Design Patterns in Right-to-Left Visualizations: The Case of Arabic Content

Muna Alebri*
University College London

Noëlle Rakotondravony†
Worcester Polytechnic Institute

Lane Harrison‡
Worcester Polytechnic Institute

Abstract

Data visualizations are reaching global audiences. As people who use Right-to-left (RTL) scripts constitute over a billion potential data visualization users, a need emerges to investigate how visualizations are communicated to them. Web design guidelines exist to assist designers in adapting different reading directions, yet we lack a similar standard for visualization design. This paper investigates the design patterns of visualizations with RTL scripts. We collected 128 visualizations from data-driven articles published in Arabic news outlets and analyzed their chart composition, textual elements, and sources. Our analysis suggests that designers tend to apply RTL approaches more frequently for categorical data. In other situations, we observed a mix of Left-to-right (LTR) and RTL approaches for chart directions and structures, sometimes inconsistently utilized within the same article. We reflect on this lack of clear guidelines for RTL data visualizations and derive implications for visualization authoring tools and future research directions.

Index Terms: Design Patterns, Right-To-Left Visualizations, Data Journalism

1 Introduction

Following the rising progress of information technology and data availability, more and more diverse populations are using data visualization as an essential part of how they produce and consume information. The diversity of the visualization recipients motivated researchers to advocate for more inclusive visualization design (*e.g.*, include people with disabilities [27, 28], reflect diverse demographics [13]). One cannot exclude the vital aspect of languages and scripts in visualization design to reflect diversity and inclusion. RTL script (*e.g.*, Arabic, Hebrew, Persian) users alone constitute over a billion potential data visualization users [5]. This suggests that new designs and requirements might emerge and challenge existing approaches to visualizations that overwhelmingly focus on users from Western and economically developed worlds [20, 24]. Research in Human-computer Interaction (HCI), cognitive science, and user interface (UI) design has demonstrated that the reading-writing direction can influence users' spatial perception [14], temporal representation [17], but also their preferences or expectations in interface design [25]. Standards for web design in RTL languages also propose guidelines for page structuring [3, 4] that align with the language directionality.

In data visualization, while directionality is embedded in visualizations that represent data with trends, ordered sequences, or time-series data, the mapping of RTL interface design practices to data visualizations and their elements is a less explored area. In this paper, we investigate the integration of data visualizations in RTL contexts by analyzing and mapping the design space of visualizations embedded in Arabic contexts. By combining traditional journalism with data analysis, modern data journalism puts data visualizations at its centre for telling stories and providing insights [26]. In the Arab world, the growing set of online news outlets in Arabic is already catering to a diverse visualization user bases [8, 15], bringing new opportunities to investigate the design pattern of various visual representations of data for the general audience.

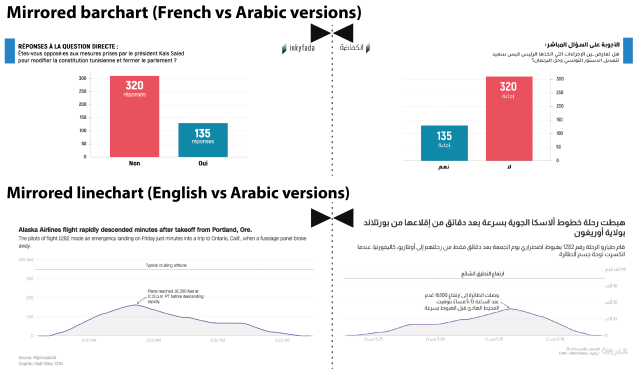

Figure 1: Data visualizations from two articles in Arabic and other left-to-right languages. Top: The bar chart is mirrored, and the data points are categorical and non-ordinal (source: Inkyfada). Bottom: Line chart mirrored along with the direction of the x-axis that represents time sequence (source: Arabic CNN).

We collected 128 visualizations integrated into Arabic data-driven articles from seven news media sources. We characterize the chart types, their composition, their textual elements, and the information they provide about the represented data. Our analysis shows a tendency among designers and a tacit knowledge to apply RTL approach for categorical data (See example in Fig. 1). Our findings also suggest that in other situations (*e.g.*, other data types, translating visualizations from LTR contexts), designers use a mix of RTL and LTR approaches for chart direction and structure. The lack of consistency signals the need for a unified standard to guide designing RTL visualizations. We contribute to understanding the design space of RTL visualizations targeted at Arabic-speaking general audiences. By highlighting both the particularities and inconsistencies in our analyzed sample, we surface research opportunities related to the creation and use of data visualization in RTL scripts, and their implications for visualization authoring tools.

2 Related Work

Researchers in data visualization are uncovering the different ways data visualization is shifting the way we communicate, produce, and consume information [16]. While research often largely focuses on the population in Western Educated, Industrialized, Rich, Democratic countries [19], the rise of data availability, digital media, and data journalism has expanded the audience of data visualization to a more diverse population [20]. This brings new opportunities for the research community to explore new data visualization design paradigms and to potentially challenge the adequacy of existing approaches for other cultural realities [24].

*e-mail: muna.alebri.19@ucl.ac.uk=
†e-mail: ntrakotondravony@wpi.edu=
‡e-mail: ltharrison@wpi.edu
= Both authors contributed equally to this work

There are over 12 RTL scripts covering 215 languages and over two billion users of the Arabic script alone [5]. Unlike English and other LTR scripts, RTL scripts are read and written from right to left. To ensure a consistent and satisfactory user experience, guidelines on UI design are beneficial to accommodate the different script directions. The World Wide Web Consortium (W3C) recommends a set of standards for implementing UIs in RTL scripts [4], including mirroring text alignment, navigation and other UI elements.

In HCI, researchers have investigated the impact of writing direction on how people's patterns of perceptual exploration, and mental images of scenes. Fuhrman and Boroditsky [17] show that when asked to arrange and interpret pictures of sequences of events, English and Hebrew-speaking participants show opposite patterns that match their reading and writing directions. Fagard and Dahmen [14] also demonstrated a similar preference between Tunisian and French children in performing simple tasks, such as filling circles with dots and tracing a circle. In data visualization, directionality is embedded in data for trends and sequences. Some data visualization creation tools (*e.g.*, Datawrapper [23], Highcharts [2]) have considered supporting RTL design, signalling the importance of addressing RTL visualization creation from a different perspective.

Analyzing the popular design practices in visualizations is a widely used research method to generate design guidelines. For instance, Chen et al. [12] mapped the design space of embellishments in data visualizations. Hao et al. [18] also explored the design space of visualizations embedded in journalistic articles. Their work provides a comprehensive overview of the most common components, offering more structured support for designing data-driven articles and the visual elements or techniques that they embed. In this paper, we map the design space of visualizations found in Arabic data-driven articles. We use Arabic visualizations as a use case as it is the root of over 80% of the languages that use RTL scripts.

3 Methodology

Our research method included two stages: (1) sampling visualizations from Arabic news articles and (2) coding these visualizations to extract design patterns.

3.1 Articles and visualizations sampling

This paper focuses on mapping the design space of RTL visualizations, regardless of the article's narrative. We sampled 51 articles and extracted 128 visualizations from seven online Arabic news outlets. On average, we found 2.56 visualizations in each article ($SD = 2.08$). We sporadically collected the visualizations over six months (November 2023 - April 2024). The articles were collected from the source main page, most read, most visited, and snowballed from these articles. We also curated visualizations using the following Arabic keywords: رسم بياني "Data visualisation" and بيانات "Data". The articles were accessed using browsers in non-Arabic-speaking countries because of the researchers' geographical location. Our sample included some of the most popular mainstream media in the Arab world: Alarabiya, Aljazeera, BBC Arabic, and CNN Arabic [1]. To ensure the breadth of the topic, visualization types, and branding style, we also included sources from independent journalistic sources. In particular, we considered the following outlets: Inkyfada, Alsifir, and Arij. Some sources in our sample presented their content in Arabic and other languages. For instance, Inkyfada offered their articles in Arabic, English, and French. We avoided infographics and focused only on visual representations where it was possible to identify the visualization type (*e.g.*, linechart, barchart). These were stand-alone visualizations depicting one dataset, whether they were single-panelled or included small multiples. Table 1 provides an overview of our sample. The topics covered in our sample reflect the reality of the Arab world and the region. For instance, we found the following topics to be the most popular: politics-covering predominantly wars and conflicts ($n = 52$), economy ($n = 32$), and immigration ($n = 15$).

Table 1: Overview of the sources, number of articles, visualizations, and topic covered in our sample.

Name	# Articles	# Visualizations	Topics
Alarabiya	1	6	Sports
Aljazeera	4	9	Politics, Sustainability
BBC Arabic	7	14	Health, Politics
CNN Arabic	20	35	Economy, Politics, Sustainability, Travel
Inkyfada	3	22	Immigration, Politics
Alsifr	10	26	Economy, Politics
Arij	6	16	Health, Politics, Society
Total	51	128	

3.2 Visualization Coding

The coding process was conducted to understand the design patterns found in visualizations designed for RTL scripts. For our coding process, we adapted prior work methods in annotating the basic structure of visualizations [9, 11]. The first and second authors who carried out the coding process are fluent in Arabic, which is vital to identifying certain textual elements' meanings. These authors coded each visualization independently, and several meetings were held to enhance and refine the coding. Several discussions were held to negotiate disagreements. We provide all the visualizations and coding of our sample in the supplementary material [7].

We classified our codes into three categories, considering elements of a visualization that may have different positions and directions. First, **Chart** constitutes of the following elements: *type, X-axis direction, Y-axis position, legend, interaction, colour, and embellishment type*. Second, we classified the textual elements of a chart under the **Text** category, which included *title, caption, annotation type, and textual descriptions for screen reader*. The third category was **Source**, which included the *source position, data availability, publication logo position, ownership of the visualization design, and visualization author attribute*. Table 2 provides a detailed description of each code. As the table shows, our codes focus predominantly on positions and the presence or absence of a visualization aspect; this is to understand and reflect on the importance of directionality of visualization for RTL scripts.

4 Analysis

In this section, we provide an overview of design patterns used to generate visualizations to be embedded in RTL scripts.

Regarding visualization *type*, similar to prior work [11] sampling visualization from LTR contexts, we observed a dominance of standard charts. In particular, barcharts, including stacked and grouped bars, were the most frequent chart type (38%), followed by linecharts (25%) and maps (20%). Pie charts (7%) were also used, followed by tables (4%). Other types, such as scatter plots, area plots and dot charts, were less common. For the *axis direction and position* analysis, we selected 57 visualizations from our sample that had an axis (*e.g.*, linechart, barchart, scatter plot). Figure 2 summarizes the most common design patterns of these elements classified by the data type.

For *categorical data* in the X-axis where direction does not matter (*e.g.*, Fig. 1), we found that the majority of our sampled visualization (81%) to position the Y-axis on the right (⌟). This suggests a considerable consensus over the axis design for categorical data. We found two articles from BBC-Arabic and Alsifr in which the Y-axis position was not consistent within the same article.

Table 2: Overview of the code book for the chart, textual, and source components.

Name	Description
Type	The visualization type *(e.g., barchart, linechart, map, table, donut)*
X-axis Direction	If data is numerical, indicate X-axis direction *(RTL, LTR)*
Y-axis Position	If possible, indicate the Y-axis position *(Left, Right)*
Legend	Where is the legend position if available *(e.g., top-left, top-centre, bottom-left)*
Interaction	How is the visualization displayed? *(static, interactive)*
Colour	Does the visualization contain at least two distinct colours? *(y/n)*
Embellishment Type	What type of embellishment is used? *(backgrounds, icons, illustrations)*
Title	Does the visualization contain a title? *(y/n)*
Caption	Does the visualization contain a description of the data or the visualization? *(y/n)*
Annotation Type	What type of annotation does the visualization contain? *(numerical, textual, combination)*
Textual Description for Screen Reader	Is there a meaningful description (i.e., Arabic, describes the visualization) of the visualization for the screen reader? *(y/n)*
Source Position	If available, where is the data source located in a visualization? *(e.g., top-right)*
Data Availability	Is there a mention of how to access the raw data? *(y/n)*
Publication Logo Position	If available, where is the publication logo located in a visualization? *(e.g., top-right)*
Ownership of The Visualization Design	Are there any indications that the visualization is borrowed from another venue? *(y/n)*
Visualization Author Attribute	Is the visualization designer's name provided in the main visualization area? *(y/n)*

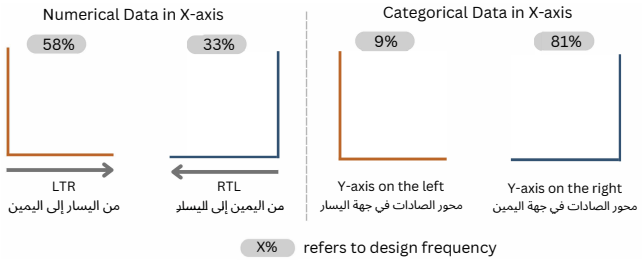

Figure 2: Popular X-axis and Y-axis design patterns. *Left*: axis design patterns found on numerical data. *Right*: axis design patterns found on categorical data. **The Percentage** refers to the frequency of the design pattern within the sampled visualizations (with axis).

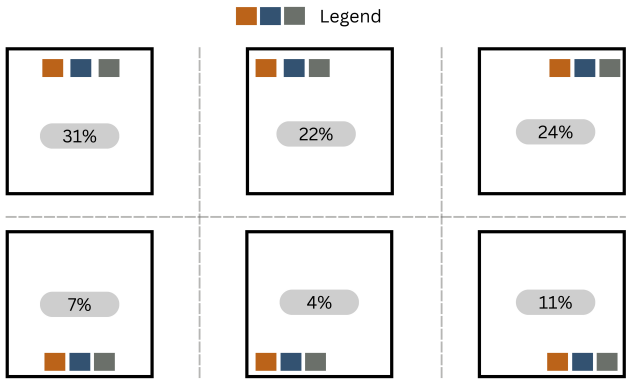

Figure 3: Design patterns of legend positions found in visualizations embedded in RTL scripts.

When the X-axis depicted *numerical data* (*e.g.*, time series), the most frequent pattern (58%) was placing the Y-axis on the left, and the X-axis direction was from LTR (⮑). Looking at the sources of the visualizations that employed this pattern, we found that 85% of them came from mainstream media (*e.g.*, CNN-Arabic, BBC-Arabic), and the rest came from independent news outlets (*e.g.*, Arij). The following popular axis design pattern (33%) was that the Y-axis was mirrored to the right, and the X-axis was also mirrored where the direction was RTL (⮐). We also found that this pattern was most frequently employed by independent news outlets (84%), such as Inkyfada and Alsifr. Next, as shown in Fig. 3, several *legend position* patterns were found on the visualizations that had a legend ($n = 45$). Although there was no single dominant position of the legend, the top position was more prominent (77%). In particular, we found legends placed at the top centre (31%) to be the most frequent, followed by legends placed at the top-right (24%) and top-left position (22%).

Regarding *interaction*, most of our sample was static visualization (66%), similar to a recent content analysis of data-driven articles written in English [18]. Available interactions allowed the users to query "details on demand" and not change the orientations of the charts. *Colour* was also present in most of the sampled visualizations where 56% contained at least two distinct colours while the rest had a single colour or used black ink. *Embellishments* were also found in our corpus but were less frequent (27%). Embellishments are visual elements that carry a functional or aesthetic purpose (*e.g.*, icons, images). Specifically, we found that 54% of the embellished visualizations containing background patterns and images were the most employed. Icons and pictographs were equally popular as well, where 54% of our sample contained these elements. Illustrations were less common. We found that 24% of the embellished visualizations included an illustration on the side to depict the overall topic of the visualization. The percentages do not add to a 100 as some contained multiple embellishment types. These findings align with prior work [6] sampling embellished visualizations from English sources and found that backgrounds and pictorial elements were the most common strategies applied.

Textual patterns The vast majority of the visualizations included a *title* (82%). *Captions* were also common (40%) to explain the visualizations and their data. *Annotations* were also frequently used; in particular, the majority used numerical annotations (59%), 20% used textual annotations, and 21% used a mixture of the two. Regarding the *textual description for screen reader* used for assistive technologies, 52% provided a meaningful description under the

alternative text attribute or the *aria-label* attribute. A meaningful description is provided in Arabic and related to the visualization. The other visualizations did not meet our criteria because they were described in English, used the article title, or used generic descriptions of the visualization type (*e.g.*, map, info).

Source patterns More than 66% of the visualizations disclosed the *source of the data*, and 36% of these visualizations provided a link to access the original data. Two common design patterns regarding the placement of the source were found: bottom-right (84%) and bottom-left (12%). To enforce publication branding, *logos* were frequently added to a visualization (57%). As shown in Fig. 4, the most common logo positions were: Top-left (71%), bottom-right (19%), and bottom-left (10%). All publication venues sampled in this paper with a logo did not maintain the same logo position across its visualizations, except for Inkyfada. Furthermore, some visualizations (23%) included attributes to the visualization designer.

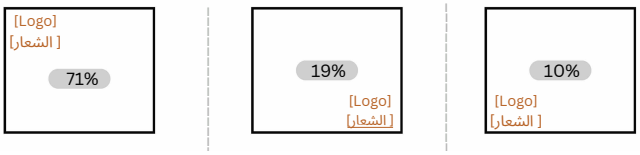

Figure 4: Design patterns of logo position found in visualizations embedded in RTL scripts.

We also found that 12% of the visualizations were borrowed and replicated from an English version in another source. Among these visualizations, we noticed two adjustment patterns: (a) *textual translation* and (b) *textual translation and design mirroring*. Textual translation refers to replicating the visualization by translating the content into Arabic while maintaining the visualization structure. Textual translation and design mirroring refer to translating the content into Arabic and modifying the position and direction of chart components to fit the script direction (see Fig. 1). We observed this pattern more frequently in our sample, where over 66% mirrored at least one chart component. In some interesting examples ($n = 3$), the Y-axis position was mirrored even when the English version already had the Y-axis on the right side. In articles from Inkyfada- a sources that offered their content in English, French, and Arabic, when they mirrored the web interface, they also mirrored the visualization design (*e.g.*, see Fig. 1). The mirroring adjustment included mirroring the logo position, X-axis direction, Y-axis position, and source position.

5 Discussion

This work presents an overview of the design patterns used to create visualizations embedded in RTL scripts, particularly in Arabic. The landscape presented in this paper extends prior contributions aimed at mapping the visualization practice (*e.g.*, [10, 18]). Mapping contributions are critical as they reveal the power of design. Kennedy et al. [21] suggest that using certain visualization conventions (*e.g.*, clean layout, including data source) grants a visualization specific qualities such as objectivity and impartiality. Although the design patterns in this paper are not best practices as we did not evaluate them, they provide a glimpse of the leading practices to be assessed. In addition, they may guide designers and encourage them to think critically about direction and position, especially if they are designing visualizations for scripts they are unfamiliar with.

The axis design patterns observed in our sample present a unique style of visualizations created for RTL scripts based on the data type. On the one hand, there was considerable agreement on positioning the Y-axis to the right for categorical variables (see Sec. 4), as shown in Fig. 2. This observation provides practical implications of the type of support that visualization authoring tools may provide for RTL scripts and endorse tools to continue supporting RTL scripts. On the other hand, with numerical variables, we observed two closely popular patterns: maintaining LTR visualization structure (⮑) and using RTL mirroring approach (⮐)). The proximity of frequency of utilizing these patterns implies a level of ambiguity in how designers make decisions about the axis direction and position with numerical data. We speculate that some designers may get their inspiration from web design guidelines for RTL scripts (*e.g.*, [3, 4]) to mirror the X-axis while others using the LTR approach may have applied coordinate system directions as it is the same in English (LTR) and Arabic (RTL). Future work should interview visualization designers of RTL scripts to understand further the assumptions, references, and guidelines that designers use to make decisions about the axis position and direction.

Although there are no clear guidelines on designing visualizations for RTL users, there seems to be tacit knowledge to use mirroring. For instance, we found that designers mirrored the visualization design when articles existed in other languages, as shown in Fig. 1. This includes mirroring elements such as the axis, source position, and logo position. Similarly, our analyzed sample suggests that mirroring adjustments are widely implemented when visualizations are borrowed from LTR script sources. Nevertheless, there were a few instances where the mirroring approach used was inconsistent, even within the same article. This inconsistency may negatively impact the reader's experience as they must change their reading direction multiple times and learn to read the visualization. Prior work [22] indicates that when readers encounter unfamiliar visualization and form an incorrect framing, whether it is about the content or the visual encoding, it may lead to confusion, frustration and disengagement from exploring the visualization. To mitigate consistency issues, future work may investigate how the mirroring guidelines similar to those applied to web design (*e.g.*, W3C [4]) could be mapped to visualization design for RTL scripts. Furthermore, empirical investigations may investigate the impact of direction on the reader's interpretation, speed of comprehension, and experiences with data visualization.

The following limitations should be considered when understanding our work. First, we considered one example of RTL scripts (i.e., Arabic). Expanding to other RTL scripts may be beneficial in understanding whether our design patterns apply to other RTL scripts and the impact of culture within RTL scripts. Nevertheless, the substantial number of Arabic script users prompted us to select Arabic as a case study. Second, we considered visualizations found in news articles only, as these are the visualizations that the general public would mostly consume. Future investigations are encouraged to consider visualizations from other source types (*e.g.*, government, scientific journals) as they may have different approaches in their visualization design.

6 Conclusion

We reported a design space of visualizations embedded in RTL scripts. We sampled visualizations from Arabic news outlets as examples of the visualizations that RTL users consume. Our analysis of the chart structure, textual elements, and source components provides an overview of the common practices of designing RTL visualizations. Our findings also suggest that designers tend to utilize the RTL approach when depicting categorical data, while in other situations (*e.g.*, numerical data, translating a visualization from LTR context) designers tend to use a mixed approach (RTL and LTR) suggesting some ambiguity in the design decision process. This suggests that designers may benefit from and utilize a feature that supports mirroring. We encourage community discussion towards creating guidelines for designing RTL visualizations to ensure a similar level of consistency to the UI of web design.

References

[1] Arabic newspapers online. https://www.w3newspapers.com/arabic/ Accessed November 01, 2023. 2

[2] Internationalization. https://www.highcharts.com/docs/advanced-chart-features/internationalization Accessed April 20, 2024. 2

[3] Material Icons Guide | Google Fonts. https://developers.google.com/fonts/docs/material_icons Accessed on 2023-04-18. 1, 4

[4] Structural markup and right-to-left text in HTML, 2021. https://www.w3.org/International/questions/qa-html-dir Accessed April 20, 2024. 1, 2, 4

[5] Languages Using Right-to-Left Scripts, 2023. https://www.w3.org/International/questions/qa-scripts Accessed April 20, 2024. 1, 2

[6] M. Alebri, E. Costanza, G. Panagiotidou, and D. P. Brumby. Embellishments Revisited: Perceptions of Embellished Visualisations Through the Viewer's Lens. *IEEE Transactions on Visualization and Computer Graphics*, 30(1):1424 – 1434, 2023. doi: 10.1109/TVCG.2023.3326914 3

[7] M. Alebri, N. Rakotondravony, and L. Harrison. Supplementary material, 2024. https://doi.org/10.5522/04/26150749.v1 Accessed July 03, 2024. 2

[8] E. Appelgren, C.-G. Lindén, and A. Van Dalen. Data Journalism Research: Studying a Maturing Field across Journalistic Cultures, Media Markets and Political Environments. *Digital Journalism*, 7(9):1191–1199, Oct. 2019. doi: 10.1080/21670811.2019.1685899 1

[9] A. Arunkumar, L. Padilla, G.-Y. Bae, and C. Bryan. Image or Information? Examining the Nature and Impact of Visualization Perceptual Classification. *IEEE Transactions on Visualization & Computer Graphics*, 30(1):1–16, 2023. doi: 10.1109/TVCG.2023.3326919 2

[10] B. Bach, Z. Wang, M. Farinella, D. Murray-Rust, and N. H. Riche. Design patterns for data comics. *Conference on Human Factors in Computing Systems - Proceedings*, 2018-April:1–12, 2018. doi: 10.1145/3173574.3173612 4

[11] M. A. Borkin, A. A. Vo, Z. Bylinskii, P. Isola, S. Sunkavalli, A. Oliva, and H. Pfister. What Makes a Visualization Memorable? *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2306–2315, 2013. doi: 10.1109/TVCG.2013.234 2

[12] Q. Chen, Z. Liu, C. Wang, X. Lan, Y. Chen, S. Chen, and N. Cao. VizBelle: A Design Space of Embellishments for Data Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 2022. doi: 10.48550/arXiv.2209.03642 2

[13] P. Dhawka, H. A. He, and W. Willett. We are the Data: Challenges and Opportunities for Creating Demographically Diverse Anthropographics. In *Proceedings CHI*, pp. 1–14. ACM, Hamburg, Germany, 2023. doi: 10.1145/3544548.3581086 1

[14] J. Fagard and R. Dahmen. The effects of reading-writing direction on the asymmetry of space perception and directional tendencies: A comparison between French and Tunisian children. *Laterality: Asymmetries of Body, Brain and Cognition*, 8(1):39–52, Jan. 2003. doi: 10.1080/713754473 1, 2

[15] N. Fahmy and M. A. majeed Attia. A Field Study of Arab Data Journalism Practices in the Digital Era. *Journalism Practice*, 15(2):170–191, Feb. 2021. doi: 10.1080/17512786.2019.1709532 1

[16] S. L. Franconeri, L. M. Padilla, P. Shah, J. M. Zacks, and J. Hullman. The Science of Visual Data Communication: What Works. *Psychological Science in the Public Interest*, 22(3):110–161, Dec. 2021. doi: 10.1177/15291006211051956 1

[17] O. Fuhrman and L. Boroditsky. Cross-Cultural Differences in Mental Representations of Time: Evidence From an Implicit Nonlinguistic Task. *Cognitive Science*, 34(8):1430–1451, Nov. 2010. doi: 10.1111/j.1551-6709.2010.01105.x 1, 2

[18] S. Hao, Z. Wang, B. Bach, and L. Pschetz. Design Patterns for Data-Driven News Articles. In *Proceedings CHI*. ACM, Honolulu, HI, USA, 2024. doi: 10.1145/3613904.3641916 2, 3, 4

[19] J. Henrich, S. J. Heine, and A. Norenzayan. Most people are not WEIRD. *Nature*, 466(1):29, 2010. doi: 10.1017/S0140525X0999152X 1

[20] A. Jena, M. Butler, T. Dwyer, K. Ellis, U. Engelke, R. Kirkham, K. Marriott, C. Paris, and V. Rajamanickam. The Next Billion Users of Visualization. *IEEE Computer Graphics and Applications*, 41(2):8–16, Mar. 2021. doi: 10.1109/MCG.2020.3044071 1

[21] H. Kennedy, R. L. Hill, G. Aiello, and W. Allen. The Work That Visualisation Conventions Do. *Information Communication and Society*, 19(6):715–735, 2016. doi: 10.1080/1369118X.2016.1153126 4

[22] S. Lee, S.-H. Kim, Y.-H. Hung, H. Lam, Y.-A. Kang, and J. S. Yi. How do People Make Sense of Unfamiliar Visualizations?: A Grounded Model of Novice's Information Visualization Sensemaking. *IEEE Transactions on Visualization and Computer Graphics*, 22(1):499–508, 2016. doi: 10.1109/TVCG.2015.2467195 4

[23] R. Mintzer-Sweeney. Support for right-to-left languages in all visualizations, 2022. https://blog.datawrapper.de/right-to-left-visualizations/ Accessed April 20, 2024. 2

[24] N. Rakotondravony, P. Dhawka, and M. Bancilhon. Beyond English : Centering Multilingualism in Data Visualization. In *Workshop on Visualization for Social Good, IEEEVIS*, pp. 1–5. IEEE, Melbourne, Australia, 2023. doi: 10.48550/arXiv.2309.06659 1

[25] L. Salmerón, R. Abu Mallouh, and Y. Kammerer. Location of navigation menus in websites: an experimental study with arabic users. *Universal Access in the Information Society*, 16:191–196, 2017. doi: 10.1007/s10209-015-0444-x 1

[26] E. Segel and J. Heer. Narrative Visualization: Telling Stories with Data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):1139–1148, Nov. 2010. doi: 10.1109/TVCG.2010.179 1

[27] K. Wu, E. Petersen, T. Ahmad, D. Burlinson, S. Tanis, and D. A. Szafr. Understanding Data Accessibility for People with Intellectual and Developmental Disabilities. In *Proceedings CHI*, pp. 1–16. ACM, Yokohama, Japan, 2021. doi: 10.1145/3411764.3445743 1

[28] K. Wu, M. H. Tran, E. Petersen, V. Koushik, and D. A. Szafir. Data, Data, Everywhere: Uncovering Everyday Data Experiences for People with Intellectual and Developmental Disabilities. In *Proceedings CHI*, pp. 1–17. ACM, Hamburg, Germany, 2023. doi: 10.1145/3544548.3581204 1