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Bridging evidence-to-care gaps with mHealth: Designing a symptom checker for parents accessing knowledge translation resources on acute children's illnesses in a smartphone application

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ABSTRACT

Background: Smartphone applications offer a novel platform for delivering health information to parents. This study created and evaluated an app-based symptom checker that recommends educational tools to parents based on their child's symptoms.
Methods: Symptoms extracted from 23 knowledge translation (KT) tools for 10 children's illnesses comprised a set of plain-language symptoms. The symptom checker works by producing confusion matrices evaluating a child's reported symptoms against possible illnesses, comparing precision scores to examine how well each illness matched reported symptoms, and ordering possible illnesses by performance score. Performance was evaluated by extracting symptoms from 8 clinical vignettes, and examining correct first-try matches.
Results: We created a final list of 54 plain-language symptoms. Visualizations of the symptom set creation process and logic mapping are presented, as well as images of the working symptom checker. The symptom checker matched 100% (8/8) of tested clinical vignettes to the appropriate illness resource.
Discussion: Symptom checkers are a potentially useful tool to integrate into apps that parents use for their children's health. The design of these systems has the potential to change parents' relationship with technology, affecting both their adoption and acceptance of symptom checkers. Our design choices contribute to addressing current barriers to the adoption of symptom checkers, reducing functional, critical, and interactive literacy requirements for parents.

1. Background

All children suffer from common illnesses, and can expect to be sick up to ten times a year, or by another measure up to once a school month [1]. The majority of acute children's illnesses are treated at home, [2], and do not require parents to take their child to an emergency department (ED) [3]. Among the ED visits that do occur, 30% are unnecessary in Canadian children under 18, treatable instead at a family physician's office or at home [4]. Parents with low health literacy (i.e. their ability to learn, process, and use health information) tend to overestimate illness severity and seek care early to get answers about the illness, rather than seeking reassurance from a healthcare professional [5]. Improving parents' health literacy is associated with decreased ED use and improved child health outcomes [6,7]. However, 30% of Canadian parents, and between one-third to one-half of American parents visiting an ED in 2019 had low health literacy [5,6,8].

Sources of health information for parents commonly include family members, healthcare professionals, and the internet [2]. In a survey of US mothers, the internet was a preferred source of health information, with 76% using it, followed by 44% seeing health providers, and 35% turning to family and friends [9]. However, these sources of information have been insufficient for addressing parent health literacy. Barriers include parents being uncomfortable asking family members for help regarding their child's health [10], and obtaining information from healthcare professionals via phone services (e.g. 811 in many Canadian provinces, NHS Direct in the UK) is limited by staff availability and clinic hours. In addition, parents find interacting with phone services frustrating due to the perceived irrelevance and repetitiveness of questions [2]. The internet is arguably the largest resource for child health information, and a representative EU survey of more than 26,000 individuals showed that 61% of all internet searches were carried out for others, and of these, 90% for family members [11]. However, barriers to its use include functional literacy (e.g. making symptom spelling errors), critical literacy (e.g. following inaccurate health information), and interactive literacy (e.g. not being able to use the information) [12].

Abbreviations: AI, Artificial Intelligence; ED, Emergency Department; BMI, Body Mass Index; KT, Knowledge Translation; RCT, Randomized Controlled Trial.

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Software applications (referred to as “apps”) are computer programs designed for smartphones and tablets. Apps help address important issues to Canadian healthcare, such as primary care access and unnecessary medical visits [13]. Apps offer a platform for mHealth (mobile Health) solutions that provide a novel way of delivering health content to parents. Apps in North America are primarily found on the Google Play Store and Apple App Store, although other stores such as the Microsoft Store are available. More than 96% of Americans [14], and 87% of Canadians [15] own a cell phone, while smartphones are owned by 85% [16], and 84.4% [17], respectively. The ubiquity of this technology contributes to the potential utility it holds for widespread dissemination of health content. Apps have a history of being a popular tool with parents, regardless of their level of health literacy [18]. However, there is debate about whether health apps for parents impact child health outcomes. There is a proliferation of apps that now cover a range of acute and chronic childhood illnesses, but reviews have shown variable outcomes evaluating app impact. A systematic review of digital health interventions for acute childhood illnesses did not support impact, based on urgent care utilization [19]. Similarly, a systematic review of randomized controlled trials (RCTs) for eHealth apps for parents showed no effect on their child’s Body-Mass Index (BMI) [20]. However, a later study supported the efficacy of parent-targeted digital tools for promoting health when using a broader definition of outcome measures (including caloric intake, attitudes, knowledge, and self-efficacy) [21], while a systematic scoping review found support for dyadic (caregiver/child) eHealth interventions [22]. However, study quality frequently prevented strong conclusions from being drawn [19,23-26].

We have co-developed with Canadian parents a smartphone app that houses knowledge translation (KT) tools centered on ten common childhood illnesses. Co-developed tools are important to the user experience, as they ensure relevant information and features are selected during development. Here, feedback from parents suggested that a symptom checker would help connect them to the appropriate resource (KT tool). Conceptually, symptom checkers are an example of a recommender system: an algorithm that allows decision makers to access others’ experiences [27]. Recommender systems used in health apps are often symptom checkers, such as those used in Ada, Babylon, or WebMD [28]. These symptom checkers can be used to connect parents’ needs to health information, but often present symptoms in confusing vocabulary or organization, and may have low accuracy [29,30]; these barriers prevent parents being connected to relevant information. Our app’s symptom checker aims to bridge this evidence-to-care gap in three ways: improving how symptoms are presented to parents, the logic used to connect them to the relevant resources, and the quality of actionable information provided at the endpoint. Here, we aimed to have parents select symptoms from a short checklist written in lay language in order to describe their child’s illness, and connect those symptoms to a KT tool.

The symptom checker uses the checklist to filter the KT tools recommended by the app, using a logic system evaluated for efficacy on validated pediatric clinical vignettes. The KT tools (found at echokt.ca/tools) integrate evidence-based research/information with relatable stories based on parents’ lived experience. The tools are co-developed with parents, healthcare professionals, and researchers, and include a description of common symptoms for each condition as well as information on when to seek medical and emergency care. The tools are delivered as videos, eBooks, audiobooks, and infographics [31-40]. If parents need to take action, the app provides a map with nearby hospitals, listed by driving time. We envision this app being used by parents to quickly reach relevant information to inform care decisions for their child. To our knowledge, this is the first app made for Canadian parents to help manage their children’s acute illnesses [41]; the co-development process of the app is reported elsewhere [42].

The aim of this paper is to describe our approach to creating one aspect of the app – the symptom checker, and present results from an evaluation of our symptom checker using validated clinical vignettes.

2. Methods

2.1. KT tools for children’s illnesses

The resources our symptom checker recommends as content include a set of KT tools representing 10 children’s illnesses: 8 acute children’s illnesses, as well as asthma and chronic pain [31-40]. Table S1 in the Appendix summarizes the set of illnesses these tools cover, and the types of KT tool available for each illness at the time of symptom checker creation: 10 videos, 5 infographics, 7 eBooks, and 1 audiobook.

2.2. Symptom set creation and refinement

Two researchers (UM and JB) compiled a set of illness symptoms mentioned in these KT tools, extracting from each tool the symptoms of the illness it covered, before constructing a matrix, mapping tools to symptoms. Then, we combined duplicate symptoms to shorten and simplify this mapping. For example, the symptoms, “Extreme tiredness,” “Sleepy,” “Very sleepy and difficult to wake,” were renamed as “extremely tired,” “sleepy/very tired,” and “very sleepy and difficult to wake up,” before being consolidated to one symptom, “sleepy/very tired.”. Two researchers (HB and JB) examined the list of symptoms for plain-language symptom equivalents, drawing from the National Center for Health Marketing’s plain-language thesaurus for medical communications [43], and the Center for Disease Control’s Everyday Words for Public Health Communication [44], where available (e.g. “wheezing” is more plainly described as, “trouble breathing”). Symptoms that were vague or described a constellation of symptoms were removed (e.g. “allergic reaction” was removed as it is not a single symptom). We (HB and JB) then discussed potentially equivalent symptoms and reached a consensus on which symptoms should be consolidated (e.g. “difficulty feeding or eating,” “refusing to eat, drink, or nap,” and “not hungry,” were consolidated under “refusing to eat, drink, or nap”). Finally, one researcher (JB) consolidated the symptoms present in each KT tool for each illness, reviewed any differences between tools covering the same illness, and addressed these by adding symptoms found in at least one tool for that illness to the final list of symptoms.

We then reviewed all tools, focusing on symptoms requiring an emergency response from parents (e.g. calling 911 or visiting an ED). These symptoms were then examined for symptoms to remove or consolidate, remaining symptoms mapped to illness and body part, and the final list integrated into the symptom to illness mapping. These results were visualized using a process chart called a Sankey diagram that maps inputs and outputs to visualize flow within a system [45].

2.3. Symptom to body part mapping and visualization

We labeled the mapping of plain-language symptoms by affected body part, consistent with the approach of symptom checkers from Johns Hopkins All Children’s Hospital [46], and the Healthwise symptom checker used by organizations such as MyHealth Alberta [47], and the University of Michigan [48]. In addition, we created a category of emergency symptoms for each illness, consistent with the “Emergency” section in each KT tool. We then used a Sankey diagram to visualize our recommender system’s logic map from body part to symptom, and symptom to illness. Tables S2 and S3 in the Appendix give details of these mappings.

2.4. Symptom checker implementation

The symptom to body part mapping, and symptom to illness mapping, were used to create the logic for our recommender system. The symptom to body part mapping was integrated into the symptom selector avatar, to connect body parts that parents selected on the avatar, to related symptoms. The symptom to illness mapping was used to match the child’s symptom profile to the list of available tools, comparing the number of symptoms matched to each tool’s symptom profile. We designed this symptom checker with minimal information complexity in mind, for parents with moderate technical proficiency.

2.5. Symptom checker performance and evaluation

We then determined how to best match a child's symptom profile to the correct illness resource. We began by extracting symptom profiles from previously developed clinical vignettes of illness that had a diagnosis related to one of our illness resources [29,49]. Table 1 presents the clinical vignettes and extracted symptoms used. Because only five pediatric profiles were available (ages 0-18), we examined the list again for vignettes with a diagnosis matching our illness resources, that did not include symptoms exclusive to older patients, and included these after making a note of which profiles were not specifically developed for pediatric patients. This use of vignette profiles as equivalent pediatric profiles allowed for the inclusion of asthma and a second fever vignette in the performance evaluation.

Our recommender system takes as input one of these extracted symptom profiles, compares each symptom to the list of expected symptoms for an illness profile, and generates a symptom-wise confusion matrix of how well the illness profile (actual symptoms) was predicted by the vignette symptom profile (predicted symptoms). The four outputs of the symptom comparison confusion matrix (TP: true positives, TN: true negatives, FP: false positives, and FN: false negatives) are counts of the number of symptoms that were present in actual and predicted symptoms (TP), not present (TN), or mismatched (FP & FN). Once the first confusion matrix is generated, the process repeats by comparing the same clinical vignette to each other illness profile, and generating a confusion matrix. Therefore, one clinical vignette will be compared to each of our 10 illness profiles, and generate 10 confusion matrices. Then, each of these matrices is used to generate 20 performance metrics (Table 2):

Then, we compare the performance of each illness profile at predicting the clinical vignette's symptoms by comparing the performance metrics.

Table 2
Performance metrics used for symptom checker evaluation.

Metric
Sensitivity/recall (TPR)
Specificity (TNR)
Precision (PPV)
Negative predictive value (NPV)
Miss rate (FNR)
Fall-out rate (FPR)
False discovery rate (FDR)
False omission rate (FOR)
Positive likelihood ratio (LR+)
Negative likelihood ratio (LR-)
Prevalence threshold (PT)
Jaccard (TS/CSI)
Accuracy
Balanced accuracy (BA)
F1 score
Matthews (MCC/phi coefficient)
Fowlkes-Mallows index
Informedness (BM)
Markedness (deltaP)
Diagnostic Odds Ratio (DOR)
True positives (TP)
True negatives (TN)
False positives (FP)
False negatives (FN)

For each performance metric tested, the top-performing illness profile (as measured by maxima or minima, as appropriate) was selected as the illness from which resources would be recommended to parents. We then examined how many illness profiles were correctly matched to the symptom profile's illness label, for each performance metric. The performance metrics that matched the most vignettes to the correct illness resources on the first try were identified as candidate metrics to implement in our current recommender system. Fig. 1 summarizes this process in a simplified comparison of two candidate illness profiles' performance for one clinical vignette.

Table 1
Clinical vignettes and extracted symptoms.

Source Paper	Diagnosis	Patient age	Simplified vignette	Extracted symptoms
Semigran 2015	Acute otitis media	18 months	18 mo f, 1 week rhinorrhea, cough, congestion, irritable, lack of appetite, fever, in daycare	1. agitated, crying, fussy, or irritable 2. coughing 3. fever 4. refusing to eat, drink, or nap 5. runny nose
Semigran 2015	Bee sting without anaphylaxis	9 years	9 y/o m, bee sting, swollen and tender upper lip; no tongue swelling, drooling, stridor, rash, or other complaints	1. swelling of eyes, face, or lips
Semigran 2015	Rocky mountain spotted fever	8 years	8 y/o m, Fever, chills, joint pain, headache, rash wrists/ankles	1. cold hands or feet 2. fever 3. rashes or hives
Semigran 2015	Salmonella	14 years	14 y/o m, nausea, vomiting, non-bloody diarrhea, mild abdominal cramps (T = 100.1), mild abdominal tenderness, diarrhea after attending a picnic and eating undercooked chicken,	1. diarrhea 2. fever 3. nausea 4. stomach pain 5. throwing up/vomiting
Semigran 2015	Constipation	5 months	5 mo m, difficulty/delay in passing hard stools, strains for hours, may miss a day, screams when passes stool and occasional spots of blood, weaned from breastmilk to cows' milk, now feeding normally	1. difficult or painful poops
Semigran 2015	Asthma	27 years	27 y/o f, Hx of asthma, mild shortness of breath, wheezing, 3 days cough, symptoms not responsive to inhalers, recent cold	1. breathing problems 2. coughing 3. difficulty sleeping
Semigran 2015	UTI	26 years	26 y/o f, painful urination, urgent need to urinate, more frequent urination for 2 days, sexually active; no fever, chills, nausea, vomiting, back pain, vaginal discharge, vaginal pruritus	1. painful or burning pee 2. peeing often
Hill 2020	Ross River Fever	19 years	19 y/o m. 2 weeks of fever with chills, muscle aches and joint pain with swelling and stiffness at joints. Rash. Fatigue. Swollen glands. Headache behind the eyes. Chief complaint = fever	1. cold hands or feet 2. fever 3. rashes or hives 4. sleepy/very tired

* Abbreviations: mo: month-old; y/o: year-old; Hx: history; m: male; f: female; T: temperature.

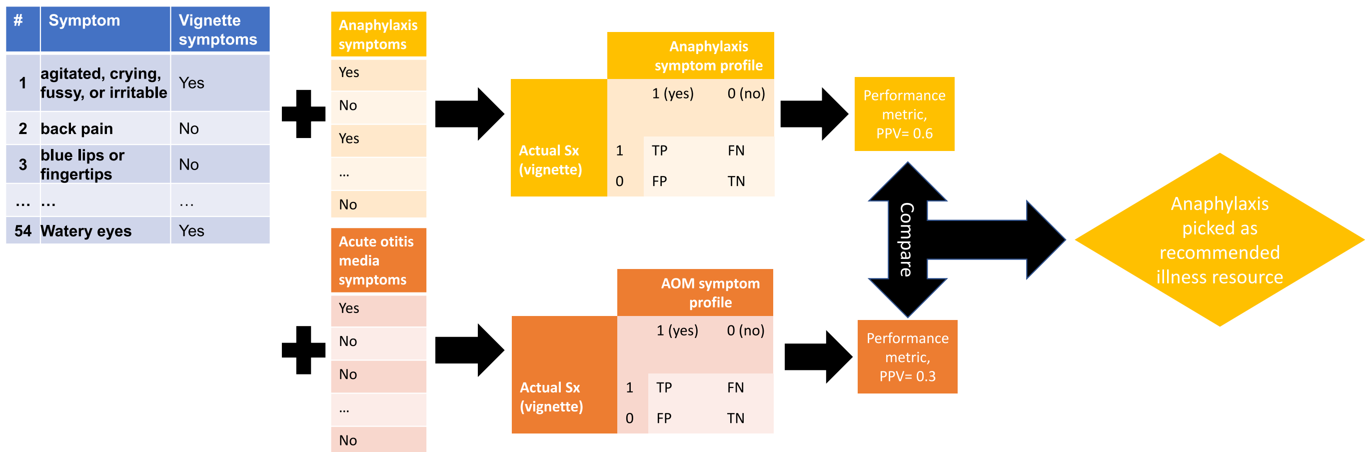

Fig. 1. Symptom checker process for resource selection. The vignette symptoms and set of symptoms for each illness are compared, a confusion matrix generated and used to produce a performance metric, and the top-performing illness's corresponding resources recommended. A correct match is made when the recommended resource matches the vignette diagnosis.

3. Results

3.1. Symptom set creation and refinement

We extracted 83 symptoms from 23 tools covering 10 children's illnesses. After removing 3 symptoms and consolidating 44 symptoms down to 18 symptoms, a final list of 54 symptoms remained. Fig. 2 is a visualization of this process.

3.2. Mapping symptoms to body parts

The symptom checkers we used as models to develop our symptom checker's design commonly indexed symptoms by six body regions (commonly divided into: head, chest, abdomen, genitals or urinary, leg or foot, arm or hand) [46-48,50-52]. We consolidated arms or hand and leg or foot under "Arms and legs", due to the low number of arm- and leg- specific symptoms overall, and added an additional category, "Emergency symptoms." Table S3 in the Appendix provides details of this process, while Table 3 below shows the mapping counts for symptoms per body part (note: one symptom can be assigned to multiple regions, e.g. coughing is assigned to both "head/neck" and "chest/upper back").

3.3. Recommender system logic visualization

Fig. 3 shows the Sankey diagram visualizing how body parts, symptoms, and illnesses are connected.

Table 4 shows a count of symptoms mapped to each illness.

3.4. Symptom mapping integration and recommender system

The body part to symptoms mapping, and symptom to illness mapping, were integrated into our app for parents as the basis for the logic behind our symptom checker's recommender system. This symptom checker allows parents to select a body part from a cartoon avatar of a child, and symptoms related to that body part are highlighted in a static list below it. Then, the system compares the symptoms selected to the symptom labels for each illness, and recommends relevant resources specific to one illness to parents. Fig. 4 shows the current implementation of our symptom checker. A flat, alphabetized list is used to display symptoms, to reduce information complexity for parents.

3.5. Symptom checker performance evaluation

Table 5 presents the results of performance metric-based resource selection. Of the eight clinical vignettes matched to resources, five performance metrics were found to predict the correct illness resource to recommend, on the first try, 100% (8/8) of the time:

1. Precision (PPV; proportion of correct positive guesses)
2. Positive likelihood ratio (LR+, likelihood that child has this condition)
3. Markedness (deltaP, trustworthiness of predicted negatives)
4. False discovery rate (FDR, among all predicted symptoms the % that are actually negative)
5. Prevalence threshold (PT, the ratio of positive predictive value over prevalence)

4. Discussion and conclusion

In this study, we created and evaluated a plain-language symptom checker for 10 common children's illnesses based on 23 KT tools co-developed with parents. We found that the top-performing of five of the performance metrics used for illness recommendation were consistently the correct corresponding children's illness across clinical vignettes. We will contextualize these results in symptom checker literature, discuss how this feature was integrated into our app to increase impact, and present a decision framework for designing recommender systems.

4.1. Discussion

4.1.1. Symptom checker evaluation

Symptom checkers for parents include options such as the Johns Hopkins All Children's Hospital [46], Mayo Clinic [50], University of Michigan [48], MyHealth Alberta [47], and apps such as Ada Health [51], and Telus MyHealth [52]. While resources such as Ada Health were found to provide high quality content in our previous work [41], a study examining 12 publicly available symptom checkers found their overall accuracy was poor, at 51%, and that 51% of the tools examined made recommendations that overused health system resources [53]. That these tools made overutilization recommendations is troubling, because this misinformation trains parents to overutilize health system resources. These results were corroborated by a published review of symptom checkers, with 10 included studies showing that these systems exhibit low diagnostic accuracy (19%-36%) [54].

Previous work suggests that a demonstrable evidence base and explainable decision algorithm are knowledge gaps preventing users from making informed decisions when using symptom checkers, introducing

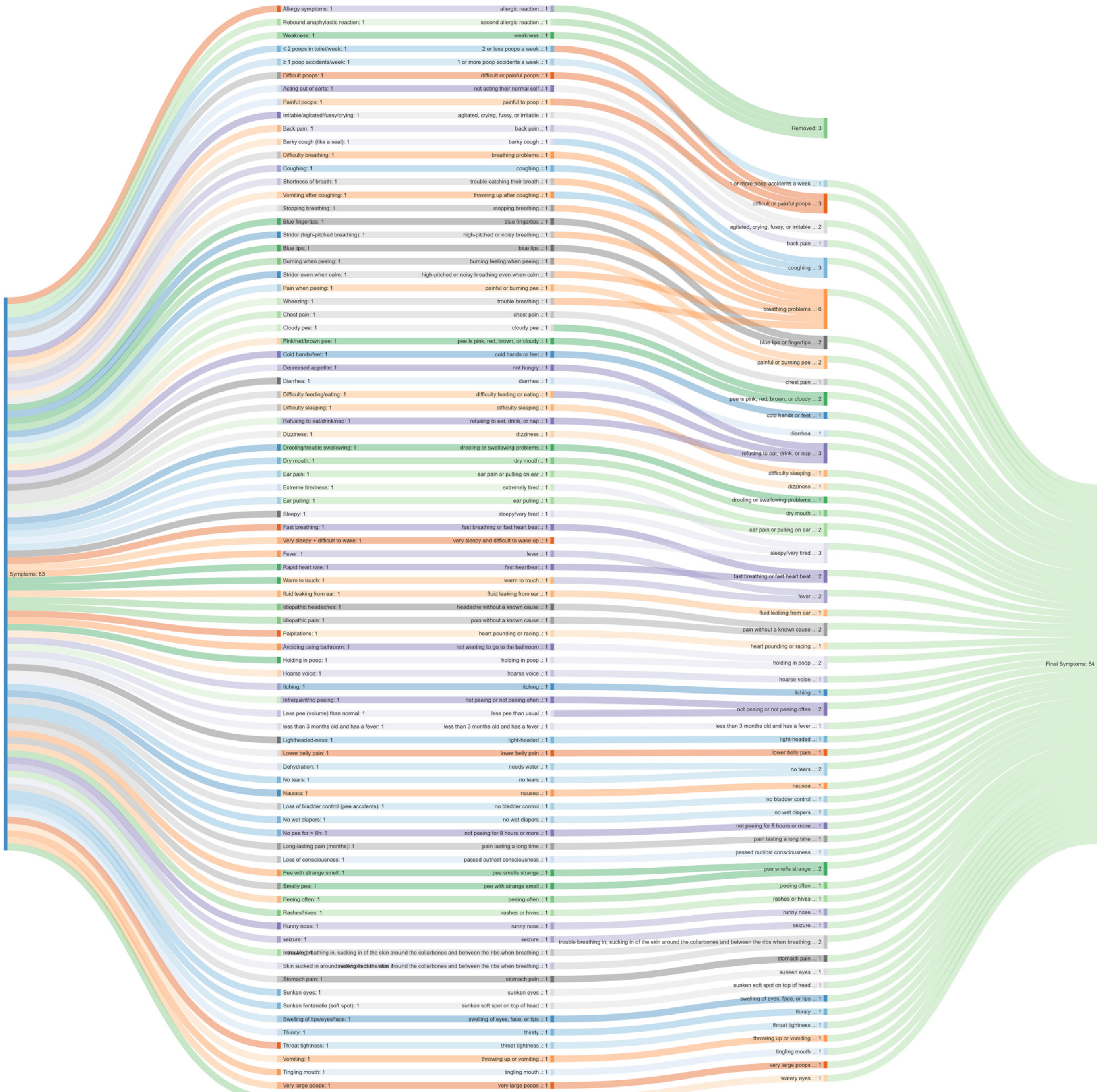

Fig. 2. Sankey diagram showing symptom renaming, removal, and consolidation from 83 down to 54 symptoms.

unnecessary risk to an already inaccurate process [28]. Here, we have explained the decision algorithm used to connect users with KT tools. Results from our symptom checker evaluation are preliminary and can only be compared to other symptom checkers' performances on a subset of all possible illnesses. However, our symptom checker's performance supports further investigation of integrating co-developed illness resources into symptom checkers.

Table 3
Symptom counts per body part.

Region	Symptom count
Head/neck	33
Chest/upper back	14
Stomach/lower back	14
Pelvis	22
Arms/legs	7
Emergency symptoms	23
Total	113

4.1.2. Approach to symptom mapping

Our approach to symptom mapping balanced brevity of information against specificity of symptoms when creating and consolidating our final symptom map, to prevent parents either being overwhelmed with a long list of options, or underwhelmed by missing symptoms that should be selected. We accomplished this by consolidating our list of symptoms by 35%, and only removing 3.6% of symptoms while maintaining all included symptom to illness mappings during consolidation. This improves on the language used by symptom checkers for describing symptoms, which can

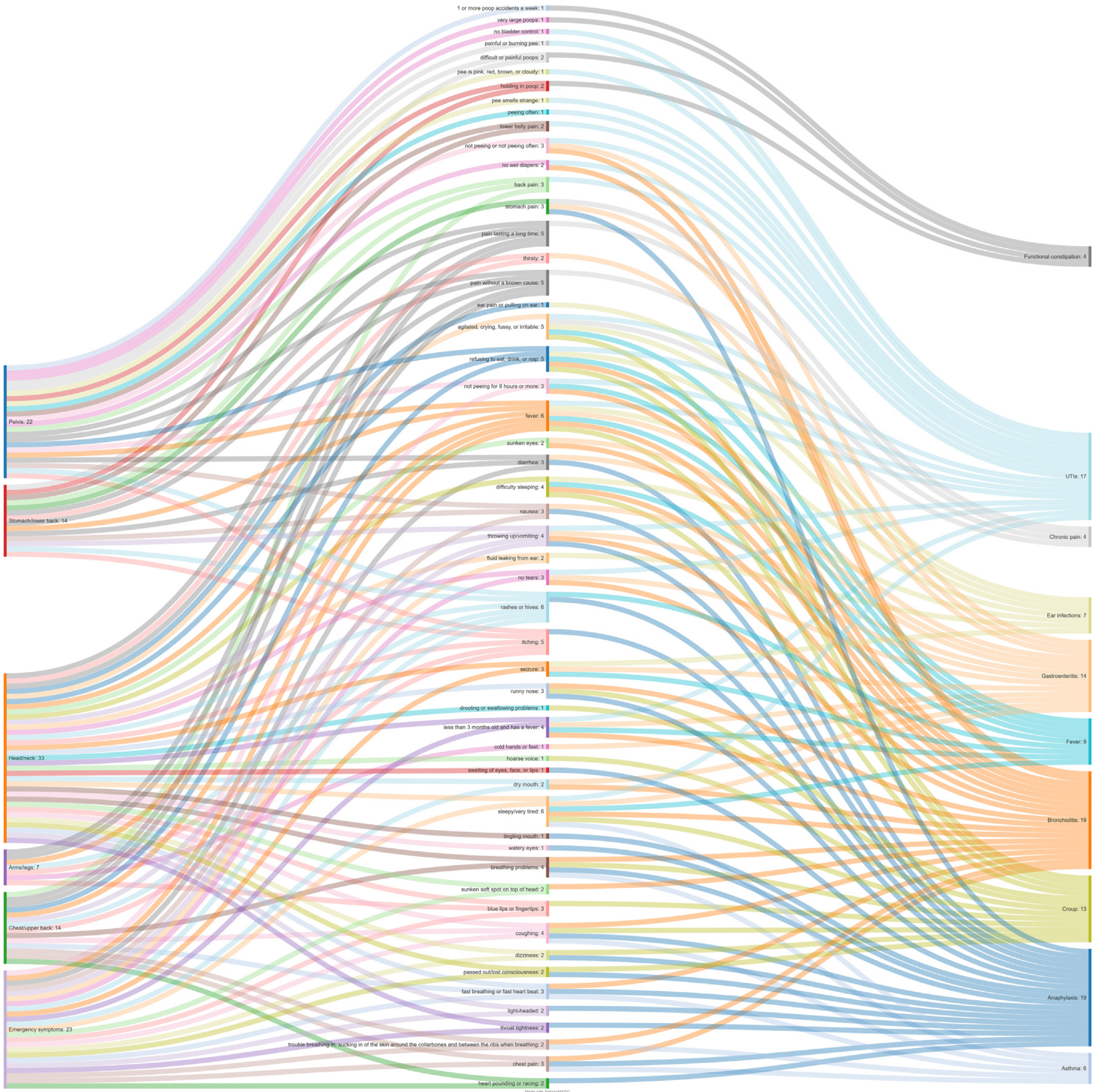

Fig. 3. Sankey visualization mapping together body part, symptom, and illness.

Table 4
Count of symptoms mapped per illness (symptoms can overlap between illnesses).

Illness	Symptom count
Anaphylaxis	19
Asthma	6
Bronchiolitis	19
Chronic pain	4
Croup	13
Ear infection	7
Fever	9
Functional constipation	4
Gastroenteritis	14
Urinary Tract Infections (UTIs)	17
Total	112

be inconsistent (e.g. mixing symptoms, illnesses, and symptom categories in the list of symptoms), vague (e.g. "Breast problems- Child" is a vague symptom description) [46], or lengthy (e.g. the AI-based Ada Health app asks users many questions, each on a different screen) [51].

When visualizing symptom to body part mapping in the symptom checker, we implemented a static, alphabetic list of all symptoms. When a body part is selected, symptoms relevant to that body part are highlighted for consideration. The ability for our symptom checker to highlight symptoms relevant to one body part without hiding other symptoms from view does not reduce the amount of information visible to parents based on their selection of a body part. It is important to note that all symptoms are always displayed, to allow parents to build familiarity with the symptom list. This approach filters relevant content by symptom profile, then connects parents to a narrative that embeds and contextualizes actionable

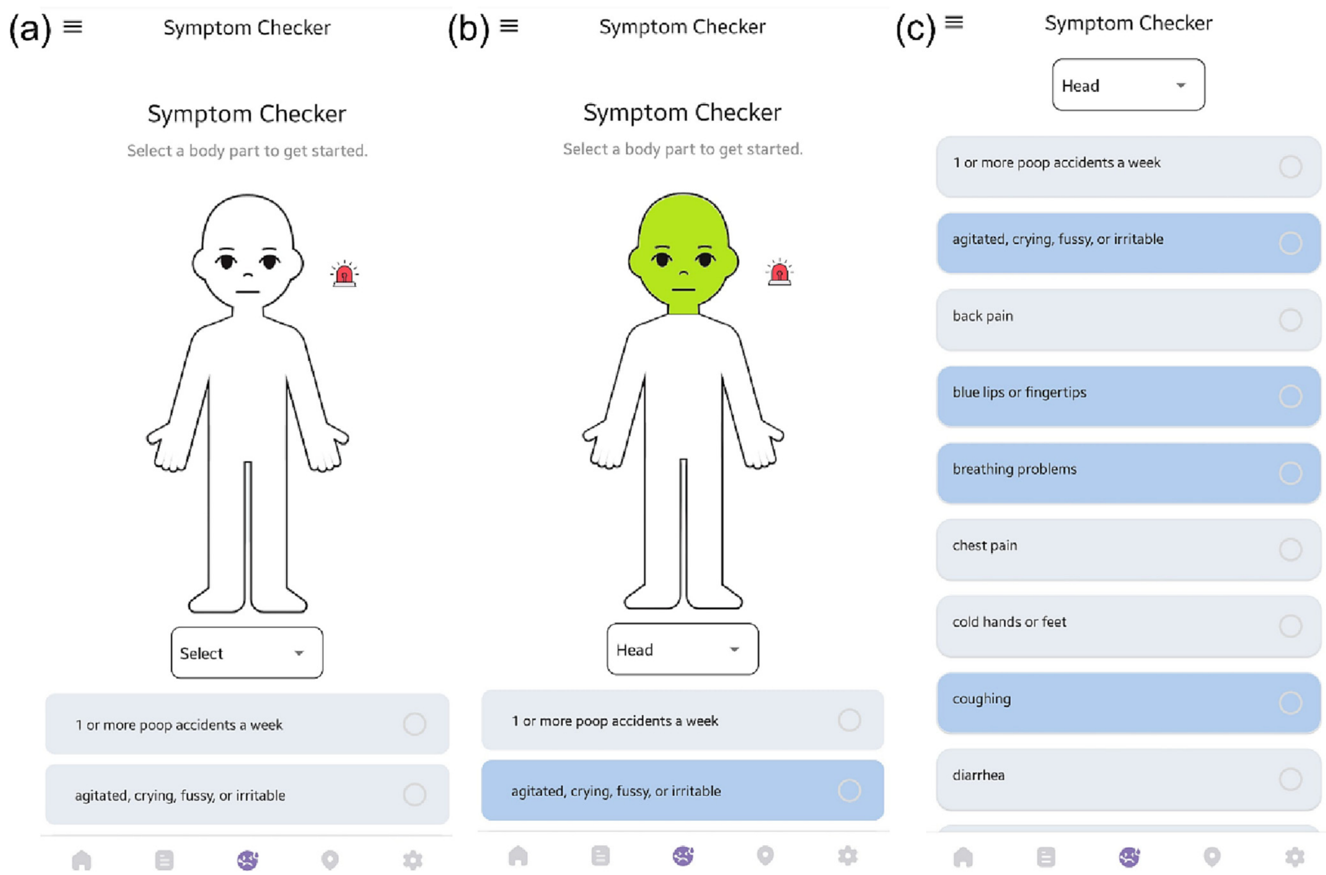

Fig. 4. Symptom checker (a) when beginning use- note the red "emergency symptoms" button, (b) when a body part is selected (in green), relevant symptoms are also highlighted (in blue), and (c) the symptom list is static, while highlighting is dynamic, based on body part selection.

information. Similarly, the app Baby and Child First Aid by British Red Cross connects parents to first-aid knowledge using plain-language injury headings, but focuses on immediate needs for first aid that a parent can administer, concrete written next-steps, tools (e.g. a burn cooling timer), and short, approximately 30 second videos [55]. Embedded links in each injury page lead to additional, more detailed content. By contrast, to get to content using the hierarchical menu structure in apps such as HANDi Paediatric, more general menu items are presented first (e.g. "My child has a high temperature"), which lead to more specific options (e.g. "Common less serious infections"), and finally to content (e.g. "Ear ache") [56]. Both approaches are designed to efficiently move parents from recognition of a problem to actionable information, and this design is consistent with the principle of information findability in Morville's User Experience Honeycomb, which emphasizes "navigable web sites and locatable objects" [57].

Table 5
Comparison of performance metrics for correctly matching resources to vignettes on the first try.

Performance metric	Correct matches (/8)
Precision (PPV)	8
False discovery rate (FDR)	8
Positive likelihood ratio (LR+)	8
Prevalence threshold (PT)	8
Markedness (deltaP)	8
Jaccard (TS/CSI)	7
F1	7
TP	6
FN	6
Sensitivity/recall (TPR)	6
Negative predictive value (NPV)	6
Miss rate (FNR)	6
False omission rate (FOR)	6
Negative likelihood ratio (LR-)	6
Balanced accuracy (BA)	6
Matthews (MCC/phi coefficient)	6
Fowlkes-Mallows index	6
Informedness (BM)	6
Accuracy	4
TN	2
FP	2
Specificity (TNR)	2
Fall-out rate (FPR)	2
DOR	Not usable; dividing by 0

4.1.3. Relationship between app design and impact

AI approaches to symptom checker adoption for self-triage revealed a latent (i.e. hidden) feature that differentiated future symptom checker adoption: whether subjects' attitudes towards AI and symptom checkers binned them as either technology acceptors, or technology rejectors. Acceptors were 5.6 times more likely to use symptom checkers in the future [58]. A key message from this result is the need to offer approachable, trustable technology that resonates with a broad range of parents' information seeking habits. An examination of information seeking in acute childhood illness that used physicians' consultation rates as outcome measures suggested using tools that indicate where resources were located, offered professionally validated content, and delivered the resources in multiple formats to parents [2]. This study also suggests that barriers to these needs led to increased parent anxiety. Parents' emotional state is important in health decisions made for their child, and the anxiety and despair produced when no good treatment options are present, make these decisions more difficult and can lead to a perceived loss of control [59]. Change to health locus of control has been shown to affect health decisions, and it has been suggested that this occurs through modulation of parent attitudes toward the health behaviour [60], for example in vaccine decisions.

4.1.4. Decision framework

Table 6 is a framework for designing health-related recommender systems for parents based on our experiences developing this symptom checker. It is meant to serve as a starting point for systematically developing symptom checkers, since to our knowledge, there are no frameworks currently available. Each goal is composed of guiding items, and contextualized using our recommender system's development to embed these questions in a real-world process. We deliberately framed these goals in computing science terms, where possible, to facilitate discussions with developers involved in the technical side of recommender system development.

4.1.5. Limitations

One limitation of this work was the limited set of childhood illnesses with accompanying co-developed KT tools. While a more comprehensive inventory of childhood resources from which to pull symptoms to inform the recommender system would be ideal, our goal of connecting parents to our set of KT tools by extracting and structuring co-developed information did not require a complete set of information to function. The second limitation we encountered is that the recommender system is not currently set up to handle cases where no good matching resources are found (e.g. if a child has a bleeding nose or unexplained bruising), and the system does not yet have the logic in place to return "no results" or recommend third-party resources. Finally, the low availability of pediatric vignettes targeting conditions covered by the symptom checker limited the extent and thoroughness of our evaluation.

4.1.5.1. Future work. The symptom checker's promising preliminary evaluation should be viewed in the context that the symptom checker is not currently capable of handling illnesses that are not covered by its resource database. In addition, diagnoses are grouped under headings (e.g. Fever covers multiple types/causes of fevers). Improving this symptom checker to enable it to be assessed comparably to previous work could be handled in a number of ways, e.g. by adding more illness coverage, or by adding a null condition (where no resource is recommended for illnesses not covered). Future work should involve an expanded evaluation with more expert-validated vignettes. Large language model algorithms, such as ChatGPT, may be useful for this purpose.

We plan to carry out a second, acceptability-focused evaluation of the symptom checker with parents to gather their feedback on our approach to a symptom checker. Questions will be based on the User Experience Honeycomb, a highly-used framework that examines seven different facets of a user's experience [57]. In future work, consistent with previous recommendations for improving health communication around pediatric fever [61], we may integrate the terms parents use when discussing each illness into the search algorithm, and evaluate the system for its effects on parent decision-making (e.g. as measured by health system resource use).

4.2. Innovation

Our symptom checker's performance is based on disease symptom profiles found in co-developed knowledge tools, the first symptom checker to do so. It was consistently able to correctly match symptom profile to illness on the first try, unlike current symptom checker offerings. The use of co-developed knowledge as the basis for the symptom checker's logic shows promise as an effective means of connecting how parents discuss their child's illness, to the appropriate educational tool. In addition, embedding co-developed tools in a co-developed app ensure that the user experience has been considered and incorporated into each stage of supporting parents' information needs?.

In our approach to symptom presentation, we use a top-level static list as a menu so that objects are always locatable in the expected place, without having to remember how to navigate to them. This approach is expected to reduce user navigation errors and improve speed in a visual interface (as opposed to an audio- or mixed-interface), consistent with previous findings of how less technically proficient users navigate menus [62,63], supporting this feature's usability by a broad group of parents.

4.3. Conclusion

Symptom checkers are a potentially useful tool to integrate into apps that parents use for their children's health. The design of these systems has the potential to change parents' relationship with technology, affecting both their adoption and acceptance of symptom checkers. Our recommender system was designed for a broad audience of parents with multiple ways of accessing KT tools, to accommodate different use styles. The layout

Table 6
Framework for designing recommender systems for parents.

Step	Goal	Guiding items	Example from our system
1	Outline audience characteristics related to system adoption or rejection	• Audience reading level • Health literacy level • Technical proficiency • Attitude towards technology • Other access requirements	We prioritized making the app accessible to parents with low health literacy and moderate technical proficiency (e.g. they could download and use a smartphone app), who were enthusiastic about adopting the app. Other requirements were parents having limited internet access when using the app, due to a rural/remote location.
2	List system inputs and outputs	• List of features • List of content • Linking logic • Expected output	The 83 symptoms from our tools are features, the 10 tools are content. One or more symptoms is selected, which is compared to symptom labels on each tool.
3	Describe how information is input into the system	• Navigating to the system • Interactions with system • Menu appearance • Menu structure • Menu functions	Parents click "symptom checker" on the app homepage. The app displays a flat list of symptoms shown under a child's avatar with selectable body parts. Selecting a body part highlights related symptoms. Multiple symptoms can be selected by tapping a checkbox next to each.
4	Describe the system's logic and target outputs	• Symptom profile equivalence • Equivalent rank handling • Error responses • Output display • Output limitations	We checked that all tools had different symptom profiles. Symptom profile is checked against each tool's symptom labels, and the number of matching symptoms compared between tools. Output is a list of tools in descending order of symptom matches. Tools with no matched symptoms are not displayed.
5	Evaluate the system's performance	• Metric of interest • Real-world/validated data availability • Evaluation inputs • Measurement target • Performance target	Test accuracy of system at recommending resources. Inputs were symptom profiles from eight clinical vignettes of childhood illnesses. Correct responses were defined as the system's first tool recommendation and vignette being the same illness.

of the symptoms is a flat list, designed to decrease user errors and increase speed of use. Finally, we took a balanced approach to symptom naming and complexity, reducing our list length while maintaining mappings when consolidating symptoms. These design choices contribute to addressing current barriers to the adoption of symptom checkers, reducing functional, critical, and interactive literacy requirements for parents [12].

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Declaration of Competing Interest

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

James Benoit reports a relationship with Oracle for Research that includes: funding grants. All authors work with PEC Innovation Board member Sarah Elliott (JB, LH, SDS).

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Appendix A. Supplementary data

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References

[1] Gellner C. Should I be worried if my child gets sick too often? [cited 2022 14 Apr]; Available from. https://healthcare.utah.edu/the-scope/shows.php?shows=0_5nzgsffm#:~:text=Babies%2C%20toddlers%2C%20and%20preschoolers%20get,to%20three%20times%20a%20year; 2021.
[2] Neill SJ, et al. Parent's information seeking in acute childhood illness: what helps and what hinders decision making? Health Expect. 2015;18(6):3044–56.
[3] Houston AM, Pickering AJ. 'Do I don't I call the doctor': a qualitative study of parental perceptions of calling the GP out-of-hours. Health Expect. 2000;3(4):234–42.
[4] Canadian Institute for Health Information. Sources of Potentially Avoidable Emergency Department Visits; 2014..
[5] May M, et al. Why Parents Seek Care for Acute Illness in the Clinic or the ED: The Role of Health Literacy. Acad Pediatr. 2018;18(3):289–96.
[6] Morrison AK, et al. The relationship between parent health literacy and pediatric emergency department utilization: a systematic review. Acad Pediatr. 2013;13(5):421–9.
[7] DeWalt DA, Hink A. Health literacy and child health outcomes: a systematic review of the literature. Pediatrics. 2009;124(Suppl. 3):S265–74.
[8] CIHI. In: CIHI, editor. NACRS emergency department visits and length of stay by province/territory; 2019 Ottawa, ON.
[9] Manganello JA, et al. Pediatric injury information seeking for mothers with young children: The role of health literacy and ehealth literacy. J Commun Healthc. 2016;9(3):223–31.
[10] Jones CH, et al. Information needs of parents for acute childhood illness: determining 'what, how, where and when'of safety netting using a qualitative exploration with parents and clinicians. BMJ Open. 2014.;4(1).
[11] Reifegerste D, Bachl M, Baumann E. Surrogate health information seeking in Europe: Influence of source type and social network variables. Int J Med Inform. 2017;103:7–14.
[12] Jain AV, Bickham D. Adolescent health literacy and the Internet: challenges and opportunities. Curr Opin Pediatr. 2014.;26(4).
[13] Aboueid S, et al. The use of artificially intelligent Self-Diagnosing digital platforms by the general public: Scoping review. JMIR Med Inform. 2019;7(2):e13445.
[14] Pew Research C. Demographics of Mobile Device Ownership and Adoption in the United States; 2019..
[15] Government of Canada, C.R.-t., & Telecommunications Commission (CRTC). Communications Monitoring Report 2018 - Communications Services in Canadian Households: Subscriptions and Expenditures 2012-2016; 2018..
[16] Pew Research Center. Mobile Technology and Home Broadband 2021. Available from. https://www.pewresearch.org/internet/2021/06/03/mobile-technology-and-home-broadband-2021/; 2021.
[17] Statistics Canada. Table 22-10-0143-01 Smartphone personal use and selected smartphone habits by gender and age group; 2021..
[18] Meyers N, et al. Parents' use of technologies for health management: a health literacy perspective. Acad Pediatr. 2020;20(1):23–30.
[19] Donovan E, et al. Digital interventions for parents of acutely ill children and their treatment-seeking behaviour: a systematic review. Br J Gen Pract. 2020;70(692):e172–8.
[20] Hammersley ML, Jones RA, Okely AD. Parent-focused childhood and adolescent overweight and obesity ehealth interventions: a systematic review and meta-analysis. J Med Internet Res. 2016;18(7):e203.
[21] Zarnowiecki D, et al. A systematic evaluation of digital nutrition promotion websites and apps for supporting parents to influence children's nutrition. Int J Behav Nutr Phys Act. 2020;17(1):17.
[22] Shaffer KM, et al. Dyadic psychosocial ehealth interventions: systematic scoping review. J Med Internet Res. 2020;22(3):e15509.
[23] Dol J, et al. Impact of mobile health interventions during the perinatal period on maternal psychosocial outcomes: a systematic review. JBI Evid Synth. 2020;18(1):30–55.
[24] Huang KY, et al. Use of technology to promote child behavioral health in the context of pediatric care: a scoping review and applications to low- and middle-income countries. Front Psychiatry. 2019;10:806.
[25] Jansen R, Reid M. Communication technology use by caregivers of adolescents with mental health issues: systematic review. JMIR Mhealth Uhealth. 2020;8(8):e13179.
[26] Slater H, et al. End user and implementer experiences of mhealth technologies for noncommunicable chronic disease management in young adults: systematic review. J Med Internet Res. 2017;19(12):e406.
[27] Resnick P, Varian HR. Recommender systems. Commun ACM. 1997;40(3):56–8.
[28] Tsai C-H, et al. Exploring and promoting diagnostic transparency and explainability in online symptom checkers. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems; 2021.
[29] Semigran HL, et al. Evaluation of symptom checkers for self diagnosis and triage: audit study. bmj. 2015:351.
[30] Semigran HL, et al. Comparison of physician and computer diagnostic accuracy. JAMA Intern Med. 2016;176(12):1860–1.
[31] Campbell A, et al. Parents' information needs and preferences related to bronchiolitis: a qualitative study. CMAJ Open. 2019;7(4):E640–5.
[32] Thompson AP, et al. Parents' experiences and information needs related to childhood fever: A systematic review. Patient Educ Couns. 2020;103(4):750–63.
[33] Archibald MM, Scott SD. Learning from usability testing of an arts-based knowledge translation tool for parents of a child with asthma. Nurs Open. 2019;6(4):1615–25.
[34] Meherali S, et al. Understanding parents' experiences and information needs on pediatric acute otitis media: a qualitative study. J Patient Exp. 2019;6(1):53–61.
[35] Reid K, et al. Development and usability evaluation of an art and narrative-based knowledge translation tool for parents with a child with pediatric chronic pain: multi-method study. J Med Internet Res. 2017;19(12):e412.
[36] Scott SD, et al. Pediatric information seeking behaviour, information needs, and information preferences of health care professionals in general emergency departments: results from the Translating Emergency Knowledge for Kids (TREKK) Needs Assessment. Cjem. 2018;20(1):89–99.
[37] Scott SD, et al. Protocol for a systematic review of the use of narrative storytelling and visual-arts-based approaches as knowledge translation tools in healthcare. Syst Rev. 2013;2:19.
[38] Scott SD, et al. Stories – a novel approach to transfer complex health information to parents: A qualitative study. Arts & Health. 2012;4(2):162–73.
[39] Hartling L, et al. Storytelling as a communication tool for health consumers: development of an intervention for parents of children with croup. Stories to communicate health information. BMC Pediatr. 2010;10:64.
[40] Hartling L, et al. A randomized controlled trial of storytelling as a communication tool. PLoS One. 2013;8(10):e77800.
[41] Benoit J, et al. Characteristics of acute childhood illness apps for parents: environmental scan. J Med Internet Res. 2021;23(10):e29441.
[42] Benoit JRAH, Scott SD. Co-Design of an mHealth app for parents managing acute childhood illnesses: An exploratory, mixed methods study In review. ; 2022..
[43] National Center for Health Marketing. Plain language thesaurus for health communications; 2007..
[44] Centers for Disease Control and Prevention. Everyday Words for Public Health Communication; 2016..
[45] Bogart S. SankeyMATIC; 2022 Nov 16; 2021. Available from. https://sankeymatic.com/
[46] Johns Hopkins All Children's Hospital. Symptom Checker. Available from. https://www.hopkinsallchildrens.org/Patients-Families/Patient-Family-Resources/Symptom-Checker; 2022.
[47] Alberta MyHealth. Check your symptoms; 2022 Feb 11; 2022. Available from. https://myhealth.alberta.ca/Health/pages/symptom-checker.aspx.

[48] University of Michigan Health. Symptom checker. Available from. https://www.uofmhealth.org/health-library/sx; 2022.
[49] Hill MG, Sim M, Mills B. The quality of diagnosis and triage advice provided by free online symptom checkers and apps in Australia. Med J Aust. 2020;212(11):514–9.
[50] Mayo Clinic. Symptom Checker. Available from. https://www.mayoclinic.org/symptom-checker/select-symptom/itt-20009075; 2022.
[51] Ada Health. Health. Powered by Ada; 2022 Feb 17; 2022. Available from. https://ada.com/.
[52] Telus Inc. TELUS Health MyCare. Available from. https://www.telus.com/en/personal-health/my-care; 2022.
[53] Ceney A, et al. Accuracy of online symptom checkers and the potential impact on service utilisation. PLoS One. 2021;16(7):e0254088.
[54] Wallace W, Chan C, Chidambaram S, Hanna L, Iqbal FM, Acharya A, Normahani P, Ashrafian H, Markar SR, Sounderajah V, Darzi A. The diagnostic and triage accuracy of digital and online symptom checker tools: a systematic review. NPJ Digit Med. 2022;5(1):118. https://doi.org/10.1038/s41746-022-00667-w. PMID: 35977992; PMCID: PMC9385087.
[55] British Red Cross. Baby and child first aid. [cited 2021 12 Sept]; Available from. https://play.google.com/store/apps/details?id=com.cube.rca.bcfa&hl=en_CA&gl=US; 2021.
[56] Devon N. HANDi Paediatric app: advice for common childhood conditions. Available from. https://devonccg.nhs.uk/health-services/children-and-young-people/handi-app.
[57] Morville P. User Experience Design. [cited 2021 14 Sept]; Available from. https://semanticstudios.com/user_experience_design/; 2004.
[58] Aboueid S, et al. Latent classes associated with the intention to use a symptom checker for self-triage. PLoS One. 2021;16(11):e0259547.
[59] Jackson C, Cheater FM, Reid I. A systematic review of decision support needs of parents making child health decisions. Health Expect. 2008;11(3):232–51.
[60] Amit Aharon A, et al. A path analysis model suggesting the association between health locus of control and compliance with childhood vaccinations. Human Vacc Immunotherapeut. 2018;14(7):1618–25.
[61] Niforatos JD, Pescatore R. Search Engine Queries for Pediatric Fever During "Cold and Flu" Season. Cureus. 2019;11(4):e4464.
[62] Padhi DR, et al. Hierarchy or List? Comparing menu navigation by emergent users. Proceedings of the 9th Indian Conference on Human Computer Interaction. Bangalore, India: Association for Computing Machinery; 2018. p. 29–34.
[63] Padhi DR, et al. Hierarchy or List? Comparing menu navigation by emergent users. Proceedings of the 9th Indian Conference on Human Computer Interaction; 2018.