Mobile search made easier: An ability-based mobile search prototype for people with dyslexia

Jason Reed
Centre for HCI Design, City, University of London
jasonreed3@gmail.com

Andrew Macfarlane
Centre for HCI Design, City, University of London
a.macfarlane-1@city.ac.uk

Stephann Makri
Centre for HCI Design, City, University of London
stephann@city.ac.uk

ABSTRACT

Although 1 person in 14 has dyslexia, most search interfaces are designed based on a 'one-size-fits-all' approach, creating inequity for neurodiverse searchers. This is also the case for mobile search, which accounts for most Google searches. While existing research has found search typically presents greater challenges for people with dyslexia, no prior work has examined how best to support them when searching on mobile devices. Rather than focus on addressing their search difficulties, we adopted an *ability*-based design approach. This involved designing a prototype, based on modifications to Google's mobile SERPs, aimed at enhancing their abilities – identified through interviews and observations with mobile searchers with dyslexia. A user evaluation found several of the modifications were useful; they supported searchers with dyslexia in making relevance judgements and boosted their resilience and self-efficacy. Based on these findings, we propose four broad design principles for mobile search interface design. This research provides valuable insight into how to better support mobile searchers with dyslexia that can inform IIR research and design. It also demonstrates the potential of ability-based design approaches in supporting neurodiverse searchers.

CCS CONCEPTS

• **Information systems** → Information retrieval; Users and interactive retrieval; Search interfaces; • **Human-centered computing** → Interaction design; Interaction design process and methods; User centered design; Accessibility; Empirical studies in accessibility.

KEYWORDS

Mobile search, Dyslexia, Ability-based design, Inclusive design, Simulated work task situations

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1 INTRODUCTION

Dyslexia is a neurological difference which typically impacts reading and writing fluency, and may also present challenges relating to short-term memory, concentration, and rapid naming [3]. Dyslexia has an estimated prevalence of 7% of the global population [27], although estimates vary depending on definition and sampling approach [33]. Despite its prevalence, most existing search interfaces are designed based on principles of universal design – a 'one-size-fits-all' approach that can create inequity for neurodiverse searchers by focusing on supporting the needs and abilities of the population at large, rather than supporting neurodiversity [21]. For example, search interfaces often place heavy reliance on successfully interpreting large chunks of text when deciding which search results might be useful, which may be more difficult for a person with dyslexia. As search has become ubiquitous in our daily lives, finding information using mainstream search engines such as Google is essential for accomplishing key work, study and everyday life information tasks, such as writing reports or identifying medical conditions.

While existing research has found search typically presents greater challenges for people with dyslexia [3, 11, 20, 26], no prior work has examined the impact of dyslexia on mobile search, nor how best to support searchers with dyslexia on mobile devices. This is surprising, given that searching on mobile devices has become firmly established as an important way of searching; as early as 2015, Google announced more mobile searches were being conducted than desktop searches [30]. It is also surprising since, in recent years, mobile Search Engine Result Page (SERP) design has become more complex, incorporating several types of layout and rich results [23]. On the one hand, this may require more sophisticated search skills, which some people with dyslexia may find more difficult to develop [3, 11, 20]. On the other, these alternative layouts may provide design opportunities in the mobile context to present search results in ways that can benefit searchers with dyslexia, such as the future work recommendations by Morris et al. [25] and Kvikne and Berget [17].

The lack of prior focus on mobile search and dyslexia highlights an important research gap in understanding how well existing mobile search interfaces support people with dyslexia and using this understanding to improve support. This study takes the first important steps to filling this gap by asking '**how can we modify mobile search engine results pages (SERPs) to better align with the abilities of searchers with dyslexia?'** This question reflects an ability-based design approach [35] where, rather than focusing on addressing the difficulties people with dyslexia experience during mobile search, we focused on understanding and designing to enhance their *abilities*. As Wobbrock et al. put it, "by focusing *on users' abilities rather than disabilities*, designers can create interactive systems better matched to those abilities" [35]. This is a more ethical approach to design, as it does not inherently regard neurodiversity as a 'problem' to be compensated for, but rather an opportunity to leverage through design.

To examine how searchers with dyslexia interact with mobile search interfaces, we conducted interviews and observations of directed mobile web search tasks with 10 participants, framed by Borlund's IIR evaluation model [7]. Following an ability-based design approach, we fed the insights gained into their mobile search behavior into the design of a prototype mobile search interface - based on several modifications of Google's mobile SERPs - aimed at enhancing their abilities. These modifications included: providing prominent image-based rich results (e.g., interactive carousels displaying images and links to potentially relevant pages), showing expanded results to provide a stronger indication on the SERP of which pages within a site might be relevant to the user's search query, and incorporating filters (customized to the user's information task domain) to support easier result assessment and triage. A user evaluation of the prototype found the above modifications were useful; they supported searchers with dyslexia in making relevance judgements and boosted their resilience and self-efficacy. Based on these findings, we propose four broad design principles for mobile search interface design.

The contributions of this paper are: 1) an enriched understanding of the mobile search behavior and, in particular, the search-related abilities of people with dyslexia, 2) a mobile search prototype designed based on an understanding of this behavior and, in particular, these abilities and 3) a set of design principles for mobile search interfaces that better support people with dyslexia by enhancing their abilities, grounded in data from a user evaluation of our mobile search prototype.

The rest of this paper is structured as follows: first, we discuss related work, focusing on summarizing the impacts of dyslexia on IIR and introducing the ability-based design and IIR evaluation approaches we draw on. Next, we present our research methodology, followed by the method and findings of the two key phases of our research; Phase 1: User interviews and observations and Phase 2: Ability-based design and evaluation. We then discuss the implications of our findings and propose four broad suggestions for mobile search interface design, before concluding and suggesting possible avenues for future work.

2 RELATED WORK

In this section, we first review prior research on the impacts of dyslexia on interactive information retrieval (IIR), as well as research on user interaction with search engines in mobile device contexts. We then provide context around the ability-based design ethos our study was grounded in by discussing relevant literature. Finally, we overview and justify the use of Borlund's IIR evaluation model, which we use to frame the search tasks in our study.

2.1 Impacts of Dyslexia on IIR

Information seeking is a cognitively taxing process that often involves reading vast amounts of information, evaluating its relevance and often applying or synthetizing it [24]. A person's ability to identify relevant information within a SERP and the web pages or documents linked from it can strongly influence their search success [5]. Prior studies comparing information seeking across people with and without dyslexia (using desktop search interfaces) have demonstrated marked differences in their interaction behavior [4, 10, 11, 20]. For example, MacFarlane et al. [20] demonstrated that phonological working memory difficulties can negatively impact searches of people with dyslexia; they had more difficulty identifying non-relevant search results than people without dyslexia. Building on this work, Cole et al. [10] found that searchers with dyslexia also had difficulties with other aspects of search, including formulating queries and refining searches. This was in contrast with searchers without dyslexia. Participants with dyslexia also reported low self-efficacy in evaluating web-based information sources in general.

Other comparative studies have also identified key differences in interaction behavior among people with and without dyslexia. For example, Palani et al. [26] observed simulated work tasks (SWTs) with 27 participants (14 with dyslexia), analyzing a mix of eye-tracking, search log and self-report data. They also presented participants with pre-populated fixed-query SERPs to compare information extraction behavior across groups. Difficulties experienced by those with dyslexia spanned the entire information search process. These included: difficulty spelling search terms during query formulation, increased backtracking from retrieved pages to the SERP when examining and triaging results, and increased time spent reviewing documents before extracting information (due to fixating on content rather than skimming).

While most studies of how people with dyslexia search for information, including the above, have focused on identifying the difficulties they experience, there has also been some (albeit limited) focus on the approaches they use to overcome those difficulties. For example, Berget and Sandnes [4] observed 40 participants (20 with dyslexia) completing 10 information search tasks on Google and found that existing query-building support (autocomplete, autosuggest and autocorrect/'did you mean?') helped to overcome some of the difficulties they experienced during the query formulation stage of search. However, they also highlighted that better support was needed post-query submission, at the search result examination, triage and information extraction stages of search.

Other research has revealed some of the SERP and information design-related needs and preferences of searchers with dyslexia, thereby making some headway on how to better support people with dyslexia in desktop search interfaces. Kvikne and Berget [17] interviewed eight people with dyslexia about their experiences of web-based information searching, with a goal of developing more accessible search UIs. Suggestions from the study's participants around potential improvements to SERP design were wide-ranging, and included: emphasizing knowledge graph content, including more visual white space, and ranking results based on the retrieved page's reading level. In interviews and surveys with searchers with dyslexia, Morris et al. [25] noted a content design preference of 'large fonts,' 'images' and 'lists over paragraphs.' This study also found an association between a retrieved document's readability and its reported relevance to the search task. Fourney et al. [13] further analyzed the data from Morris et al.'s study, identifying design features in retrieved documents (including image size and sentence to non-sentence text ratio) that aided cognitive accessibility for searchers with dyslexia during information extraction. Both studies generated design recommendations for search environments, aimed at breaking down some of the 'barriers' they identified.

Li et al. [18] conducted a study of web users' reading speeds and preferences to investigate the potential benefits of Firefox's Reader View feature, which transforms HTML pages into *"a structured, well-formatted one for better readability."* Notably, participants with dyslexia (42 of 391) *"perceived the readability of Reader View pages as equally high as non-dyslexic participants perceived the readability of standard websites"*, suggesting that Reader View's design changes may assist those with dyslexia during the information extraction stage of search.

In summary, while there is now a growing body of research examining the impacts of dyslexia on Web search and how to support IIR for people with dyslexia, no prior work has examined dyslexia's impact on *mobile* search and what potential modifications to mobile search interfaces might best support them. This is the research gap our study fills.

2.2 Mobile Search Interaction

Previous studies have used observation and evaluation methods to gain a richer understanding of search experiences specific to the mobile device context, in contrast to desktop use cases. Jones et al. [14] identified the shortcomings of formative search engine interfaces on small screen devices. Later work has considered how mobile search interfaces elicit specific user behaviors during search result triage [37] and discussed how search task relevance can differ for users in the mobile context [1].

2.3 Ability-Based Design

This research takes an ability-based design approach to feeding our findings from interviews and observations of the mobile search behavior of people with dyslexia into a prototype mobile search interface. Ability-based design is a framework for improved accessibility, predominantly characterized by adjusting the designer's stance towards a central focus *"on what people can do, rather than on what they cannot do"* [35]. Designers are encouraged to take active responsibility for a system's usability through designing interfaces that *"provide the best possible match to users' abilities"* [36]. This approach aims to actively reduce the 'disability gap' which emerges during interactions between individuals and the environment, as described by the Nordic relational model of disability [19]. Its design principle of 'adaptability' inspires self-adaptive or user-adaptable interfaces that bolster users' personal dignity during interaction. Ability-based design goes beyond the more homogenous, 'one-size-fits-all' approach of universal design, encouraging the implementation of adaptable interfaces that are designed to address the user needs of specific subgroups.

Although they did not specifically cite an ability-based design approach, existing investigations of IIR [11, 17, 25] identified common workarounds employed by users with dyslexia during search tasks that can be considered ability-based. These included using visual media (images and videos) to support understanding [17, 25] and utilizing external cognition (e.g. by opening multiple tabs or making notes) whilst reviewing retrieved information [11]. This highlights an opportunity for applying the principles of ability-based design to search interfaces, including mobile search interfaces. Rather than reflect a 'deficit' model of disability, with a focus on what people with dyslexia find difficult when searching, our research aims to leverage users' abilities by modifying Google's existing mobile search interface, specifically its SERP, based on ability-based behaviors we identify. No prior studies of dyslexia and search have claimed to have followed an ability-based design approach. However, we believe this is a more positive and ethical approach to designing for diverse user needs.

2.4 IIR Evaluation

The prescribed search tasks used in our observations were framed by Borlund's IIR evaluation model [7]. This model was proposed as a framework for assessing the effectiveness of IIR systems. Information search tasks are provided to participants as 'simulated work task situations' (SWTs), through a *"short textual description that presents a realistic information requiring situation that motivates the test participant to search the IR system"* [8]. This realistic motivation seeks to counterbalance the otherwise non-realistic essence of prescribed search tasks. In Borlund's model, the perceived relevance of retrieved documents, as judged by the participant, is considered as a key success metric for comparability between systems. Borlund's model has been successfully used to empirically assess the effectiveness of IIR systems in numerous studies, as documented in a meta-review [8]. To elicit as naturalistic behavior as possible from simulated search tasks, Borlund recommends SWTs should be relatable, topically interesting, and with enough imaginative context for participants to be able to attempt them confidently. As Borlund's model is useful for comparing systems, it was particularly suitable for our study – which sought to understand the perceived differences between the regular Google mobile search interface and a modified interface (our prototype) among mobile searchers with dyslexia. Indeed, Berget and MacFarlane [2] highlight that the cognitive, user-centered nature of the model is effective in identifying and addressing issues specific to searchers with dyslexia, supporting our decision to use it.

3 METHODOLOGY

In this section, we present the methodology used in our study. First, we explain and justify our decisions around participant recruitment, then discuss ethical considerations. Then, in the next section, we break down our study into two key phases: Phase 1 – User interviews and observations and Phase 2 – Ability-based design and evaluation. We discuss the method and results for each phase separately.

3.1 Participant Recruitment

We recruited participants through the researcher's personal and professional contacts and through snowball sampling. We recruited 10 participants, who all completed the Phase 1 interviews. Table 1 summarizes the participants' involvement in the study's next stages. Of those 10, six agreed to take part in the Phase 1 observation in the required timeframe. Seven of the 10 participants then took part in the Phase 2 evaluation. Of those seven, three had been both

Table 1: Summary of participation during the study

Phase	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*	*P10*
1: Interview	X	X	X	X	X	X	X	X	X	X
1: Observation	X		X	X	X	X	X			
2: Evaluation	X	X		X	X			X	X	X

interviewed and observed in Phase 1; the remaining four had only been interviewed.

All participants met the following criteria: they were aged over 18, used search engines on mobile devices at least once a day and had a formal diagnosis of dyslexia. This sample size was appropriate to provide sufficient information power [22] to address our research aim. Information power is an alternative qualitative data sampling principle to data saturation, where the more insight provided relevant to the aim, the lower the sample size needed. While much of our sample size was dictated by the practicalities of recruiting searchers with dyslexia (which can be particularly difficult [2]), the vast majority of the data we collected was highly-relevant to our aim and made this relatively small sample size sufficient. Participation was voluntary but was incentivized by a donation of £10 to a charity of each participants' choice. Interviews and observations took place remotely to provide convenience for participants, who were based throughout the UK. They were conducted only with people with dyslexia as our aim was not to compare their mobile search behavior with people without dyslexia, but to ascertain their search-related *abilities* to ground our ability-based prototype design in. As formal diagnoses represent sensitive information [2], we did not ask to see proof of their dyslexia diagnosis. Instead, we asked them to complete a brief screening process to assess for signs consistent with dyslexia, using questions from the Adult Dyslexia Checklist [31] and a digit span test [5]. All displayed multiple signs of dyslexia. During screening, participants also confirmed they were comfortable participating, including discussing their experiences around the impacts of dyslexia on mobile search.

3.2 Ethical Considerations

Ethical approval was granted by the Department of Computer Science Research Ethics Committee. All participants provided informed consent and all data was anonymized before analysis. All study materials were designed to be accessible. Following best practice guidance [2], questions were written in clear and plain language and search tasks were designed not to require excessive intellectual effort that may cause anxiety or distress, and to avoid lowering participants' self-esteem.

4 PHASE 1: USER INTERVIEWS & OBSERVATIONS

We now discuss our data collection and analysis approaches for the user interview and observation parts of our study. We then discuss how the findings from these interviews and objectives fed into the design of our prototype mobile search interface.

4.1 Data Collection Approach

We conducted semi-structured interviews (average 11 mins. each) with 10 participants, to understand their mobile search needs, challenges and, most importantly for our ability-based design approach, their abilities. We used an interview approach inspired by the Critical Incident Technique [6], where we asked them to talk through in detail *"a recent example where you used Google on your mobile to search for information. What were you searching for, and how did you find the information that you needed?"* We did not ask them to try to recreate their search, as we recognized memory is fallible and results may have changed since they undertook the search. To understand their self-efficacy, they rated their agreement on a 10-point Likert scale with the statement 'I am confident in using Google on my mobile phone to find the information that I need' (adapted from [10]) and to elaborate on their reasoning. They were also asked to discuss 'key differences...between searching on a phone and using a PC/Mac.'

Six of the 10 participants then also took part in an observed moderated search session that complemented the interviews, to build an understanding of their mobile search behaviors (particularly those grounded in ability) through the completion of tasks designed to mirror common mobile search scenarios [1]. They joined a video call on their own mobile device to encourage naturalistic behavior. The mobile Lookback platform was used to record audio and two video sources (of the participant in-situ, and the mobile browser with visual indication of on-screen interactions) throughout the session. The researcher read each simulated work task out verbally and participants were asked to use Google mobile search to complete it. Google mobile search was chosen given its high share of usage [32] and because all participants regularly used it. Tasks included a verificative task around a topical information need (verifying train or postal strike dates), intended as a simple search task to build participants' confidence, and three more complex everyday life decision-making tasks in the domains of travel, cooking, and shopping (Table 2). We used prescribed tasks to ensure observed information search behaviors were consistent, allowing comparison with the study's later evaluation stage. The decision-making tasks incorporated a template approach, where participants customized part of the task to reflect their own information needs. This aimed to encourage realistic task performance as per Borlund's [8] framework, and to balance the topic effect across participants.

Following a similar approach to Palani et al. [26], we invited participants to complete each task by submitting one or more self-defined queries, reviewing as many retrieved results pages as they liked, and stating their findings out loud. In line with previous observations of people with dyslexia [11], we did not instruct participants to think aloud, as this could impact their working memory and therefore affect their task performance. We asked questions

Table 2: Template Simulated Work Tasks (SWTs) provided to participants during Phase 1 observations

Task	***Domain***	***Template Simulated Work Task (SWT)***
T1	Strike dates	You need to plan a trip using the train later in [month], but you have heard about the ongoing train strikes across the UK. Use Google to find out when the next strikes are happening.
T2	Travel	You have booked a holiday to [a place in the UK or abroad] for next [season] and want to plan 3 fun and interesting things to do there. Use Google to find some options.
T3	Cooking	You have [friends/relatives] visiting your home for dinner next weekend, and you'd like to cook a [type of cuisine/diet] meal for them. Use Google to find suitable options that you haven't cooked before.
T4	Shopping	You'd like to buy a gift for [a friend/relative]'s birthday. They like [interests/type of item]. Use Google to find 2 or more suitable options.

immediately after each task, using visual prompts on their mobile device. They were asked to rate their prior domain knowledge for each task, helping to identify any prior-knowledge effects that may impact performance. Other questions, drawn from Morris et al. [25] focused on ascertaining participants' perceived relevance of the information found; they were asked to identify which retrieved pages were relevant to their task and were asked to rate their agreement on a 5-point Likert scale with statements such as 'I was able to find all of the information that I needed to accomplish the task'.

4.2 Data Analysis Approach

We conducted an inductive qualitative analysis, based on many of the principles of Thematic Analysis [9], to identify common and contrasting themes grounded in the interview and observation data. This was with the aim of distilling these into ability-based design objectives. We first transcribed and reviewed the interviews, iteratively grouping phrases that related specifically to mobile information search experiences into common codes. We focused on participants' accounts of their needs, challenges, and ways of overcoming these challenges. We then reviewed the audio-visual recordings of the observed search tasks over multiple passes. Participants' interactions with Google's mobile SERPs and retrieved web pages and documents were noted and timestamped using Excel, then annotated with any related utterances and visible reactions from the participants during the tasks, as well as explanatory and attitudinal responses from the post-task questions to enrich our understanding of their experiences. Codes were generated iteratively to encompass specific user actions and challenges, task outcomes and mostly importantly for our study, their ability-based behaviors and tactics. We also captured quantitative data, including number of: search queries submitted, web pages/documents opened, returns to SERP, and total time spent on SERP and retrieved pages. While this data was not used specifically to drive our prototype design, it provided a holistic understanding of task performance and therefore helped us better understand our participants' mobile search experiences. Due to the relatively small sample size, we did not attempt to make statistical comparisons across this quantitative data.

4.3 Findings and Design Implications

The vast majority of participants (nine out of ten) self-reported strong confidence in finding information they need when conducting mobile searches on Google. Participants explained how their frequent, habitual use of Google contributed towards this confidence. For example P4 stated "*I carry the phone around with me and... if I have a thought or ponder, I'll just search it.*" However despite high self-efficacy, five participants said they needed to be resilient when examining search result pages. They demonstrated this resilience in two ways: firstly, by looking over them multiple times. For example, P2 stated *"I know that the majority of the time I'm going to find an answer...even if it takes me a couple of times to look through it."* Secondly, they demonstrated resilience by staying patient and carrying on with the search task in spite of difficulty. P4 described this as *"persevering without self-criticism"*. Also despite high self-efficacy, participants did not always perceive their searches as successful. During the observed search tasks, participants only 'strongly agreed' that they were 'able to find all of the information that I needed to accomplish the task' for 50% of tasks and stated they thought they had found irrelevant information during 33% of tasks. This highlights an opportunity to improve the mobile search experience for people with dyslexia through design changes to SERPs. Four design objectives were developed based on the interview and observation findings. We used these to guide our modifications to Google's mobile SERPs aimed at better matching the abilities of searchers with dyslexia. Although firmly grounded in our findings, these objectives were also informed by relevant HCI literature to help elucidate the design space [28]:

DO1: Maximize information scent on SERPs to reduce users' need to satisfice: We observed Day's [12] 'adjusting behavior' category of resilience, which involves modifying behavior to overcome anticipated difficulty, among all participants. As well as visiting sites they were already familiar with (all participants), five participants actively interacted with image-based results that were prominently displayed in the ranked results list. In contrast, no participants interacted with text-based accordion results (scrolling past these elements in the SERPs), despite their high prevalence. Images presented within retrieved pages, such as interactive visual carousels to support browsing content categories (used by P1, P3, P4) also aided users' recognition, relevance judgement and wayfinding. This supports previous findings from studies of desktop search and dyslexia [17, 25, 26] and highlights a specific ability in using visual cues to discern information scent; images strongly supported mobile searchers with dyslexia in deciding *"whether to exert time and energy navigating through the information"* [29].

DO2: Support users' evolving information needs during exploratory search: P1, P3, P4, P6 and P7 all took exploratory approaches to the decision-making tasks, following up potential 'leads' and experiencing *"shifts in thinking"* [29], refining their information needs based on information found. For example, P4 started the travel task with the broad search query 'australia summer activities', but refined it to 'australia free summer activities' because the initial results were *"expensive things, so I would avoid doing them because the flights are expensive."* As participants demonstrated strong learning through searching, illustrated in more sophisticated search queries, this highlights a design exploration-related design opportunity.

DO3: Support users in assessing and triaging search results by providing additional user control: The interviews and observations emphasized that searchers with dyslexia often invested considerable reading time and cognitive effort in interpreting search results, to support result triage. P3 described the triage stage in the context of their daily mobile search use: *"I wouldn't say it's a challenge, just something you have to keep filtering through... I always manage to find something [relevant]"*. During the observations, participants spent an average of 61 secs. per decision-making task reviewing the SERP. Providing additional control over which results are presented and how could support them in navigating through them without feeling overwhelmed. This could potentially address some of the inequity produced by mainstream search engine algorithms as highlighted by Morris et al. [25], who states *"ranking features may not place relevant pages that best match the needs of searchers with dyslexia near the top of the SERP."*

DO4: Extract potentially relevant content from web pages and refer to it within the search results to reduce cognitive effort when assessing and triaging results: Mobile content, often within external websites rather than SERPs, was often problematic to interpret due to navigation, layout and usability-related issues. For example, four participants (P1, P3, P5 and P6) found the Tripadvisor mobile website difficult to navigate and therefore found it challenging to locate relevant content within it. Other barriers included length of retrieved pages and text-heavy content (P1, P4, P6) and slow loading times (P1, P3). From an ability perspective, participants demonstrated a willingness to invest considerable effort reading web page text to locate potentially relevant content and to persevere despite these barriers. Drawing on Kirsh [15], as designers we have the opportunity to *"reshape work spaces to alter the [cognitive] cost structure of the activity that takes place in those spaces."* While external mobile sites are outside our scope, we wanted to make content as accessible as possible on our SERPs.

Identifying participants' search-related abilities in Phase 1 and grounding our design objectives in an understanding of them paved the way for us to design a mobile search prototype that focused primarily on enhancing the abilities of mobile searchers with dyslexia. In the next section, we discuss the ability-based design and evaluation of the prototype.

5 PHASE 2: ABILITY-BASED DESIGN AND EVALUATION

This section begins by discussing our prototype design approach. This discussion includes a description and screenshots of the final prototype design. We then explain and justify the approach we used to evaluate our prototype with users who have dyslexia and how we analyzed the data from the user evaluation. Finally, we present the findings from our evaluation before summarizing our findings across both phases of our study.

5.1 Design Approach

The next phase involved an iterative interaction design process, driven by the ability-based design objectives from the previous section and the broad guiding question 'how can we support people with dyslexia with common mobile search tasks, by modifying Google's mobile SERPs to better align with their abilities?' We generated several ability-based features to incorporate in our prototype based on the design objectives, such as 'prioritize image-based rich results' and 'allow iterative filtering of results.' Although primarily ability-focused, our design features aimed to address the difficulties participants with dyslexia mentioned in their interviews and experienced in their observations in Phase 1 as an important byproduct. Indeed the ethos across both phases of our study was an 'ability-first' one, where we prioritized understanding and designing for the search-related abilities of people with dyslexia, without ignoring or downplaying the impact of the difficulties they experienced.

We made low-fidelity digital sketches of potential modifications to consider how each feature could best be designed. As the scope of our project was on improving the interaction design of SERPs, and back-end coding would be very time-consuming, we incorporated only those features that did not require code-based implementation. This means, for example, that we did not implement interactive features such as offering page previews from within the SERP.

Candidate features were validated against the qualitative analysis from Phase 1 to identify which design modifications to Google's mobile SERPs might be most impactful, based on their 'groundedness' to the interview and observation data, resulting in a final set of six design modifications (A-F in Table 3).

A responsive, interactive prototype was produced in Figma and Anima featuring SERPs for the verificative (strike dates) task and each decision-making search task domain (travel, cooking and shopping). The prototypes were designed based on searches submitted by participants during the observation, depicting results from queries they submitted. These results were manually incorporated into the prototypes, using results and metadata returned by the 'live' Google mobile SERPs for each query as a basis. To formatively evaluate the effectiveness of these prototype designs, we worked with three HCI experts with informed perspectives around dyslexia. The experts were asked to evaluate the designs against a set of nine heuristics and participate in a group discussion, to identify design refinements that could improve the prototypes' usability and better support users with dyslexia towards task completion. The final prototype designs incorporated all six design modifications shown in Table 3. Figures 1 and 2 illustrate the SERPs that participants interacted with during the observations in Phase 1 for the cooking

Table 3: Design modifications applied to prototype SERPs

ID	*Description of modification*	*Related design objective(s)*	*SERP(s) with this modification*
A	Prioritization of visual rich results	DO1	T2, T3, T4
B	More extensive use of images to summarize results and support relevance assessment	DO1	T2, T3, T4
C	Show expanded within-site results	DO1, DO2, DO4	T2, T3
D	Directly link and navigate to potentially relevant content on retrieved page	DO4	T2
E	Give more visual prominence to website source names	DO1	T1, T2, T3, T4
F	Allow iterative result filtering	DO2, DO3	T1, T3

and travel tasks, alongside the counterpart modified SERPs from the prototype.

5.2 Evaluation Approach

To evaluate the effectiveness of the prototype, seven participants each completed SWTs while interacting with the pre-populated SERPs and the mobile web pages linked from them. Again, following a similar approach to Palani et al. [26], each SERP contained a fixed search query for each task, but participants were invited to review as many results pages to address the need. As with the Phase 1 observations, the task scenarios allowed for some personalized 'framing' of the information need, as shown in Table 4.

Since the prototype SERPs were based on search queries made by participants during Phase 1 observations, the tasks mirrored the earlier scenarios from the observations in Phase 1. This allowed us to compare the behaviors and experiences of searchers with dyslexia when interacting with the modified mobile SERPs to those when using the original, unmodified Google mobile search interface. All of the participants had taken part in Phase 1 (three had been observed, all had been interviewed). While this was mostly a practical decision, based on difficulty accessing a large number of mobile searchers with dyslexia, it did provide scope for comparison between their experiences across interfaces. While we remained alert to the possibility of the modified interfaces more readily resonating with them, because their experiences helped inform their design, this concern was not reflected in the evaluation data; their experiences were sufficiently varied to assure us that the design modifications we made were likely to be useful for a broader range of searchers with dyslexia than those who took part in our study.

The finding from Phase 1 that many participants needed to be particularly resilient during the results assessment and triage (rather than query formulation) stage of their searches supported our practical decision to present pre-populated SERPs in an interactive front-end prototype rather than one with back-end integration. This also mitigated the risk of results personalization impacting the findings.

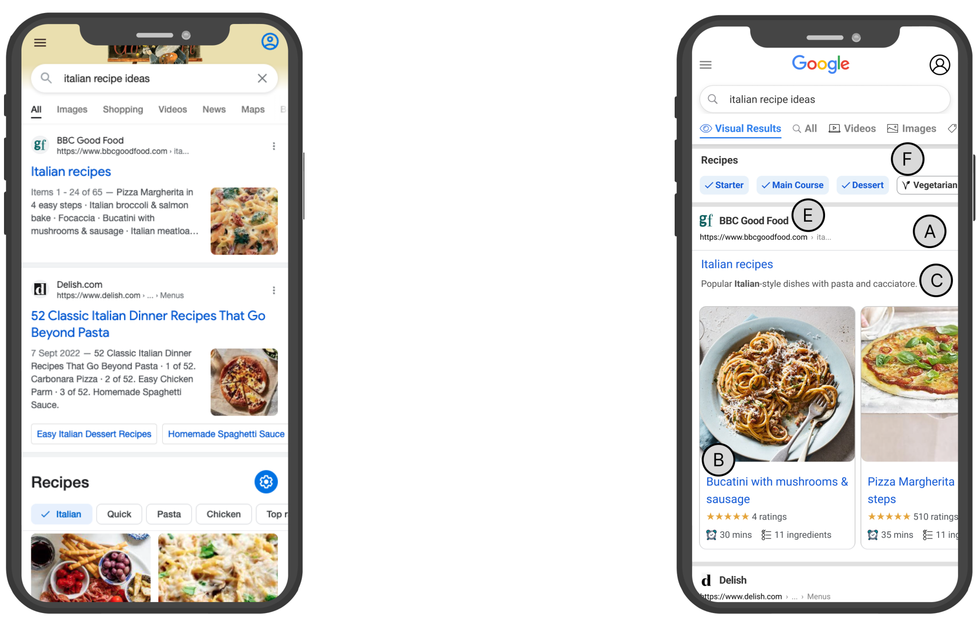

Figure 1: Original mobile SERP used by P3 when conducting the cooking search task (left) and modified SERP prototype design for the same search query (right), labelled with its component design modifications (see Table 3 for list of modifications).

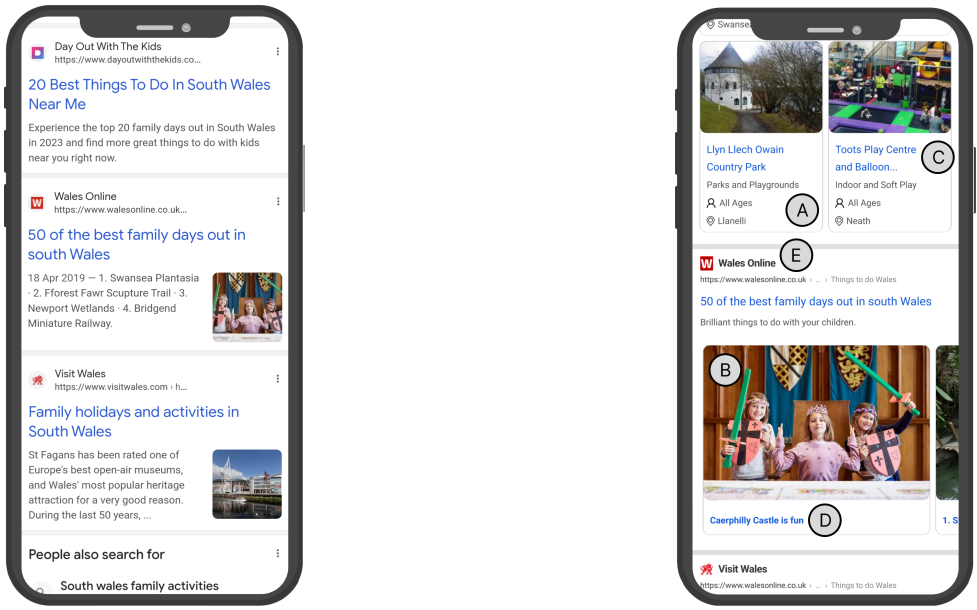

Figure 2: Original mobile SERP used by P6 when conducting the travel information search task (left) and modified SERP prototype design for the same search query (right), labelled with its component design modifications (see Table 3 for list of modifications).

Table 4: Template Simulated Work Tasks (SWTs) provided to participants during Phase 2 (evaluation) observations

Task #	*Domain*	*Template Simulated Work Task (SWT)*	*Fixed Search Query on SERP*
T1	Strike dates	You need to plan a trip using the train later in January, but you have heard about the ongoing train strikes across the UK. Use Google to find out when the next strikes are happening.	'uk train strikes january'
T2	Travel	You have booked a holiday to South Wales for next [season] and want to plan 3 fun and interesting things to do there with [friends/relatives]. Use Google to find some options.	'south wales family activities'
T3	Cooking	You have [friends/relatives] visiting your home for dinner next weekend, and you'd like to cook an Italian meal for them. Use Google to find some suitable options that you haven't cooked before.	'italian recipe ideas'
T4	Shopping	You'd like to buy a gift for [female friend or relative's] upcoming birthday. They like vintage clothing. Use Google to find 2 or more suitable options.	'vintage clothing for women'

After each SWT, the same post-task questions as in the Phase 1 observations were asked. To collect attitudinal data around the mobile search experience, we followed an approach similar to Wessel et al. [34] who, like us, examined whether design changes in search result presentation improved usability for people with dyslexia. We asked participants if they had a preference between the modified SERP interface they interacted with, or the default Google mobile SERP for the same search query terms ('Please can you provide a rating of which version you prefer?'). Responses were collected using a seven-point Likert scale (1 = 'Strongly prefer Version 1', 4 = 'neither', 7 = 'Strongly prefer Version 2'), while both platforms were displayed on-screen for review. Participants were asked to explain their decision verbally.

5.3 Data Analysis Approach

For the Phase 2 evaluation, data analysis followed the same process as the Phase 1 observations through first summarizing the task sessions into an Excel grid of timestamped interactions, annotated with related phrases and attitudinal feedback from participants. However, to compare user behaviors and attitudes with the Phase 1 data, a more deductive approach to analysis was taken. Previous codes from the Phase 1 observations were used as 'lenses' during analysis of this qualitative data. Codes that mirrored those from Phase 1 were replicated to allow for direct comparison (e.g. 'verifying information by cross-checking'), while new codes were inductively generated (e.g. 'backtracking through the same information to decide relevance'). A second deductive stage compared the data against the design objectives to evaluate the observed user experiences against our intended outcomes.

5.4 Evaluation Findings

Between designs, the mean number of web pages examined to address each task across participants was similar (3.4 in Phase 1; 3.9 in Phase 2). Participants actively engaged in search result triage across tasks, with some individualized behaviors. For example, P1 and P4 were quicker to satisfice during tasks in both the Phase 1 observation and Phase 2 evaluation. Key findings are discussed below. As participants did not visibly interact with or mention modifications D and E, these features are not discussed in our findings.

Mobile search outcomes and user experiences can be improved for users with dyslexia through ability-based approaches to SERP design. Participants reported positive and preferable mobile search user experiences resulting from the modifications made to the mobile SERPs. A preference for the modified SERP design was stated in 24/28 (86% of) observed task sessions, with a strong preference (median=1) for the travel and cooking tasks and a mild preference (median=3) for the strike dates and shopping tasks. Self-reported measures of relevance were also higher with the modified interfaces; in 79% of the evaluation search tasks, participants rated 'strongly agree' to 'I was able to find all of the information that I needed to accomplish the task' (50% in Phase 1), while they only stated they had found irrelevant information in 21% of the evaluation search tasks (33% in Phase 1).

Search results that incorporate large, clear images can improve mobile search usability for users with dyslexia. The inclusion and placement of visual rich results and image carousels in prominent positions on the mobile SERP (modifications A and B) supported all participants with search result triage when undertaking visual-centric search tasks (cooking and travel), assisting them in identifying task-relevant information. This was achieved in two ways: The first was by augmenting information scent to drive exploratory behaviors. P2 stated *"the visual aspect is really helpful for me...I feel like if there's pictures, I'm more like engaged in looking through. My stamina for searching is increased"*. The second was by reducing interaction cost. P10 stated *"without clicking the links and without getting lost, I can basically see the highlights of what I need"*. This positive impact on exploration is also demonstrated by notable increases in time spent browsing the search results during the cooking task (a 164% increase on Phase 1) and shopping task (193% increase). Given the positive comments regarding images, this is much more likely to reflect engagement rather than difficulty. However, the findings also highlight the importance of carefully focusing on how image-heavy SERPs are implemented. P9 reported that images dominated results in the shopping SERP, masking other informational cues such as the result's URL. Similarly, P5 described how the rich results impaired their experience during the travel task: *"I don't know if the pictures are too big or if there's too much going on visually. Part of it also might be that I'm used to normal Google so I can navigate that."* However, during the cooking task, the same participant commented that the images provided beneficial visual cues. This reflects the need to include images in SERPs without allowing them to over dominate.

Providing search results that link and navigate to specific parts of web pages or documents that contain potentially relevant content can make relevance assessment easier. In Phase 1, five of the six observation participants demonstrated challenges navigating through content on webpages or documents linked from SERPs. No participants demonstrated these challenges when using the prototype SERPs in Phase 2. This may be due to an increase in the links provided on the modified SERPs that directed searchers towards individual web pages (i.e. directly to specific recipes or places of interest, rather than to an 'overview' article page) that contained potentially relevant content (modification C).

Indeed, five of the seven evaluation participants reported that this modified design feature improved their search experience. This preference is illustrated by P4, who compared Google's standard search snippet for BBC Good Food against the modified expanded results and stated "*just looking at the top result, it will say "Pizza Margherita in four easy steps" and then it just has a bunch of words... It's just not user friendly. But I like on [the modified SERP] that you can scroll and review.*" This suggests increasing the amount of useful information in the SERP positively supported users' information search abilities. This is an example of where an ability-based design focus may have also addressed difficulties observed in Phase 1 as an important byproduct.

Interface features that provide additional user control over search results can support positive search outcomes, but should be learnable and prominently visible. Filters were added to the SERPs for the strike dates and cooking tasks to facilitate user control over the presented results (modification F). Users could filter the results by selecting from a limited number of facets specific to the task's domain (e.g. official news sources; meal course). Five of seven participants interacted with this on the cooking task SERP and all five participants expressed a post-task preference for this. Participants discussed two key benefits for assisting search result triage. The first (relating to the strike dates task) was controlling the information sources presented to them. P4 stated that if SERPs incorporated more filters, it *"would be really useful, especially for things where you need a definitive result."* The second (relating to the cooking task) was filtering out result categories that were not relevant to their search task. P10 stated *"when I invite friends, I always ask about their dietary requirements. So having that option from the beginning is a huge load off of your mind"*. However, it is important to consider visual presentation and learnability of filters, particularly for people with dyslexia, who may have formed resilient behavioral habits during mobile search; five participants expressed a post-task preference for the 'news and official sources' filter offered during the strike dates task, but four had not noticed the filter whilst searching. One of those participants was P5, who explained that their mobile search interactions were often habit-driven, which prevented them from noticing the filter option: *"I actually prefer this one [the modified SERP], but I didn't* *use the button [filter]. It's like you don't really look at stuff, do you, after you've used it 1,000 times?"*

5.5 Summary of Findings

Our user interviews and observations found mobile searchers with dyslexia demonstrated strong resilience throughout the search process, but did not always consider their searches as successful. Based on design objectives formed through an understanding of their abilities, we designed a mobile prototype based on modifications to Google Mobile SERPs. These modifications included prioritizing visual rich results, making more extensive use of images to summarize results and support relevance assessment, showing expanded within-site results, directly linking and navigating to potentially relevant content on retrieved pages and allowing iterative result filtering.

Participants preferred the prototype's modified SERPs to the standard Google Mobile SERPs and reported a positive user experience when interacting with it. Our user evaluation highlighted several key design principles for enhancing the mobile search experience for people with dyslexia, including: *incorporating large, clear images* in search results, *directly linking to specific parts of web pages or documents that contain relevant information* in search results and *providing additional user control to support triaging* search results (e.g. through task-domain specific filters). The user evaluation findings also highlighted that mobile searchers with dyslexia have individual differences in their experiences and may therefore benefit from personalized (or customizable) approaches to support.

6 DISCUSSION

We now discuss research and design implications of our findings. Design implications include four broad principles for leveraging the abilities of people with dyslexia in mobile search interfaces.

6.1 Research Implications

This is the first study to examine the impact of dyslexia on mobile search and how to support searchers with dyslexia on mobile devices. Its findings are important not only due to the prevalence of dyslexia and ubiquity of mobile search, but more importantly because they take vital first steps to provide greater equity for mobile searchers with dyslexia. The search experience, including on mobile devices, has traditionally been designed to be text-dominated, require detailed reading of result headings, snippets and linked pages and require constant use of working memory (e.g. to remember one's place in the search results or linked pages). However, our findings have shown that searchers with dyslexia may have abilities better suited to a different type of search interface; one that provides image-based rich results, a stronger indication of which pages within a site might be relevant to the user's search query and the ability to filter search results.

Many of our findings align with those from prior studies; they complement existing workarounds identified in desktop search, such as opening multiple tabs to avoid losing place in the search and relying on familiar information sources [11, 17]. However, they also demonstrate that mobile environments can exacerbate known dyslexia-related difficulties when using desktop search, such as interpreting result snippets and assessing web page content during results triage. Small screens on mobile devices restrict the amount of text that can be visibly displayed, requiring much more scrolling than on desktop. This can result in people with dyslexia losing their place in the SERP or web page, or finding it more difficult to locate content to re-read. Our findings also highlight the hard work and resilience many searchers with dyslexia put into their searches, emphasizing the appropriateness of ability-based observation and design approaches. While it may be laudable to try to understand and address a particular group of searchers' difficulties, this approach risks perpetuating a deficit model. Our research highlights the value of appreciating and leveraging the things that people are good at, or demonstrate resilience in. We recommend this ability-based focus for future research on dyslexia and search, in particular through incorporating inclusive approaches whereby searchers with dyslexia actively inform future mobile search engine design.

Our findings also demonstrate that, just as with desktop search [25], mobile searchers with dyslexia have individual differences in their experiences and therefore may benefit from a personalized (or customizable), rather than a 'one-size-fits all types of dyslexia' approach to support. For example, just like Morris et al.'s [25] study on desktop search and dyslexia, we found that most (but not all) participants expressed a preference for image-based rich results. Rather than assume this modification to mobile SERPs will benefit everyone with dyslexia, there is the opportunity to provide users with adaptable interfaces, with sufficient transparency to provide *"the means to inspect, override... preview, alter or test"* possible adaptations [35]. How best to implement adaptable interfaces for mobile (and desktop) searchers with dyslexia, as well as other types of neurodiversity, remains an important challenge for future research.

This study leveraged the ability-based design framework [35] with positive results; first we used the framework to build an understanding of the capabilities of mobile searchers with dyslexia. We then used it to take an 'accountable' stance in improving the user experience by prototyping specific design modifications. Aiming to enhance people's individual abilities has the potential to empower and support them, while not buying into the misguided assumption that their abilities (or difficulties) will necessarily be exactly the same as others [3]. We also used the framework to guide our evaluation approach, which involved understanding the impact of our modified SERPs on user behavior and attitudes, rather than how well our modified SERPs addressed dyslexia-related difficulties. How best to encourage an ability-based design approach that also addresses key difficulties people experience as a welcome byproduct requires further research.

6.2 Design Implications

Based on our findings, we propose four principles for designing mobile search interfaces to leverage the abilities of people with dyslexia. These principles are general enough to potentially apply to other types of mobile environments where search is prominent (e.g., e-commerce sites) and to desktop-based search, however further research is needed to determine the extent to which they are generalizable beyond a mobile search engine context. We also expect these principles to benefit people *without* dyslexia, although more research is also required to investigate this.

1) Integrate clear, informative images within mobile search results to augment users' understanding of retrieved results. Images can give important cues for users, giving off information scent and aiding relevance judgement. Our study found image-based rich results were particularly beneficial for everyday tasks such as shopping, travel and cooking, where images can convey more detailed meaning around criteria and attributes than words alone. We found that integrating multiple images into rich results and carousels within the SERPs for decision-making tasks, while also including relevant and understandable text annotations with appropriate visual weight, motivated users towards active exploration during their search.

2) Link to specific parts of web pages or documents that contain potentially relevant content from search results. All users (including those with dyslexia) may find navigating through retrieved pages to locate specific information challenging, particularly on mobile devices. If a user is taken straight to the part of a web page or document that contains potentially relevant content when they click on a search result, and that content is highlighted, this may save them navigation and reading time. For sites that contain multiple instances of potentially-relevant content, provide users with a clear overview of these instances within the search result. It may also be possible to facilitate the cycling through of instances, similar to the 'search within page' functionality within most web browsers. This could empower users to compare and differentiate between results without navigating away from the search page.

3) Allow users to refine presented search results, based on categories related to their information task domain. During a single search task, users' information needs will often evolve and change in scope. We found that incorporating result filters can be a helpful way of supporting refinement of these needs, by including or excluding topics, particular information sources or refining by other attributes, such as date or, for products, review scores. This can be especially beneficial when based on common and understandable categories relating to the original search query (e.g. dietary requirements in a cooking task).

4) Provide users with additional control and choice over how search results are presented to them and how they can interact with them. People (including those with dyslexia) have a range of visual processing abilities, yet SERPs are ranked algorithmically and there is limited scope for users to decide what content is displayed to them and how in search results. Allowing users to customize how search results are displayed, so they are presented in clearly structured and predictable ways [16], and the ability to change those preferences on a search-by-search-basis based on their information and search-related needs could support the comprehension of results pages and, in turn, result assessment and triage. This design principle extends beyond filtering search results to cover more extensive result customization (e.g. length and detail of snippets, accessibility of language, balance of images versus text in results etc.).

7 CONCLUSION

This study aimed to better understand the mobile information search behavior, and specifically the search *abilities* of people with dyslexia. Through a user-centered, ability-based design and evaluation process, we interviewed people with dyslexia about their mobile search needs and behavior and observed them using Google's mobile search to complete directed simulated work tasks on their own mobile devices. We fed the findings into the design of an ability-based mobile search prototype, based on modifications of Google's mobile SERPs. A user evaluation found that several of these modifications were effective in improving the mobile search experience for people with dyslexia. This led us to propose four design principles aimed at better supporting mobile searchers with dyslexia by augmenting their abilities: 1) integrating clear, informative images within mobile search results to augment users' understanding of retrieved results, 2) linking to specific parts of web pages or documents that contain potentially relevant content from search results, 3) allowing users to refine their search results, based on categories related to their information task domain and 4) providing users with additional control and choice over how search results are presented to them and how they can interact with them.

This research provides valuable insight into how to better support mobile searchers with dyslexia that can inform IIR research and design. It also demonstrates the importance of appreciating and leveraging searchers' abilities when designing search environments to support diverse user needs; we found ability-based design to be both an effective and *ethical* approach to design - as rather than consider neurodiversity as a 'deficit,' it recognizes that neurodiverse searchers are often resilient, resourceful searchers with abilities that can be nurtured through design. By doing so, not only might it be possible to make search easier for them, but also potentially for others at the same time. Examining to what extent design interventions aimed at searchers with dyslexia can support searchers *without* dyslexia is an area ripe for future research.

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