding the ease, simplicity, comfortability, and other aspects of using the app using a Likert scale (see Figure 3).

1

2 *Data analysis*

3 Demographic data were summarized with descriptive statistics. For the use cases survey and
4 CSUQ, we used the likert package in R 3.5.3 (R Core Team, Vienna, Austria) to graphically
5 represent the responses provided by participants for each question. For the feasibility analysis,
6 we performed an inductive content analysis of the semi-structured interviews. The analysis
7 elucidated themes from the general categories of strengths, weakness, suggested changes, best
8 medium, and best end-user, which were presented along with salient quotes to exemplify each
9 theme. We calculated the mean and standard deviation of the time to complete an entry and the
10 mean number of errors and questions asked for the usability testing.

11

12 *Institutional review board*

13 Our study received ethical clearance from the institutional review boards of Makerere University
14 and Duke University. We additionally received hospital clearance from Mbarara Regional
15 Referral Hospital and Mulago National Referral Hospital.

16

17 **Results**18 *Participants*

19 We included 28 health care providers in this study (Table 1). Of these, 25 providers completed
20 the use cases survey, 11 completed the semi-structured demand and acceptability interview for
21 the feasibility analysis, and 9 completed the usability testing. The majority of participants who
22 completed the use cases survey were male (76%, N=19), resident doctors (52%, N=13), and
23 working in neurosurgery (20%, N=5). Emergency medicine residents (44%, N=4) and intern

doctors (44% N=4) represented the majority of participants who completed the usability testing.

Use cases survey

Figure 1 illustrates the responses to the use cases survey (N=25). The top 4 potential applications of our prognostic tool, endorsed as Very Important by a majority of providers, were the decision to send a patient to the ICU (64%, N=16), the decision to operate (60%, N=15), the decision to perform a decompressive craniotomy (60%, N=15), and communication with patients or families (56%, N=14). The least endorsed use cases, selected as Very Important by fewer respondents, were the decision to obtain a CT scan (44%, N=11), the decision to offer rehabilitation (32%, N=8), and the decision to withdraw treatment (16%, N=4). Notably, there was substantial variability among providers regarding the perceived importance of the application for the latter uses, with 20-36% of providers rating the application as Not Important for those purposes.

Acceptability and feasibility analysis

Strengths of the decision support tool

Eleven participants completed the semi-structured interview. When asked about the strengths of the decision support tool, several participants highlighted the simplicity of the user interface and the rapid calculation of patient risk:

“It doesn’t need a lot of expertise in computer literacy to really feed in these things, so somebody can quickly get to know what to feed in [and] where, and they do it for you.”

“Immediately after feeding in the last variable, you get a risk outcome already there on the screen. It’s really fast.”

1 Additionally, multiple respondents stated the tool could remind providers of which data points
2 are important to collect for head injury patients, as exemplified in the quote below:

3 “Because we are in a rush we may skip some vital signs. This is good because it
4 encourages us to capture all the needed vitals. It acts like a reminder.”
5

6 Many participants agreed that this tool could provide an objective assessment of patient risk and
7 support difficult triage decisions, particularly in resource-limited settings. This sentiment was
8 captured in the following quotes:

9 “It helps you triage. The resources here are not enough to offer to everyone. We must
10 consider resources in our setting. If we could only offer surgery to one patient, [it would
11 be to whomever] is most likely to have the best shot at recovery.”

12 “This app is perfect for referral [hospitals] in the smaller cities without a CT.”
13

14 Weaknesses of the decision support tool

15 Two main weaknesses of the tool emerged, centering on connectivity challenges and resource
16 limitations. First, the majority of participants stated the application would not be feasible to use
17 in this setting if use was dependent on Internet connection. As one participant noted, Internet
18 connection can be costly, and the connection is often poor:

19 “In this setting, we don’t have free Wi-Fi, so it would be really hard for us to access if it
20 needs Internet.
21

22 Multiple providers also acknowledged the challenge to complete downstream interventions after
23 triage. This potential weakness was highlighted by one emergency medicine resident:

1 “It is also challenging in our setting because of resources. We may use the app, see they
2 need surgery, but then we can’t [offer it] because of our resources. We can’t take
3 everyone needing surgery to the theatre.”
4

5 Suggestions to improve the application

6 When asked to recommend changes to the decision support tool, providers requested the addition
7 and removal of variables, additional explanatory text, and expansion of the application scope.
8 For example, multiple participants requested that the application support risk assessment after
9 the initial triage, particularly after the patient receives interventions. This idea was elucidated by
10 one general surgery resident rotating in the neurosurgery department:

11 “Also it would be nice to be able to assess prognosis after admission. Like if they got the
12 surgery, what is their prognosis then, or if a few days passed so we can catch
13 deterioration.”
14

15 Best end-user and best medium of use

16 When asked what they thought was the best technology (e.g., smartphone, tablet, laptop, etc.) to
17 use the application, all participants identified a smartphone as the ideal medium, as “most
18 workers have smartphones, so it’s easier. A tablet is big; on rounds it would not be good.” When
19 asked about the best end-user, the majority of participants agreed the tool was best for providers
20 first assessing the patient in the emergency room. The reason multiple participants gave for
21 selecting a frontline health worker was the potential for the tool to expedite downstream care:

22 “This tool would be useful to frontline health workers because they activate neurosurgery
23 teams. If there is uncertainty, the frontline workers may take their time before calling the

neurosurgery team, causing a delay. This could help reduce that time to activate [the
neurosurgery] team.”

Misinterpretations of the tool

Importantly, some participants mistook the decision support tool for an electronic medical record (EMR) system. As captured in the quote below, some participants were keen on the application’s potential to create an organized system to track patients:

“If you are the physician for the patient you wouldn’t have to look for the patient file. Sometimes the patient file is missing, [or the] patient isn’t at their bed. With this, you can access the patient information right here. You could cross-check the app for patient information access, which would improve patient management.”

Preliminary usability testing and modified Computer System Usability Questionnaire

Nine participants completed preliminary usability testing of the application (Figure 2) and subsequent attitude survey (i.e., modified CSUQ). The average entry time, errors per entry, and questions asked per entry for both trials in the usability testing are summarized in Table 2. The average time for data entry for one case was 147 seconds. The overall entry time was slightly faster when using the application as a laptop (145 seconds) compared to a tablet (149 seconds). Entry time improved with the second entry for both groups; however, the second entry time was lower in the tablet group (131 seconds versus 139 seconds). There were few (<1) errors committed or questions asked per entry for both groups.

The responses to the CSUQ are presented in Figure 3. All participants completing the CSUQ

1 agreed that the application was quick, simple, and easy to use. All but one participant agreed that
2 the application would facilitate their work. One participant was uncomfortable with the
3 application, as they disagreed with the estimated risk score for one of the patient cases.
4

5 **Discussion**

6 This study is one of the first to investigate the acceptability and feasibility of TBI decision
7 support technology in SSA. Participants in this study affirmed our application's potential to
8 support difficult triage and resource allocation decisions and supplement communication with
9 patients and their families. We also elucidated important contextual factors, such as reluctance to
10 use this technology with end-of-life decisions, concern over inability to provide services
11 expected by patients and caretakers, and the need for this technology to be accessible offline and
12 on a smartphone. Maximally effective implementation of decision support tools in Uganda and
13 other countries in the region will require consideration of these and other logistical and ethical
14 challenges.
15

16 *Potential for use of decision support tools in this region*

17 Improved technological infrastructure in SSA has created an enabling environment for mobile
18 applications in health care (mHealth). Provided their low cost, wide acceptability, and easy
19 distribution, mHealth are becoming increasingly common in low-resource settings.^{19,20} To date,
20 the majority of mHealth initiatives in LMICs center on reminders to ensure compliance with
21 medical treatments.²¹ However, with the potential to promote faster, decentralized decision
22 making and allocation of resources, demand for decision support technologies is increasing.²²
23 While the use of several mHealth initiatives for decision support and healthcare quality

improvement has been investigated in SSA,²³ none have involved TBI decision support tools.

Therefore, our application helps to fill a need for such technology.

Potential for use of our application

A strength of our model is transparency as to which variables drive the output.²⁴ This benefit can be extended to the explanation of the risk output provided by our application, which will be updated to provide a description of which variables most contribute to a given patient's risk of poor outcome. This information may facilitate not only the initial patient assessment, but also discussions with patients and family members regarding clinical course and treatment plans.

Consistent with results from the original survey of potential uses for accurate prognostic information,¹⁷ our application was endorsed by most providers as important to decisions to obtain imaging, send patients to the ICU, and perform surgery. The intended output of our model is calibrated estimates of risk of poor outcomes with and without neurological surgery. This could further facilitate triage decisions, especially in settings where the individuals performing the initial assessment cannot rely on prior experience or data from the literature to estimate patient risk. Additionally, while two well-known TBI prognostic calculators, CRASH²⁴ and IMPACT,²⁵ estimate risk of poor outcomes at 6 months, our risk calculator estimates risk at hospital discharge. In our setting, 6-month follow-up is often not feasible, and the risk of poor outcomes at such a distant time point may therefore be less salient to triage decisions. Several respondents considered our risk calculator not important to decisions regarding which patients need rehabilitation, a decision which may seem less acute than triage decisions.

While most participants considered the tool important or very important for assessing whether a patient should get a CT scan, almost a third considered the tool unimportant for this purpose. That so many participants did not endorse this potential use for the tool may be partly attributed to the relationship between diagnostics and prognostication. While a risk calculator provides information on prognosis—which is itself informed by diagnosis—prognosis rarely informs diagnosis. Therefore, to some providers, a risk calculator may seem less useful for a decision to obtain diagnostic imaging. One may posit that in resource-limited settings, it may be prudent to only pursue costly diagnostics for patients who are most likely to benefit from an intervention, which may explain why most providers affirmed the importance of the tool for the decision to obtain imaging. However, this introduces an additional layer of complexity into the quick triage decisions most likely to be supported by this tool. Importantly, it also highlights a key challenge to the use of decision support tools in low-resource settings. Such tools may raise patient and caretaker expectations for treatment that cannot ultimately be provided.²³ This concern was echoed in the present study. In a separate survey of the providers included in this study (N=28), all but one reported considering both resources and prognosis in their treatment decisions, and respondents estimated that a patient with severe TBI would only have a 60% chance of receiving a CT scan and a 48% chance of undergoing surgery within two days, even if needed.¹⁰

Ethical considerations

Despite the challenges of resource allocation in a resource-poor setting, few providers considered our tool very important, and many considered our tool not important, for decisions regarding withdrawal of treatments. While these results contrast with the original survey, they echo previously expressed concerns about the use of decision support technologies in end-of-life care

1 decisions.²⁸ Thus, implementation of a risk calculator in this setting will require future
2 investigations into and consideration of providers' ethical and moral beliefs surrounding end-of-
3 life care, as well as the interplay between those beliefs and beliefs surrounding allocation of
4 limited resources.

5
6 Other ethical concerns regarding the use of prognostic models in any setting have been identified
7 and should also be considered before and during implementation: lack of trust in the data source,
8 consent, privacy, and transparency.^{5,29} Among these, high costs leading to exacerbation of
9 disparities is a major concern.²⁹ Currently, our intent is for the application to be free to use, but if
10 licensing fees or other costs were to be implemented in the future, equitable access requires that
11 institutions in low-resource settings can afford to use the application, especially since our model
12 relies on data from LMICs.

14 *User experience with our application and potential areas of improvement*

15 End-users in our study found the current version of our application to be relatively simple and
16 easy to use, made few errors and asked few clarifying questions during the usability testing.
17 However, the misinterpretation of our application as an EMR reveals a knowledge gap
18 concerning the use of decision support technology and underscores the importance of clear,
19 effective education on the use of the tool prior to implementation. It also identifies areas for
20 improvement of the model: providers expressed a need to re-evaluate patient prognosis over time
21 and after various interventions are implemented.

22
23 Users also endorsed a need for an offline, smartphone version of the tool. As 46% of Ugandans

1 have Internet access—82% of whom have mobile Internet subscriptions—and several mobile
2 phone companies offer 4G coverage in all major cities and 3G coverage in more rural areas,^{25,26}
3 the application would be accessible to target end-users with the means to obtain Internet access.
4 However, the strength of the Internet connection is not always reliable.²⁶ Further, while the cost
5 of commercial Internet has been decreasing, prices remain higher than in most countries in East
6 Africa²⁶ and may not be feasible for some healthcare institutions and individuals.²⁶ Our risk
7 calculator, like CRASH and IMPACT, is currently only available online; optimizing our mobile
8 application for offline use would therefore maximize its usability. However, this must be
9 reconciled with a need for our model to use data from each patient's outcome to improve its
10 performance in real time. Future work should therefore focus on developing a web-based
11 application that allows offline use in emergencies and updates the database when the connection
12 is restored. At the institutional and system levels, improving the quality and cost-effectiveness of
13 Internet connectivity would increase access to decision support tools and other key resources.

14 15 *Limitations*

16 The captured entry time and errors likely underestimate the actual values when used as intended
17 at the patient's bedside. We tested the application in quiet, private settings (e.g., doctor's office,
18 empty corridor, etc.) and provided the end-user with patient data to enter into the application.
19 However, this study was a planned preliminary feasibility assessment meant to inform a
20 pragmatic feasibility assessment in the future. Second, due to connectivity challenges, we were
21 unable to test the application as a mobile application on a smartphone, which all respondents in
22 our study identified as the device of choice. Testing should therefore be repeated with
23 smartphones. While participants agreed the app was quick to use, it is difficult to interpret the

1 data entry times we measured without a comparison to data entry onto paper or into an electronic
2 database. Additionally, due to time constraints, we were unable to complete usability testing with
3 all participants, and the perceptions of the usability of the application may have been affected by
4 selection bias. Specifically, we were unable to test the application with Ugandan neurosurgeons.
5 Most application testers were emergency medicine residents and interns, who identified triage
6 decisions as important potential uses. At these hospitals, however, the doctors who often triage
7 TBI patients are interns and emergency medicine residents, so this limitation is not prohibitive to
8 application success for this purpose. Neurosurgeons may use the application differently, e.g., to
9 decide whether and when to operate on a patient, so future studies will aim to include more
10 neurosurgeons in the usability testing.

11
12 Finally, the model tested in the present study did not output calibrated predictions and thus does
13 not represent the final model that will be put into clinical practice. Model calibration is essential
14 for producing accurate probability estimates regarding outcomes^{30,31}; however, this limitation
15 does not detract from the feasibility of such a tool as presented here. Efforts are already
16 underway to create a calibrated model with more realistic probability estimates. In the future, we
17 plan to perform a comprehensive feasibility study implementing this improved application into
18 the current workflow and assessing providers' actual uses and updated perceptions of the
19 application, as well as its impact on clinical outcomes.

21 **Conclusions**

22 In one of the first studies to investigate the feasibility and usability of a TBI prognostic calculator
23 in SSA, we elicited key potential uses and important logistical and ethical considerations that can

inform implementation of decision support tools in Uganda and other low-resource settings. While this study helps fill a need for such data, future studies investigating the use of an improved version of the application within the context of current clinical practice will provide more opportunities for improvement and greater insight into the potential of decision support tools to improve the care of TBI patients in this setting. The lessons learned from this preliminary assessment can also be applied to decision support tools for other pathologies and specialties to improve care for patients throughout LMICs.

Acknowledgements

The authors would like to thank the Duke Global Health Institute and team, the Duke University Division of Global Neurosurgery and Neurology, Mbarara Regional Referral Hospital, and Mulago National Referral Hospital for facilitating the conduction of this investigation and creation of this manuscript. We would also like to thank Syed Adil for his assistance in editing the final version of the manuscript.

Funding: This work was supported by the Duke University Center for International and Global Studies Research Award.

References

1. Dewan MC, Rattani A, Gupta S, et al. Estimating the global incidence of traumatic brain injury. *J Neurosurg*. April 2018;1-18. doi:10.3171/2017.10.JNS17352
2. Dewan MC, Rattani A, Fieggen G, et al. Global neurosurgery: the current capacity and deficit in the provision of essential neurosurgical care. Executive Summary of the Global Neurosurgery Initiative at the Program in Global Surgery and Social Change. *J Neurosurg*. 2018;130(4):1055-1064. doi:10.3171/2017.11.JNS171500
3. WHO | Global forum to improve developing country access to medical devices. WHO. doi:/entity/mediacentre/news/notes/2010/medical_devices_20100908/en/index.html
4. Moons KGM, Royston P, Vergouwe Y, Grobbee DE, Altman DG. Prognosis and prognostic research: what, why, and how? *BMJ*. 2009;338:b375. doi:10.1136/bmj.b375
5. Dijkland SA, Foks KA, Polinder S, et al. Prognosis in Moderate and Severe Traumatic Brain Injury: A Systematic Review of Contemporary Models and Validation Studies. *J Neurotrauma*. May 2019. doi:10.1089/neu.2019.6401
6. Perel P, Edwards P, Wentz R, Roberts I. Systematic review of prognostic models in traumatic brain injury. *BMC Med Inform Decis Mak*. 2006;6:38. doi:10.1186/1472-6947-6-38
7. Bowen DJ, Kreuter M, Spring B, et al. How We Design Feasibility Studies. *Am J Prev Med*. 2009;36(5):452-457. doi:10.1016/j.amepre.2009.02.002
8. English LL, Dunsmuir D, Kumbakumba E, et al. The PAediatric Risk Assessment (PARA) Mobile App to Reduce Postdischarge Child Mortality: Design, Usability, and Feasibility for Health Care Workers in Uganda. *JMIR MHealth UHealth*. 2016;4(1). doi:10.2196/mhealth.5167

- 1 9. Vedanthan R, Blank E, Tuikong N, et al. Usability and Feasibility of a Tablet-Based
2 Decision-Support and Integrated Record-Keeping (DESIRE) Tool in the Nurse
3 Management of Hypertension in Rural Western Kenya. *Int J Med Inf.* 2015;84(3):207-219.
4 doi:10.1016/j.ijmedinf.2014.12.005
- 5 10. Elahi C, Williamson T, Spears CA, et al. Estimating prognosis for traumatic brain injury
6 patients in a low-resource setting: How do providers compare to the CRASH risk
7 calculator? *J Neurosurg.* In Press.
- 8 11. Hernandez Rocha TA, Elahi C, Cristina da Silva N, et al. A traumatic brain injury
9 prognostic model to support in-hospital triage in a low-income country: a machine learning-
10 based approach. *J Neurosurg.* May 2019:1-9. doi:10.3171/2019.2.JNS182098
- 11 12. Saunders B, Sim J, Kingstone T, et al. Saturation in qualitative research: exploring its
12 conceptualization and operationalization. *Qual Quant.* 2018;52(4):1893-1907.
13 doi:10.1007/s11135-017-0574-8
- 14 13. Marshall B, Cardon P, Poddar A, Fontenot R. Does Sample Size Matter in Qualitative
15 Research?: A Review of Qualitative Interviews in is Research. *J Comput Inf Syst.*
16 2013;54(1):11-22. doi:10.1080/08874417.2013.11645667
- 17 14. Nielsen J, Landauer TK. A mathematical model of the finding of usability problems. In:
18 *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI*
19 '93. Amsterdam, The Netherlands: ACM Press; 1993:206-213. doi:10.1145/169059.169166
- 20 15. English LL, Dunsmuir D, Kumbakumba E, et al. The PAediatric Risk Assessment (PARA)
21 Mobile App to Reduce Postdischarge Child Mortality: Design, Usability, and Feasibility for
22 Health Care Workers in Uganda. *JMIR MHealth UHealth.* 2016;4(1).
23 doi:10.2196/mhealth.5167

- 1 16. Agarwal S, LeFevre AE, Lee J, et al. Guidelines for reporting of health interventions using
2 mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA)
3 checklist. *BMJ*. March 2016;i1174. doi:10.1136/bmj.i1174
- 4 17. Perel P, Wasserberg J, Ravi RR, Shakur H, Edwards P, Roberts I. Prognosis following head
5 injury: a survey of doctors from developing and developed countries. *J Eval Clin Pract*.
6 2007;13(3):464-465. doi:10.1111/j.1365-2753.2006.00713.x
- 7 18. Lewis JR. IBM computer usability satisfaction questionnaires: psychometric evaluation and
8 instructions for use. *Int J Human-Computer Interact*. 1995;7(1):57-78.
- 9 19. Deloitte. *The MHealth Opportunity in Sub-Sahara Africa The Path towards Practical*
10 *Application*.
- 11 20. Mobile health: transforming the face of health service delivery in the African Region.
12 African Health Observatory. [http://www.aho.afro.who.int/pt-pt/blog/2015/03/10/mobile-](http://www.aho.afro.who.int/pt-pt/blog/2015/03/10/mobile-health-transforming-face-health-service-delivery-african-region)
13 [health-transforming-face-health-service-delivery-african-region](http://www.aho.afro.who.int/pt-pt/blog/2015/03/10/mobile-health-transforming-face-health-service-delivery-african-region). Accessed February 20,
14 2019.
- 15 21. Källander K, Tibenderana JK, Akpogheneta OJ, et al. Mobile Health (mHealth) Approaches
16 and Lessons for Increased Performance and Retention of Community Health Workers in
17 Low- and Middle-Income Countries: A Review. *J Med Internet Res*. 2013;15(1).
18 doi:10.2196/jmir.2130
- 19 22. Macharia W. Opportunity in Delivery of Health Care Over Mobile Devices in Developing
20 Countries. 2009;9(5):11.
- 21 23. Adepoju I-OO, Albersen BJA, De Brouwere V, van Roosmalen J, Zweekhorst M. mHealth
22 for Clinical Decision-Making in Sub-Saharan Africa: A Scoping Review. *JMIR MHealth*
23 *UHealth*. 2017;5(3):e38-e38. doi:10.2196/mhealth.7185

- 1 24. Friedman J, Hastie T, Tibshirani R. *The Elements of Statistical Learning*. Vol 1. Springer
2 series in statistics New York; 2001.
- 3 25. Central Intelligence Agency. The World Factbook 2019. The World Factbook 2019.
4 <https://www.cia.gov/library/publications/the-world-factbook/geos/ug.html>. Published 2019.
- 5 26. The Collaboration on International ICT Policy for East and Southern Africa. National
6 Information Technology Survey 2017/2018 Report. 2018.
7 <https://www.nita.go.ug/publication/national-it-survey-2018-final-report>.
- 8 27. Shao AF, Rambaud-Althaus C, Swai N, et al. Can smartphones and tablets improve the
9 management of childhood illness in Tanzania? A qualitative study from a primary health
10 care worker's perspective. *BMC Health Serv Res*. 2015;15:135-135. doi:10.1186/s12913-
11 015-0805-4
- 12 28. Weber S. Impacts of Clinical Decision Support Technology on Nursing and Medical
13 Practice in U.S. Critical Care. *Can J Nurs Inform*. 2011;5(4).
- 14 29. Cohen IG, Amarasingham R, Shah A, Xie B, Lo B. The Legal And Ethical Concerns That
15 Arise From Using Complex Predictive Analytics In Health Care. *Health Aff (Millwood)*.
16 2014;33(7):1139-1147. doi:10.1377/hlthaff.2014.0048
- 17 30. Van Calster B, Vickers AJ. Calibration of risk prediction models: impact on decision-
18 analytic performance. *Med Decis Mak Int J Soc Med Decis Mak*. 2015;35(2):162-169.
19 doi:10.1177/0272989X14547233
- 20 31. Van Calster B, McLernon DJ, van Smeden M, et al. Calibration: the Achilles heel of
21 predictive analytics. *BMC Med*. 2019;17(1):230. doi:10.1186/s12916-019-1466-7

Table 1. Demographics and medical training background for participants in the study.

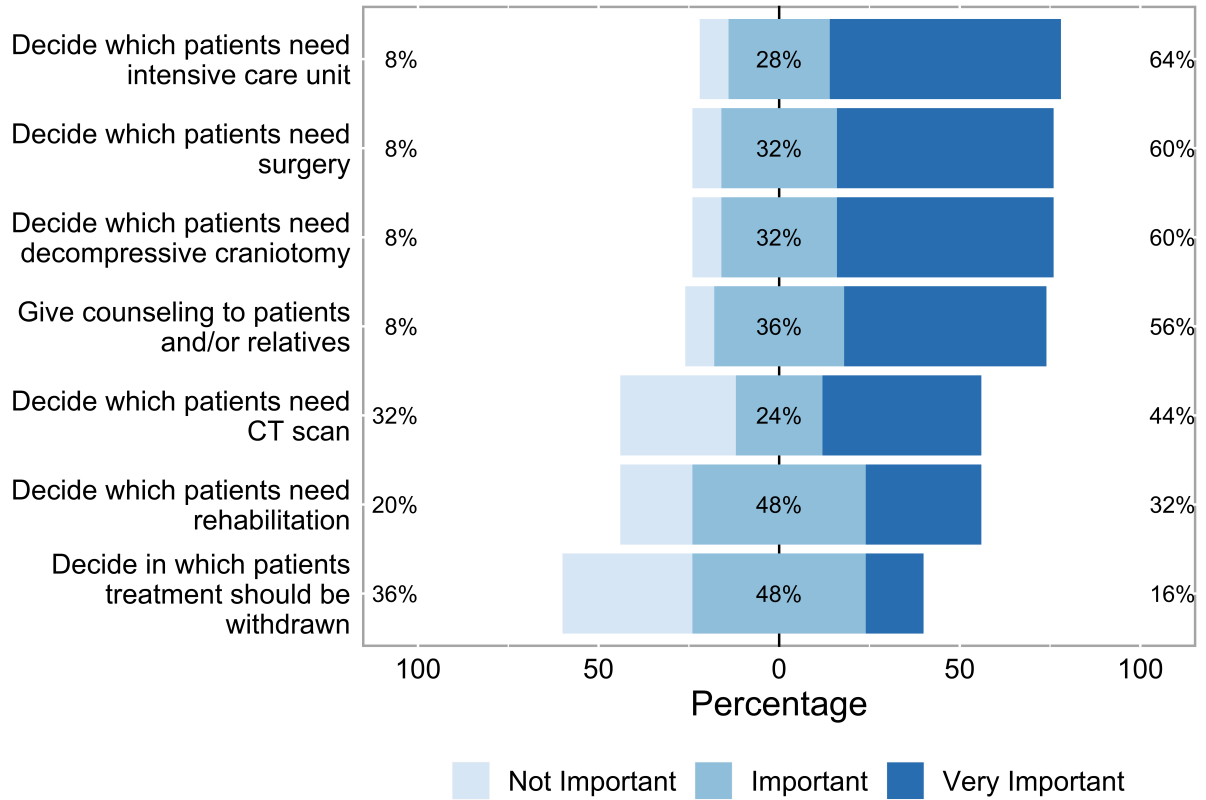
Category	Overall	Use Cases Survey	Acceptability/ Feasibility Analysis (Interview)	Preliminary Usability Testing and Attitude Survey
Total Participants, No. (%)	28	25	11	9
Demographics, No. (%)				
Female	7 (25)	6 (24)	4 (36)	3 (33)
Average age (SD), years	30.3 (6.7)	29.7 (5.2)	29.3 (5.0)	28.8 (5.1)
Medical Specialty, No. (%)				
Emergency Medicine	5 (18)	5 (20)	4 (36)	4 (44)
General Surgery	6 (21)	6 (24)	2 (18)	1 (11)
Intern Doctor	11 (39)	9 (36)	4 (36)	4 (44)
Neurosurgery	6 (21)	5 (20)	1 (9)	0 (0)
Level of Experience, No. (%)				
Consultant	3 (11)	2 (8)	2 (18)	1 (11)
Fellow	1 (4)	1 (4)	1 (9)	0 (0)
Resident	13 (46)	13 (52)	5 (45)	4 (44)
Intern	11 (39)	9 (36)	4 (36)	4 (44)
Average years of experience (SD)	4.6 (5.8)	4.3 (4.7)	3.9 (4.5)	3.1 (4.3)

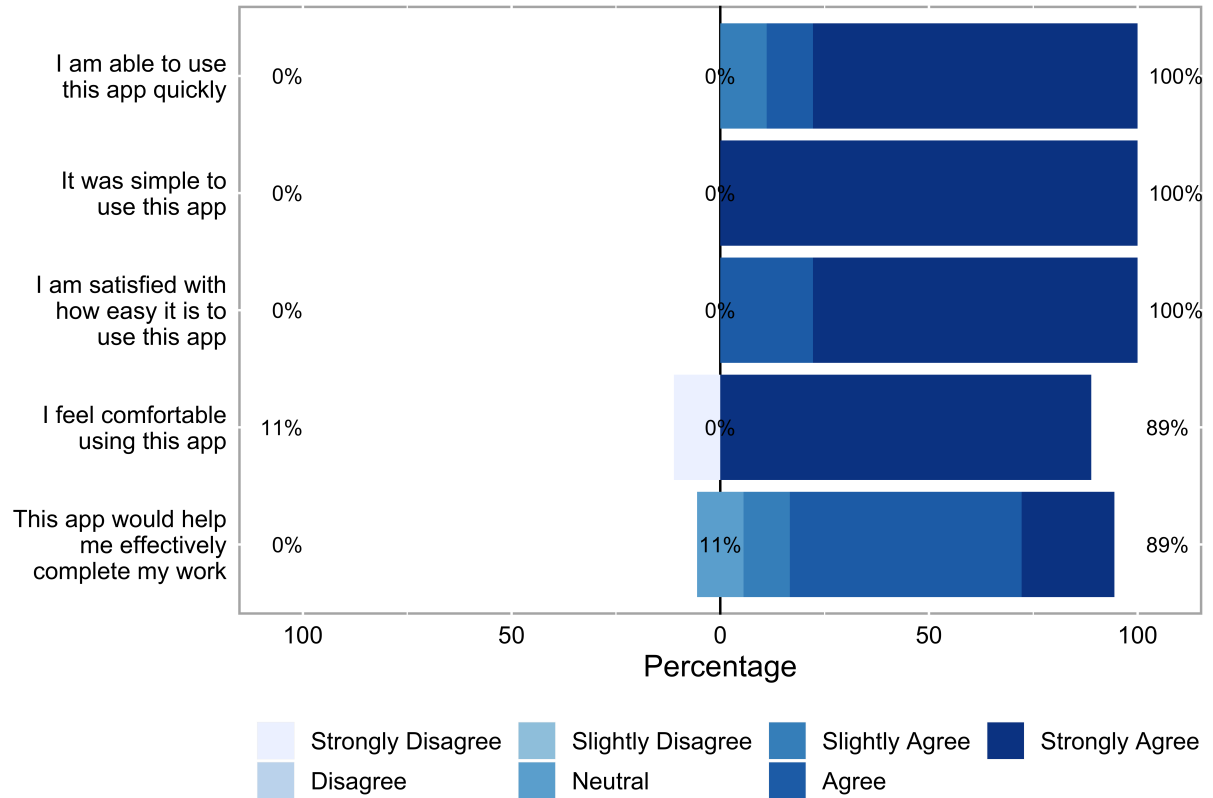
SD: Standard deviation.

Table 2. Results from usability testing of decision support tool.

Variable	Overall	Laptop	Tablet
Average Entry Time (SD), seconds			
Overall	147 (43)	145 (46)	149 (42)
First entry	158 (47)	151 (55)	167 (41)
Second entry	135 (38)	139 (42)	131 (40)
User Experience			
Average errors per entry (SD)	0.1 (0.3)	0.0 (0.0)	0.3 (0.5)
Average questions per entry (SD)	0.1 (0.3)	0.0 (0.0)	0.3 (0.5)

SD: Standard deviation.





1 **Figure 1. Participant responses to the use cases survey.**

2 Responses to a modified Likert survey rating the importance of various traumatic brain injury
3 prognostic modeling potential use cases. Percentages on the left represent participants who
4 responded with “Not Important;” percentages in the middle represent participants who responded
5 with “Important;” percentages on the right represent participants who responded with “Very
6 Important.” CT: Computed tomography.

- 1 **Figure 2. A screenshot of the web-based application used for usability testing.**
- 2 Numbers displayed represent values corresponding to one of the hypothetical cases.

1 **Figure 3. Participant responses to the modified Computer System Usability Questionnaire.**
2 Responses to a Likert survey rating agreement with statements regarding the usability of the
3 application. Percentages on the left represent participants who responded with “Strongly
4 Disagree,” “Disagree,” or “Slightly Disagree;” percentages in the middle represent participants
5 who responded with “Neutral;” percentages on the right represent participants who responded
6 with “Slightly Agree,” “Agree,” or “Strongly Agree.”

Abbreviations List

CSUQ: Computer System Usability Questionnaire

CT: computed tomography

HIV: human immunodeficiency virus

ICU: intensive care unit

LMICs: low- and middle-income countries

mERA: Mobile Health Evidence Reporting and Assessment

mHealth: mobile applications in health care

MNRH: Mulago National Referral Hospital

MRRH: Mbarara Regional Referral Hospital

SSA: Sub-Saharan Africa

TBI: traumatic brain injury

WHO: World Health Organization

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Credit Author Statement

Mr. Elahi

Conceptualization
Methodology
Software
Formal analysis
Investigation
Resources
Writing – Original Draft
Writing – Review & Editing
Visualization
Supervision
Funding acquisition

Ms. Spears

Formal analysis
Writing – Original Draft
Writing – Review & Editing
Visualization
Project administration

Ms. Williams

Investigation
Methodology
Writing – Review & Editing
Project administration

Dr. Dunn

Writing – Review & Editing

Ms. Najjuma

Conceptualization
Methodology
Investigation
Writing – Review & Editing
Supervision

Dr. Staton

Writing – Review & Editing
Project administration
Methodology
Conceptualization

Dr. Vissoci

Conceptualization

Methodology
Formal analysis
Writing – Original Draft
Writing – Review & Editing
Supervision

Dr. Fuller

Conceptualization
Methodology
Formal analysis
Investigation
Writing – Review & Editing
Supervision

Dr. Kitya

Conceptualization
Methodology
Investigation
Writing – Review & Editing
Supervision

Dr. Haglund

Conceptualization
Methodology
Writing – Review & Editing
Supervision