Experiencing Data Visualization with Language Disability

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Abstract—Current data visualization research demonstrates very limited inclusion of users with language disabilities. To address this, this paper introduces the language disabilities Developmental Language Disorder (DLD) and aphasia. We present outcomes from a novel qualitative diary study exploring whether people living with either DLD or aphasia experience and engage with data visualization in their day-to-day lives. Outcomes reveal evidence of both exposure to, and engagement with, data visualization across a week-long period alongside accompanying experiences of inclusion and exclusion of the benefits of data visualization. We report types of data visualization tasks and application domains encountered and descriptions of issues experienced by participants. Findings highlight a critical need for increased awareness of language access needs within the discipline of data visualization and a case for further research into design practices inclusive of people with language disabilities.

Inclusive visualization design practices seek to ensure equity of access to data experiences for users with diverse backgrounds and abilities. A recent scoping review found that existing research in this domain fails to document the experiences of users with language disabilities [2]. In addition, little is known about how the impact of language difficulties might inform the design and use of data visualization. We identify the need for increased awareness of language disability within data visualization and for further research to ensure equitable access to data experiences for users with diverse language abilities.

Around 10% of people in the world experience a communication disability [17]. Yet, whilst access considerations for people with perceptual, intellectual or physical disabilities have received some consideration in the Data Visualization literature [9], [19], the research on language access needs remains conspicuously absent [2]. We will begin with an introduction to the language disabilities Developmental Language Disorder [DLD] and aphasia before reporting a qualitative diary and interview study exploring the data visualization experiences of people with language disability and the implications for future inclusive visualization design.

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DEVELOPMENTAL LANGUAGE DISORDER AND APHASIA

DLD and aphasia represent two key examples of language disability. For both conditions, people experience difficulties accessing spoken and written words and language, making it difficult to communicate and understand spoken and written information. Working memory is affected in both populations [8], which may favor visualization as a tool to externalise cognition while presenting design challenges for its effective use. DLD is a neurodevelopmental condition that emerges in early childhood and persists into adulthood. It affects approximately 7% of the population and is characterized by persistent difficulties with language that are not attributable to other biomedical conditions such as hearing loss or intellectual disability [12], [11]. Individuals with DLD may experience challenges with vocabulary, grammar and discourse, impacting both spoken and written communication.

In contrast, aphasia is an acquired language disorder, most commonly resulting from brain injury such as stroke. It affects an estimated 350,000 people in the UK [18] — about 0.8% of the adult population. Aphasia can impair speaking, understanding, reading, and writing, with wide variation in severity and presentation. Some individuals may retain fluent speech but have poor comprehension, while others may have strong understanding but limited verbal output [1], [16].

Together, these conditions illustrate that language disability can occur across the lifespan—from early development to later life—and can affect individuals with otherwise typical cognitive abilities. This diversity underscores the importance of designing data visualization that is accessible to people with a range of language profiles and communication needs.

CONTEXTUALIZING DATA VISUALIZATION

As a foundation for creating data visualization experiences that are accessible to people with language disabilities, we need to better understand their existing practices around data visualization. The lack of prior research in this area means it is not obvious whether use and attitude to visualization differs from that of a more general population.

Specifically, our work was driven by two motivating research questions:

- How is data visualization used by people with language disabilities and for what purpose or decisions?
- How do people with language disabilities experience everyday data visualization?

Anticipation of possible barriers and facilitators offered by visualization is challenging. While visualization is a graphical communication medium that can be less language-dependent than other media, it can have a reliance on language for most effective use. Sometimes written and spoken language is used to annotate, contextualise and explain visualization; indeed textual annotation is often recommended as good design practice [13]. If processing language presents challenges, it is not clear how that might impact attitudes and use. On the other hand, visualization may be offered as an alternative or supplement to more language-focussed media and present a positively attractive form of communication or decision support[15]. And at a cognitive level it is not yet established the degree to which processing of graphical symbolisation (for example, perception, assembly and estimation) may be distinct from, or associated with, language processing.

A more general challenge with assessing use and attitudes to data visualization is in defining the scope of 'data visualization' that distinguishes it from a more general category of graphical communication. For non-experts in the field, this is likely to be a vaguely defined concept, if conceptualised at all. Indeed among our multi-disciplinary team of researchers, at the outset of our collaboration we each had quite different conceptualisations of 'data visualization'. And specifically among those with language disabilities, articulating this scope presents additional challenges. This presents a challenge both to multi-disciplinary research teams and in the eliciting perspectives on data visualization from a general public, and especially those with language disabilities.

As a team of researchers we are primarily interested in the role data-driven visualization plays in supporting 'everyday' decision making. That role may be immediate (for example, real-time navigation of route choices from a map); short term (for example, choice of financial investment following analysis of stock performance); or longer term (for example, political voting preference following exposure to a range of data visualizations). As such 'decision making' is also not a crisply defined concept.

METHODS

To explore these ambiguities and to gain insight into how people with language disabilities view data visualization, we conducted a phenomenological qualitative study with eight adults (four with DLD, four with aphasia). Ethical approval was gained from the Language and Communication Science proportionate review ethical committee (ETH2324-0048). The study involved three stages – briefing interview, visual data diary production, and follow-up interview. All interviews were conducted by an experienced research-based speech and language therapist [ND]. The visual data diary served as a prompt for the semi-structured interviews. Participants described each visual data example in the diary, were asked how they felt about it, the decision-making the data supported, and the process of tracking visual data for the project. At the end of the interview, each participant ranked which visual data were most important to them. The speech and language therapist used pen and paper throughout the interviews to write shared notes using keywords and simple drawings as needed.

We took the standpoint that people with communication disability were likely to be competent at data visualization. However, we were aware that their difficulties might hide this somewhat. Furthermore, the visualization designs might afford varying degrees of facilitation for engagement and understandability. With supportive communication partners they would be able to share their experiences. Supported conversation[7] techniques such as 'checking back' were used to confirm meaning was understood correctly. In this way meaning was co-constructed at times between interviewer and interviewee.

Inclusion criteria for participants were: adults with self-reported DLD or aphasia and score of at least 14/30 on the Frenchay Aphasia Screening Test[3]. Sampling was pragmatic, the first eight people who met the criteria were included.

The initial briefing interview with each participant focussed on the nature of the study and the scope of 'visual information'. We intentionally did not use the term 'data visualization', as echoed by the experience of the research team, we were not confident that this term had a clear agreed meaning to participants. The more open term 'visual information' allowed participants to define their own scope.

To assist in this briefing, participants were shown four examples of visual information that might be used with different forms of decision making. Examples exhibited various data densities and types and all involved at least some textual encoding (see Figure 1).

Participants were asked to keep a diary for one week documenting encounters with visual data. Anticipating that participants may forget to keep the diary, all had the option of daily reminders via email, text or WhatsApp message sent from the research team (6 of the 8 participants took up this offer). The form of the diary was left up to participants but example media were mentioned including photos, screenshots, written notes, and voice recordings.

Following the diary exercise, a semi-structured interview with each participant was conducted in person or online, using supported conversation[7] with a qualified speech and language therapist researcher [ND]. Interviews were designed to elicit examples of visual information recalled or shown by participants using their diary artifacts as prompts. Questions explored their context of use including motivation, their role in decision-making, the nature of engagement with the visual artifacts and emotional response to them. All interviews were recorded and later transcribed for qualitative content analysis. Results were interpreted though research team discussion and with a user representative with DLD from the study steering committee.

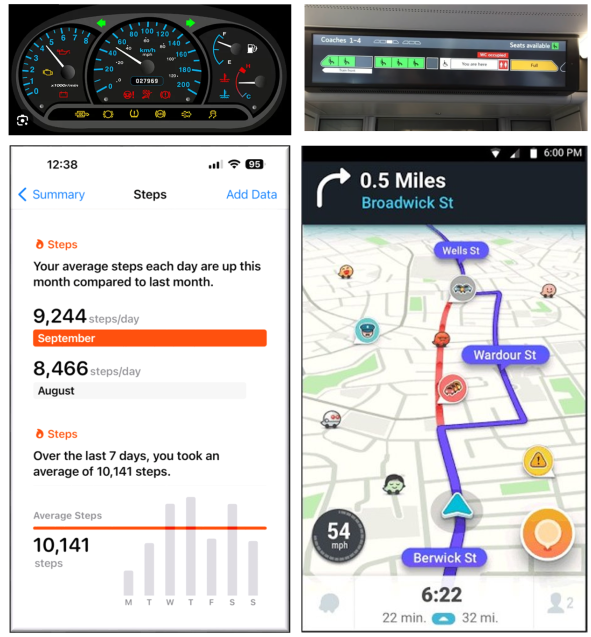

FIGURE 1. The four example images shown to participants to illustrate 'visual information'. Clockwise from top left: onboard train carriage usage (source: greateranglia.co.uk); a car dashboard (source: www.f1autocentres.co.uk); a personal health app (Source: Apple Inc.); navigation route based on live traffic data (Source: Waze, Alphabet Inc.). Note that all mix graphical with textual encoding.

RESULTS

Participant Backgrounds

Eight participants took part [P1, P3, P4, P7, P8, P10, P12, P13]. Participants ranged in age from 33 to 70 years with an equal split across gender and typical non-verbal reasoning skills (all within 2 standard deviations of the mean for their age group on the Ravens Coloured Progressive Matrices[10], [14]). Four participants with DLD [P7, P8, P10, P12] had a mean age of 49 (SD 7.7) and all were in employment. Four participants with aphasia [P1, P3, P4, P13] had a mean age of 52 (SD 12.8), were on average 7 years post-stroke (ranging between 6 and 14 years). None of the aphasia participants were in employment and all had a physical disability. The differences between DLD and aphasia profiles reflects the wider population where DLD is most commonly diagnosed in childhood while aphasia is more common in older adults where, post-stroke, some form of physical disability such as hemiplegia is not uncommon.

Participants' examples

Across interviews and diaries, 93 examples of visual information were volunteered by participants. Following interviews, an initial winnowing process was conducted independently by two of the research team [ND and AR] to remove examples considered out of scope. We defined data visualization for that purpose as *a graphical idiom where more than one data value was depicted*. This was largely to remove non-data or single datum pictographic representations such as metro station signs, recycling symbols on packaging and priority seating on public transport. This yielded an inter-rater reliability of 85% and the 45 examples independently identified as data visualization by both researchers were considered for further analysis.

To address our research questions, we wished to understand both the types of visual information (data visualization idioms following the winnowing process) and the way those idioms were used by participants. We therefore classified examples provided by participants by both idiom and task. The top-level classification from the Financial Times Visual Vocabulary[6] provided task taxonomy as this reflected the level of detail typically described by participants.

For example, one participant used spatial lookup on a 'find my phone' app to plan for their children's return home: '*...when she starts to come back. That's good. I then have to [cook] Ottolenghi!*' [P13]. Others described change over time lookup tasks such as the participant who used a heart rate monitor visualization noting that spin classes increased their heart rate, but the cross trainer did not: '*My heart rate, yep. I always... in spin. The cross trainer, hardly, yellow.*' [P1]. Others used change over time idioms for trend analysis such as for financial investment '*I self-invest me pension... as long as it's going up or across, I stay in, and once it starts coming down and I get out. And then when it goes back up again, I get back in.* [P12].

Additionally we identified the application area associated with the visual information in order to understand what context of decision-making visual support was considered. See Table 1 for a full list of our classification categories. Assignments to categories were not necessarily mutually exclusive. Where, for example, a task might involve both part-to-whole comparison and magnitude estimation we recorded both. In addition to classification, qualitative responses including accessibility and participants' emotional responses to data visualization were captured using content analysis of interview transcripts.

TABLE 1. Data visualization classifications applied to participants' visual information examples.

Classification	Source	Categories
idiom	datavizcatalogue.com	bar chart; calendar; candlestick chart; connection map; dot map; heatmap; histogram; illustration; line chart; network diagram; pie chart; radial bar chart; span chart; stacked bar chart; timeline.
task	FT Visual Vocabulary	deviation; correlation; change over time; ranking; distribution; part-to-whole; magnitude; spatial, flow.
application	Apple app store categories	business; education; finance; food and drink; health and fitness; navigation; productivity; shopping; travel; utilities; weather.

The visualization idioms used across task and application areas included topographic maps, schematic maps, bar charts, histograms, radial charts, timelines and pie charts. Figures 2 and 3 show the relative frequencies of tasks and application areas from the 45 visualization examples provided by participants.

Most common were tasks and applications centred on navigation and travel, for decisions such as choosing the quickest route to a destination, or making public transport choices. These were typically from mobile map applications on phones, public transport maps and building layout maps (most commonly in hospitals). Some used map-based apps to identify location of family members to assist in planning. When asked to identify which forms of visual information were most important to them, travel-related was most commonly cited.

Beyond navigation and spatial activity, the next most common activities related to sensor monitoring such as heart-rate monitors, energy consumption smart meters, smartwatch steps monitoring and car dashboards. These covered a wide range of decision-making types from real-time decisions while driving to longer term reflection on personal health.

Other tasks and applications mentioned by multiple participants included the use of weather apps (both in map form and time-based summaries), especially in relation to planning, such as what to wear or what form of transport to use. Some made use of productivity and financially-related visualization for decision support, such as diary planning and financial decision-making.

The most interesting insights into barriers and facilitators came from qualitative responses from interviews that revealed the relationships that participants had with the data visualization process. Content analysis[5] on all interview transcripts led to several categories of observations made by participants.

Encoding and accessibility

Colour encoding was mentioned by many as characteristic of usable visualizations. For example on a metro map '*[I] like colour coded, very clear when to change.*' [P3] and '*The colours come more quickly to me than the names.*' [P10] when talking about metro navigation on 'the green line'.

The financial domain appeared particularly prone to inaccessible visualizations, for example investment charts were highlighted by one participant as being important (used daily), but '*horrendous*' [P12] and hard to understand.

One revealing comment '*I am not stupid, but I still need simple instructions.*' [P4] highlighted the distinction between the cognitive demands of first learning how to work with an app that uses data visualization from the later task of using that data visualization to support decision making. Some participants distinguished what they could see (for example, the trend of a line) as 'easy' as distinct from the extraction of meaning from it as 'hard' *'Makes me feel good to see the numbers go down [...] but I don't really understand how this shows BMI [body mass index] because I don't understand the graph.*' [P10]. These observations may have implications for accessible visualization design that separates onboarding from steady-state use. What makes successful onboarding was less clear from participant observations. Some services which provided video introductions or explanations were liked by some participants but found confusing by others.

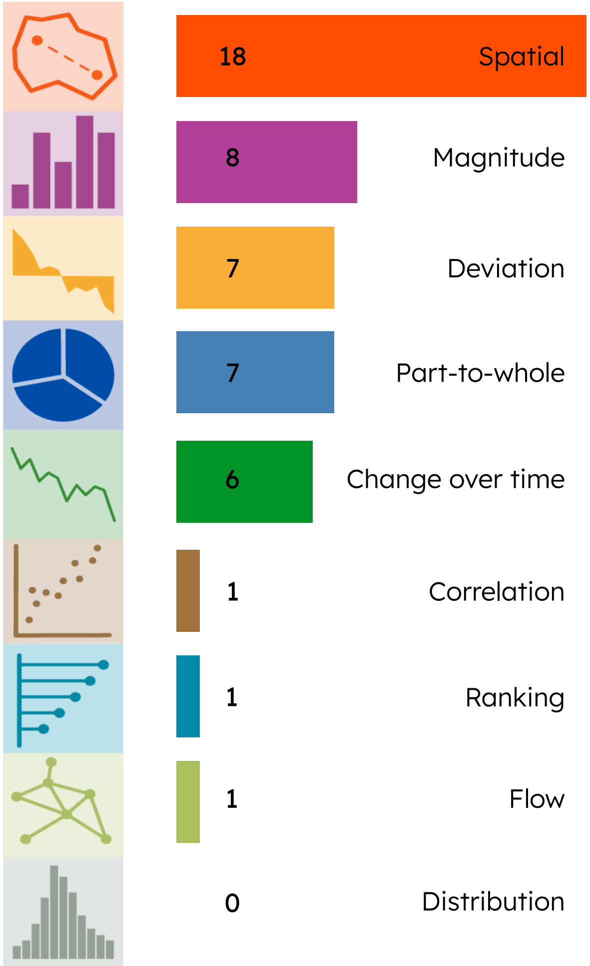

FIGURE 2. Task frequencies described by the 8 participants in their diaries and interviews. Based on the top-level categories of the FT Visual Vocabulary ft.com/vocabulary. The most frequently mentioned task type, spatial, featured in 18 of the 45 samples.

Some participants described their data visualization interaction in a way that suggested use was largely or partly inaccessible but they used partners or other carers to provide support either in interpreting the visualization or delegating the task entirely. One participant related their use of Google Maps for navigation that they found too confusing to operate: '*I don't know what to do ... I call my daughter."* ' [P3]. Not fully understanding the meaning of a visualization didn't necessarily prevent regular use:

FIGURE 3. Application areas of data visualization used to support decision making described by the 8 participants in their diaries and interviews. 13 of the 45 application areas related to navigation.

P3: '*I like it, it's very good for me.*'
Interviewer: '*What does it tell you?*'
P3:'*I don't know.*' [P3]

Some noted the confusion generated by too much visual information. For example, '*It sort of makes sense. A lot of stuff that doesn't need to be there.*' [P12]. As a result a strategy adopted by some would be to focus on a small part of a visualization that they found easier to work with. For example, using only the summary weather symbols on an interactive weather forecasting map. One participant favorably commented that their car dashboard presented visualization '*automatically*' [P4], suggesting cognitive effort could be directed toward interpreting the visual information rather than modality of interaction. This suggests that ensuring there are multiple modes in which a data visualization may be engaged can have accessibility benefits.

Trust and familiarity

A repeated theme that emerged in interviews was the trust participants had in sources of data visualization. Many sought out familiar online sources of data visualization that were often characterised as 'helpful' and 'intuitive' such as Google Maps, schematic metro maps, weather apps and digital calendars.

Where visualizations were used to support predictions, such as weather maps or public transport arrivals, if experience had suggested unreliable predictions, trust in use of visualization in these contexts was reduced. For some, lack of accuracy, detail and precision diminished their trust in visualization engagement while recognising extra detail could make use and interpretation harder (distances on metro maps and smart energy meters we mentioned as examples).

Anxiety and emotional response

Anxiety emerged as a common theme, both induced by the nature of the task, especially real-time navigation, and by visualization designs or apps that were perceived as difficult to use or understand. This sense of anxiety was noted even when familiar apps were used.

Even when people sometimes relied upon partners or carers for addition support, discomfort would sometimes prevent seeking further support. For example one participant related their experience of real-time navigation using a metro map: '*My niece met me because, on the way there, to help me through the tubes [Metro] because I can't do the tubes. And then on the way back, I didn't. I thought I was being a burden, so I didn't ask her, and I got myself in a muddle.*' [P10].

Several noted that their ability to work with data visualization would depend on their own emotional state and stress levels. This could be particularly acute for real-time decision making such as navigation:

P10: '*I get anxious right inside in my chest. Feel it all, my body heating up and I just get... but I don't know, what's the worst that can happen? Why does my body do? I know it's that flight. What's that word? Umm, flight flights or something.*'
Interviewer: '*Fight or flight?*'
P10: '*Yeah, yeah.*'

While this may apply to all who make elective use of data visualization, we speculate that the increased cognitive demand of processing language as part of the visualization engagement may make success more prone to prior state of mind among those with language disabilities.

Interestingly, one person mentioned that inaccessibility around personal health data could be advantageous as otherwise they would '*check it all the time*' [P7].

Repurposed use

Several participants related how their use of a particular visualization or service was not necessarily aligned with is primary purpose. For example one person [P10] related how they used a train ticket booking service not to buy tickets but to use as train timetable. Another [P3] who used a mobile map app on their phone was not aware the 'blue dot' they commented on was their current location so used it solely as map source without computed navigation:

Interviewer: '*So, you use it for the map?*'
P3: '*Thank you. Yeah.*'
Interviewer: '*Do you ever use it to find a route?*'
P3: '*Nope.*'

Diary Reflection

Much of the interview discussion tended to focus on the process of diary keeping itself, which proved insightful in the way the visual is used and perceived. For some, the act of keeping a 'visual information diary' was itself a valuable experience. One participant commented that '*I think you're more aware [of data visualization] in the moment probably.*' [P12]. Another said it encouraged them to reflect, '*Stepping outside detail of own life.*' [P7]. One person suggested the diary made them '*notice things*' [P3] and that while they were initially sceptical of the value of the exercise '*Now I like it.*'. Another noted '*I think it's I've got more of an appreciation for it. How it needs to be better presented without confusing. It's got to be. It's got to be simple but informative, doesn't it?*' [P12].

This reflective experience wasn't always positive. One person with aphasia [P3] noted the exercise highlighted the difference between before and after their stroke. This is an important consideration for studies of this kind as the insights gained by participants may not always be positive ones for them. While language disabilities around aphasia and DLD have much in common, we suggest this may be a key difference between the experiences of those with acquired language disability (aphasia) compared to those with developmental language disability (DLD).

DISCUSSION

Implications for Research Methods

In addition to the valuable empirical results generated by our study, it also prompted us to consider our methods for research and design around visualization for people with language disabilities. In many cases these are common to empirical visualization research more generally, but the specific needs of those with aphasia and DLD lend more importance to some of them.

Data visualization is not a well defined or agreed concept among a general population. Using more general and non-technical language to probe scope ('visual information') allowed participants to relate to the themes of data-driven visual support without relying on technical or academic language. It became quite clear in the interviews and examples provided by participants that they were engaging richly with what we might define as data visualization even if they themselves would not have framed it in this way. Care is needed in framing the themes of interest when conducting empirical user-based research, but is particularly acute when dealing with a population for whom language and terminology may be challenging.

Diary-based exercises with the option of range of modes (photos, audio recordings, handwritten/drawn paper, WhatsApp messages etc.) can accommodate the range of preferences of a diverse group of people with language disabilities. Automated daily reminders to complete diary entries were seen as helpful by participants and the research team. Researchers having confidence and familiarity with the communication technologies involved, such as mobile phone-based alerts, can help in providing clear and lower-stress guidance for participants.

The use of experienced speech and language therapists and an experienced psychologist researcher (ND, AR, MC and NB in our research team) was vital in working with participants. This allowed us to separate the challenges of eliciting and communicating participants' insights from the challenges and experiences they had of using data visualization. Following established good practice such as supported conversation[7] helped in this respect. Our approach was also informed by our steering committee that included members with DLD and with aphasia. It is important to recognise that research into inclusive data visualization should not be limited to empirical examination with those with lived experiences. The research design process itself benefits from the input of those from the populations under study.

Capturing interview records that involve a range of communication modalities in such as spoken utterances, gesture, writing and visualization presented some extra challenges. The physical artifact of the 'diary' helped in structuring the interview communication process. As was a focus on visual information for supporting everyday decision making. The extra time and resource taken to accommodate these modalities should be recognised at the outset in order to generate the rich records of people's experiences.

Implications for Inclusive Data Visualization Research

In recognising the benefits of working as a team of language, human-computer interaction (HCI), and visualization experts, we also acknowledge the challenges this presents. We saw many of the difficulties recognised in multi-disciplinary visualization research[4], not least definitions of terms and concepts. Immersion by the researcher in the 'other' of their multi-disciplinary research was helpful in both the design of the research process and the analysis and interpretation of results.

We have observed substantial and rich daily engagement with data visualization among people with language disabilities. In many cases, people were engaging with data visualization but not framing it as such. This suggests research that probes use must be creative in gathering evidence, including avoidance of inadvertent exclusionary terminology and careful elicitation such as supported conversation[7].

Accessibility of services that use data visualization was observed to vary significantly. Design guidelines for communication access, such as simplified language and visual support, are commonly not applied to data visualization. We noted a number of strategies people adopted in response to poorly accessible data visualization. This ranged from complete avoidance, to supported use with others to, in some cases, uses that were likely unintended by the visualization design. It is important that research separates motivations and ability to work with data visualization from barriers to use that arise from inaccessible design.

We observed a great diversity of visualization engagements reflecting the heterogeneity of language disability profiles and lived experience. While we identified a number of common themes that arose around language disability, there were many differences too. Research that explores this area benefits from recognising that heterogeneity. For example understanding real-time navigational decision making, may require quite different approaches to more analytical and longer term engagement such as financial planning or health monitoring.

It was not always clear whether the themes we identified with participants were unique to those with language disabilities, was simply of greater importance or common to anyone encountering data visualization for decision making. We certainly identified themes that were at least more strongly expressed by the participants than in a general population, such as the impact of anxiety in the use of visualization and the role that partners and carers played in supporting decision making. But it remains a subject of further research as to which (if any) issues around visualization design are unique to those with language disability. We as a research team are investigating this with further empirical work that compares data visualization engagement among those with aphasia, those with DLD and a control group without language disability.

CONCLUSION

Data visualization *is* used by people with language disabilities for a wide range of purposes, including navigation and travel, productivity, to engage with utilities and to make decisions around business, education and finance.

The experience of everyday data visualization for this group was found to vary by individual, and the ability to work with data visualization was changeable in response to stress levels or emotional state. The act of directing focus to attend to 'visual information', while valuable for some, was also found to highlight some participants' awareness of their disability. Our findings also indicate that the perceived reliability of visualization predictions had implications for the trust of the participants in their use.

To conclude, the work presented here reports the successful inclusion of users with language disabilities in data visualization research - made possible through the engagement of multi-disciplinary expertise (language, HCI and visualisation), multimodal and asyncronous data reporting practices (such as photo diaries or WhatsApp messages), facilitating co-constructed meaning (through expert interview), and transcription and analysis of mulitmodal interview data.

Building on the findings established, future research from our team will seek to:

- Co-design accessible, multi-sensory visualisations that enable effective personal decision-making for people with language disabilities.

- Develop methods, guidelines and prototype tools to support the creation of accessible data visualizations.
- Develop techniques that empower the participation of people with communication impairments in co-design.

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