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Reading Comprehension and Processing Time When People With Aphasia Use Text-to-Speech Technology With Personalized Supports and Features

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ABSTRACT

Background: Person-centered approaches promote consistent use of supportive technology and feelings of empowerment for people with disabilities. Feature personalization is an aspect of person-centered approaches that can affect the benefit people with aphasia (PWA) derive from using text-to-speech (TTS) technology as a reading support.
Aims: This study's primary purpose was to compare the comprehension and processing time of PWA when performing TTS-supported reading with preferred settings for voice, speech output rate, highlighting type, and highlighting color versus unsupported reading. A secondary aim was to examine initial support and feature preference selections, preference changes following TTS exposure, and anticipated functional reading activities for utilizing TTS technology.
Method and Procedure: Twenty PWA read passages either via written text or text combined with TTS output using personally selected supports and features. Participants answered comprehension questions, reevaluated their preference selections, and provided feedback both about feature selections and possible future TTS technology uses.
Outcomes and Results: Comprehension accuracy did not vary significantly between reading conditions; however, processing time was significantly less in the TTS-supported condition, thus suggesting TTS support promoted greater reading speed without compromising comprehension. Most participants preferred the TTS condition and several anticipated benefits when reading lengthy and difficult materials. Alterations to initial settings were relatively rare.
Conclusions: Personalizing TTS systems is relevant to person-centered interventions. Reading with desired TTS system supports and features promotes improved reading efficiency by PWA compared with reading without TTS support. Attending to client preferences is important when customizing and implementing TTS technology as a reading support.

People with aphasia (PWA) often experience reading changes secondary to acquired language impairment (Brookshire et al., 2014). Altered decoding, comprehension, and speed can affect goals and expectations for postaphasia reading and participation in desired activities. Even though many PWA report reading less frequently than prior to acquiring aphasia, a continued desire often exists for engaging in social, leisure, and work activities that require written text processing (Knollman-Porter et al., 2015; Parr, 1995; Webster et al., 2018, 2021; Worrall et al., 2011). Because of this, designing and personalizing supports to compensate for reading challenges as well as customizing technology

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features to maximize enjoyment is critical for maintaining quality of life and increasing text engagement by PWA.

Personalization of Supports and Features

Including PWA when designing interventions and selecting supports and technology features increases empowerment and enhances motivation and ownership of compensatory strategies (Galliers et al., 2012). Wide variability in reading habits and abilities further highlights the need for customizing technological supports and features to match personal needs and preferences (Kjellén et al., 2017; Lynch et al., 2013). Given these phenomena, personalization is valuable for many aspects of aphasia reading intervention (Thiessen & Brown, 2021).

Text-to-speech (TTS) technology is an example of a compensatory support for reading that may benefit PWA. TTS software augments written text with synthesized speech output to present content simultaneously through auditory and visual modalities. Several customizable supports and features within TTS systems allow for personalization to match an individual's unique needs and preferences. In accordance with the framework of aphasia rehabilitation model (Helm-Estabrooks et al., 2014), aligning TTS supports and features with a person's goals and reading habits increases the likelihood of consistent support use, thus facilitating greater functional gains (Dalemans et al., 2008; Lasker & Bedrosian, 2000; Webster et al., 2021; Worrall et al., 2011). The dual-modality presentation of TTS also decreases the need to rely on others to read passages aloud, thus making it an attractive compensatory support for PWA seeking independence in everyday reading tasks (Knollman-Porter et al., 2015).

TTS Technology Supports and Features

Technological advances have resulted in increased access to digital reading materials, improvement in the quality and customization of TTS software, and wider accessibility to electronic supports during everyday life activities (Gell et al., 2015). Devices compatible with TTS technology (e.g., laptops, phones, e-readers, and tablets) have become increasingly portable and have a wide variety of cost and design options (Dietz et al., 2011; Lasker, 2011).

Design options within TTS systems comprise two categories: (a) those that are direct supports to word decoding and reading comprehension and (b) those that reflect personal preferences to maximize enjoyment while engaging in reading activities. The first category includes options for controlling the rate at which text is read aloud and the highlighting of words or sentences as they are read. Adjusting these supports allows PWA to customize TTS presentation in ways that align with their strengths and challenges regarding processing speed and attention. The second category includes options for selecting a preferred voice and having highlighted words appear in a preferred color. Adjusting these features may not directly affect a person's written text processing, but it may make reading activities more enjoyable. Of course, opting for a voice that is difficult to understand because of unusual pronunciation or prosody or selecting a highlighting color that makes it difficult to visualize the letters of a word (e.g., dark burgundy highlighting with black font) could have a detrimental effect on reading. However, neither people with nor without aphasia are likely to make such selections; instead, people are apt to select options that enhance the pleasure experienced when engaging in reading activities.

TTS Supports

Exploration of technological supports is warranted given that PWA often have difficulty allocating cognitive resources during complex tasks such as reading (McNeil et al., 1991). Impaired resource allocation leads to an increase in processing load that, in turn, causes decreased task accuracy and efficiency. The dual-modality presentation afforded by TTS systems can decrease working memory and cognitive resource demands (Wallace et al., 2012). Several researchers have shown that PWA experience improved comprehension, fluency, and attention during reading tasks given combined modalities (Elkind et al., 1996; Higgins & Raskind, 2004; Lasker et al., 1997). Dual-modality presentation also decreases the time required for completing reading tasks—a variable that relates to reading efficiency (Caute et al., 2016; Harvey et al., 2013; Hux et al., 2020). This can allow PWA to process time-sensitive or lengthy written materials more easily than they can without support (Harvey et al., 2013).

Researchers have performed several studies examining the preferences and comprehension accuracy of PWA when presented with different speech output rates or highlighting options available in TTS systems (e.g., Brown et al., 2021; Hux et al., 2020). Across these studies, PWA have indicated distinct, personalized preferences about optimal settings of TTS device supports, although differences in comprehension accuracy have only rarely occurred. A brief review of existing research appears in the following sections.

Speech output rate. The speech output rate of a TTS system is a concern because many PWA have difficulty processing verbalizations presented at rates commonly preferred by people without communication problems (Knollman-Porter et al., 2015; Webster et al., 2021). To determine the effect of TTS output rate on comprehension accuracy and reading efficiency, Hux et al. (2020) had PWA process passages presented at slow (113 words per minute [wpm]), medium (154 wpm), and fast (200 wpm) rates via dual-modality TTS simulation. Comprehension accuracy did not differ significantly across the three rates; however, the majority of participants reported a preference for the slow or medium rate. Also, a significant difference occurred across the rate conditions in the time participants took to review written content after the cessation of TTS presentation; specifically, the medium rate resulted in less additional viewing time than the fast rate. Thus, adjusting the speech output rate of TTS systems supports reading by PWA by improving efficiency.

Highlighting type. TTS software can modify text presentation through the presence or absence of text highlighting synchronized with the synthetic speech generation of words or sentences. Brown et al. (2021) found that varying highlighting supports (i.e., single word, sentence, or no highlighting) did not have a significant effect on comprehension during simultaneous written and auditory content presentation. However, the majority of participants preferred either single word or whole sentence highlighting to no highlighting, claiming that it bolstered attention and fostered synchronization of reading and listening.

TTS Feature Preferences

TTS technology also offers a variety of adjustable features that can enhance the reading experience for PWA. Examples of customizable features include voice options that vary regarding gender, dialect, and prosody and colors available when highlighting options are enabled. Although modifying TTS features in accordance with a person's preferences may not directly affect reading comprehension or efficiency, having preferred features may make engagement with the technology more pleasant and, in turn, increase the time PWA attend to written texts.

Current Study

Researchers have established the benefits of dual-modality presentation as a compensatory reading strategy for some PWA (Hux et al., 2017; Knollman-Porter et al., 2019; Lasker et al., 1997; Wallace et al., 2012). However, varying isolated TTS supports has not yielded significant improvements in comprehension. Despite this, most PWA participating in TTS-related research express a preference for TTS-supported reading and many experience improved efficiency over unsupported reading (Brown et al., 2021; Hux et al., 2020; Knollman-Porter et al., 2019). Researchers have also noted that PWA express strong personal preferences for feature settings, although these tend to be individualized rather than consistent across participants (Brown et al., 2021; Hux et al., 2020, 2021; Wallace et al., 2021). Given comprehension and time benefits for some, but not all, PWA and variability in desired settings for several TTS features, investigating comprehension accuracy and processing time variables when PWA use preferred TTS settings is of interest. Thus, the purpose of this study was to examine comprehension accuracy and processing time differences demonstrated by PWA when reviewing materials in two conditions—unsupported reading and TTS-supported reading using personally selected support and feature settings. A secondary purpose was to examine initial support and feature preference selections, preference changes following TTS exposure, and anticipated functional reading activities for utilizing TTS technology. Knowing whether PWA tend to retain or change support and feature preferences following engagement with TTS technology is important for guiding practitioners in planning how much exposure to provide before finalizing setting options. Specific research questions included the following:

(1) What are study participants' preferences regarding the TTS supports of speech output rate and highlighting option and the TTS features of voice and highlighting color prior to the experience of processing written content with TTS output?
(2) How does comprehension accuracy vary when study participants process written content in an unsupported condition and one in which TTS supports and features match personal preferences?
(3) How does processing time vary when study participants process written content in an unsupported condition and one in which TTS supports and features match personal preferences?
(4) How do TTS support and feature preferences of study participants vary between initial selections and those made following multiple opportunities to process written content with TTS output?
(5) What opinions do study participants have about TTS use in functional activities, and how do they foresee using TTS in the future?

Method

Participants

Participants included 12 men and eight women with chronic aphasia. They ranged in age from 36 to 75 years (M = 60, SD = 10.89) and were between 3- and 257-month poststroke or stable encephalopathy (M = 107.90, SD = 84.08). Participants had completed between 12 and 20 years of education (M = 15.80, SD = 2.12). All were right-hand dominant prior to acquiring aphasia and spoke American English as their primary language. Participants passed hearing and vision screenings to ensure adequate sensory abilities to complete the experimental tasks. The three participants who regularly wore hearing aids (i.e., C, F, and O) had received audiological services within the past year and demonstrated sufficient hearing to process conversational speech while wearing the aids. For all other participants, the hearing screening required perception in at least one ear of 1000-, 2000-, and 4000-Hz tones presented at 40 dB. The vision screening required accurate name identification in each of 12 rows of five names printed in 22-point, Times New Roman font. Candidates who could not independently utilize the technology needed for remote administration of the experimental procedures or did not have sufficient caregiver support to access the technology were excluded from participation ($n = 2$).

Demographic information and participants' standardized test results appear in Table 1. Results of standardized testing served descriptive rather than exclusionary purposes. Given that some participants had assessment data from prior research participation, we utilized existing records when available and did not repeat testing unnecessarily. If a participant had not performed the desired assessments within the past 12 months, we administered the missing measures prior to implementing other study procedures. Assessments included the Aphasia Quotient portion of the Western Aphasia Battery—Revised (WAB-R; Kertesz, 2006); the Comprehension of Spoken Paragraphs subtest of the Comprehensive Aphasia Test (Swinburn et al., 2004), and the Paragraph Factual subtest of the Reading Comprehension Battery for Aphasia—Second Edition (LaPointe & Horner, 1998).

Participants' WAB-R Aphasia Quotient scores ranged from 14.5 to 97.8 ($M = 64.56$, $SD = 22.62$). Per cutoff scores provided in the scoring manual, one participant exhibited very severe aphasia (i.e., scores ≤ 25), five exhibited severe aphasia (i.e., scores between 26 and 50), seven exhibited moderate aphasia (i.e., scores between 51 and 75), and six exhibited mild aphasia (i.e., scores between 76 and 93.8; Kertesz, 2006). The remaining participant scored above the threshold for an aphasia diagnosis according to WAB-R criteria but had a clinical diagnosis of aphasia and demonstrated language difficulties on other administered assessments.

Materials

Materials Binder

Participants received a binder containing research materials as well as computer operation and video conferencing instructions prior to study participation. The computer operation and video conferencing instructions incorporated aphasia-friendly formatting such as large font size and inclusion of images to support comprehension (Brennan et al., 2005; Rose et al., 2003). We placed all other research materials in six zippered pouches within the binder. Each pouch contained a set of 5 × 8 in. laminated cards for expressing TTS preference selection for voice (i.e., a title card and "male" and "female" voice cards), speech output rate (i.e., a title card and "faster," "just right," and "slower" rate cards), highlighting type (i.e., a title card and "no highlighting," "word highlighting," and "sentence highlighting" cards), or highlighting color (i.e., a title card and yellow, blue, gray, green, and pink highlighting color cards); multiple-choice comprehension question response (i.e., orange, green, yellow, and blue cards); or response selection confirmation (i.e., yes and no cards). Figure 1 provides a visual display of the binder contents.

Computer

Restrictions imposed secondary to the COVID-19 pandemic forced remote administration of study procedures via Webex or Zoom. To facilitate remote connection, we loaned participants a 17-in. Dell laptop computer equipped with WebEx or Zoom video conferencing software. Upon startup, the laptop screen was blank except for a single link connecting to a virtual video conferencing room.

PowerPoint Slideshows for TTS Education and Feature Selection

We created slideshows using Microsoft PowerPoint to provide TTS education information and to structure participants' selection of TTS support and feature preferences. The PowerPoint slides defined TTS output, explained the opportunity to read and listen simultaneously when using TTS technology, and identified various customizable TTS supports (i.e., speech output rate and highlighting type) and features (i.e., voice selection, and highlighting color). We presented all topics with aphasia-friendly formatting including large font, abundant white space, and images to support comprehension. The slideshow also included a sample video recording of a short passage presented with TTS system output.

Newspaper Articles

We edited 13 newspaper articles (12 experimental and one practice) for use when presenting personalized TTS-supported and unsupported reading tasks. All articles originated from U.S. news outlets were accessible online and were about topics of general interest but were unlikely to contain content familiar to participants. We edited the articles by removing full sentences to make them consistent regarding length (range in sentences: nine to 14 sentences, $M = 11$, $SD = 1.54$; range in words: 184–219 words, $M = 202.08$, $SD = 11.74$) and Flesch–Kincaid grade-level readability score (Flesch, 1948; range: nine to 10.9 grade level, $M = 10.02$, $SD = 0.73$).

Comprehension Questions

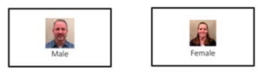
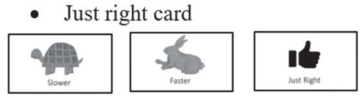
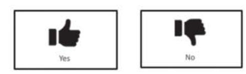
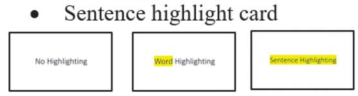
Each experimental article had six researcher-generated comprehension questions associated with it; the practice article had three associated questions. Each question appeared as an incomplete sentence with the final word or phrase missing along with four possible response options. Target responses reflected explicit content and maintained consistent wording and terminology from the article. Following the Structure Building Framework and Construction–Integration Model of Reading (Gernsbacher, 1997; Kintsch, 1998;

Table 1. Participant demographic and testing information.

								WAB-R	CAT	RCBA
Participant	**Race**	**Gender**	**Age (years)**	**Education level (years)**	**Time postonset (months)**	**Aphasia type**	**Fluency type**	**Aphasia quotient (100)**	**Spoken paragraph (4)**	**Paragraph factual (10)**
A	White	Female	66	14	257	Anomic	Fluent	70.0	4	9
B	White	Male	53	12	175	Broca's	Nonfluent	56.0	3	7
C	White	Female	75	16	255	Broca's	Nonfluent	37.1	3	9
D	White	Male	51	16	152	Broca's	Nonfluent	71.1	4	10
E	White	Female	71	15	38	Anomic	Fluent	88.5	3	10
F	White	Male	71	18	52	Transcortical motor	Nonfluent	61.7	4	8
G	White	Female	36	18	68	Anomic	Fluent	91.5	4	10
H	White	Female	75	12	106	Anomic	Fluent	65.0	1	8
I	White	Female	46	16	3	Anomic	Fluent	97.8	4	10
J	White	Male	66	20	19	Conduction	Fluent	71.7	3	9
K	White	Male	51	19	14	Transcortical sensory	Fluent	61.1	2	6
L	White	Male	48	16	209	Broca's	Nonfluent	49.2	2	3
M	White	Male	59	16	125	Broca's	Nonfluent	31.9	2	6
N	White	Male	57	12	180	Wernicke's	Fluent	44.4	2	6
O	White	Male	67	16	41	Global	Nonfluent	14.5	0	4
P	White	Male	66	16	35	Conduction	Fluent	78.9	2	10
Q	White	Male	50	16	118	Broca's	Nonfluent	42.4	2	7
R	White	Male	73	16	222	Anomic	Fluent	81.3	2	8
S	Black	Female	59	16	47	Anomic	Fluent	90.8	3	10
T	White	Female	60	16	42	Anomic	Fluent	86.2	4	10

Note. WAB-R = Western Aphasia Battery–Revised; CAT = Comprehensive Aphasia Test; RCBA = Reading Comprehension Battery for Aphasia.

Figure 1. Binder contents.

Materials binder		
Computer information	**Preference selection materials**	**Experimental materials**
Computer use instructions • Inserting charger • Turning laptop on/off • Logging into desktop • Connecting to Wi-Fi	Zippered pouch: Voice • Voice preference title card • Male voice card • Female voice card 	Zippered pouch: Multiple choice • Multiple choice color title card • Orange card • Green card • Yellow card • Blue card 
WebEx or Zoom Meeting Instructions • Accessing WebEx • Joining meeting • Changing volume • Exiting WebEx • Troubleshooting audio/video errors	Zippered pouch: Rate • Rates (in words per minute): 100, 130, 160, 190, 220, 250, 280 • Rate preference title card • Slower rate card • Faster rate card • Just right card 	Zippered pouch: Yes/no • General preferences title card • Yes card • No card 
	Zippered pouch: Highlighting • Highlighting preference title card • No highlight card • Word highlight card • Sentence highlight card 	
	Zippered pouch: Highlighting color • Highlighting color preference title card • Yellow card • Blue card • Gray card • Green card • Pink card 	

Kucheria et al., 2018; Rupp et al., 2006), the questions measured surface-level, concrete understanding of text reflecting comprehension of word and sentence meanings. Using multiple-choice formatting with four response options allowed content recognition to drive responses rather than free recall. This procedure ensured that the experimental task results better reflected reading comprehension than memory functioning. Completion of a dependency analysis following procedures established in previous research (e.g., Brown et al., 2018; Hux et al., 2020; Knollman-Porter et al., 2019) confirmed that people without language impairment, learning disability, or cognitive impairment could not guess correct responses to comprehension questions more than 40% of the time without having previously read the corresponding article. Hence, consistently selecting correct answers was dependent on reading and comprehending a stimulus article.

Reading Stimuli Presentation

We used Kurzweil 3000 software to create written only and combined written and auditory presentations of stimulus articles for unsupported and TTS-supported experimental conditions, respectively. Kurzweil 3000 is assistive technology software that augments written passages with TTS output. The software allows for customization of the TTS supports of speech output rate and highlighting type and the TTS features of voice and highlighting color.

We formatted each stimulus article to appear centered on the laptop screen in 22-point, Times New Roman font for the unsupported reading condition. Stimulus articles appeared on a participant's screen through the researcher's sharing of her screen. We used the same written text version of each stimulus article augmented by a participant's preferred support and feature selections as established during an initial experimental session for the

TTS-supported condition. For voice options, participants choose between the Microsoft David or Microsoft Heather voices. Speech output rate options included 100, 130, 160, 190, 220, 250, and 280 wpm. For text highlighting, we offered no highlighting, single word highlighting, or sentence highlighting. Highlighting color options were yellow, light blue, light green, pink, or gray. Acethinker Screen Grabber Pro software allowed us to capture audio and video stimulus recordings personalized for each participant. We handled occasional disruptions in TTS system functioning (e.g., failure to pause speech output at a period) by making minor text adjustments (e.g., insertion of a white period). This ensured smooth and consistent presentation of stimuli across participants.

Reading Task PowerPoint Slideshows

We used PowerPoint to create reading task slideshows to present the experimental stimulus recordings and comprehension questions. PowerPoint playback features ensured controlled and systematic presentation of articles and comprehension questions. We established a unique presentation order for each participant by randomly distributing the experimental articles across four slideshows such that each condition included two sets of three randomized articles.

Each stimulus trial began with presentation of the selected article formatted in the unsupported or TTS-supported reading condition. Each comprehension question appeared on a separate slide following the article. Question stems appeared at the top of the screen, and the four response options appeared in 2 × 2 grids with one cell each colored yellow, green, orange, or blue (see the Appendix). The subsequent slide requested yes/no confirmation of a participant's response. Across all stimulus articles, target responses corresponded with each color option approximately the same number of times.

Procedure

Institutional review boards approved the procedures prior to participant recruitment and data collection. This study was registered with clinicaltrials.gov and assigned clinical trial registry number 01446r.

Each participant performed the research procedures during two individual sessions occurring within 1 week. We video- and audio-recorded all experimental sessions using a Canon HF R700 or R800 camera and via Webex or Zoom to capture the processing time of each condition and to document participants' verbal and/or gestural responses regarding TTS support and feature selections.

Session 1

We first reviewed with each participant the TTS education slideshow using its associated script. We then utilized the TTS feature selection slideshows to assist participants in customizing supports and features in accordance with their preferences. Participants used the supplied selection cards to indicate a preferred voice, speech output rate, highlighting type, and highlighting color, if appropriate. We encouraged participants to provide rationales for their selections when this was feasible given expressive language abilities.

Procedures for selecting preferred settings were comparable across TTS supports and features. As an example, participants selected a preferred speech output rate by first locating and confirming accurate discrimination of the "slower," "faster," and "just right" rate cards. Then, they listened to and read along with a recording of TTS output at 190 wpm (i.e., "This is the medium rate. Do you want the rate to be slower, faster, or is it just right?"). Using the rate cards, participants indicated their satisfaction with the rate. If a participant requested a faster rate, a recorded sample corresponding to the next faster rate was played; conversely, if a participant requested a slower rate, a recorded sample corresponding to the next slower rate was played. This process continued until a participant decided on a preferred speech output rate.

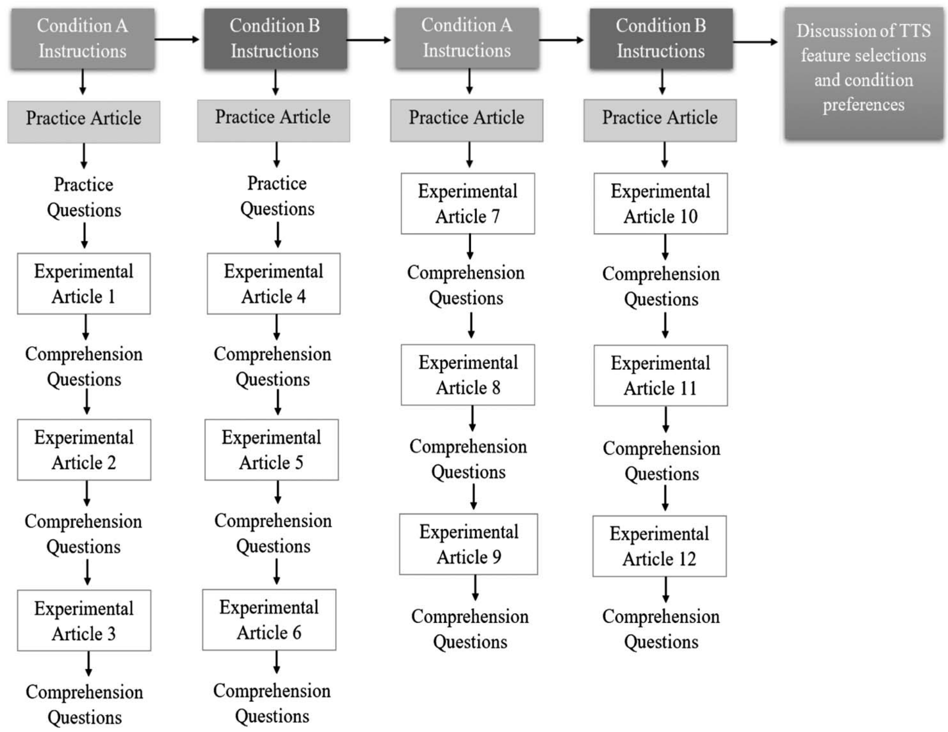
We confirmed satisfaction with feature selections by using the Kurzweil 3000 software to create and present a two-sentence TTS sample using all of a participant's personalized settings. If a participant subsequently expressed a desire to change a TTS support or feature setting, we returned to the corresponding section of the slideshow and repeated the selection process. We then repeated the two-sentence audio and video sample using the newly selected preferences. This procedure continued until the participant confirmed satisfaction with all selected settings.

Session 2

The second experimental session required performance of reading tasks presented both in the unsupported and TTS-supported reading conditions. Between Sessions 1 and 2, we created custom TTS audio and video recordings based on a participant's preferred support and feature settings and inserted the recordings into the appropriate PowerPoint slideshows.

Participants performed the reading tasks using the four sets of stimulus articles and associated comprehension questions. They could take breaks between stimulus sets as desired. Presentation alternated between stimulus sets for the unsupported and TTS-supported reading conditions (i.e., A ➔ B ➔ A ➔ B). Half of participants began with the unsupported condition, and half began with the TTS-supported condition. We opted to use a block design for stimulus presentation to ensure participants were aware of the content presentation features for upcoming reading passages. Figure 2 displays the Session 2 procedures.

Figure 2. Session 2 procedures. TTS = text-to-speech.



Participants located and removed the colored multiple-choice response cards and yes/no confirmation cards from zippered pouches in the binder. Presentation of the reading task slideshow began with an audio sample using a participant's preferred voice to test and adjust the loudness level. We then read aloud the written instructions appearing on the laptop screen and completed the practice reading task to familiarize participants with the task and current condition. This was followed by performance of the experimental trials beginning with the first stimulus set and progressing through each subsequent stimulus set in the pre-established order; repetition of the practice article—but without the comprehension questions—at the start of each subsequent set provided familiarization with the upcoming condition.

We instructed participants to read each article one time at their own pace when completing trials in the unsupported condition. Once a participant indicated completion, we progressed through the comprehension question slides. We read aloud each comprehension question and the response options appearing on the screen. To respond, a participant held up the colored response card corresponding with the desired answer; they then used the yes/no response cards to confirm the answer. Remote administration of the study procedures prompted use of this strategy as an alternative to having participants point to desired responses.

We used similar procedures to perform the experimental task in the TTS-supported condition. Participants listened to and simultaneously read each experimental article. Advancement to the first comprehension question occurred automatically 1 s after cessation of the speech output. Once again, we read each question and response options aloud, and participants used the response cards to select and confirm answers.

The session concluded with our posing of questions to solicit participants' opinions about the TTS support and feature selections they had made for the TTS-supported condition. We prompted participants to discuss any desired preference changes now that they had performed the reading tasks. We also asked participants which of the two conditions (i.e., unsupported or TTS-supported) they preferred and which they felt best aided their comprehension. We displayed each of these questions in written form, read them aloud, and provided supplemental explanations as needed to facilitate understanding. Finally, we asked which condition participants would be more likely to use during functional reading activities and how and with what materials they would likely use TTS technology if it were available to them in the future. Participants responded verbally and nonverbally as able given their expressive speech and language challenges. Participants with severe expressive challenges were given choices of possible question responses (e.g., books, newspaper articles, and text messages). If a participant's communicative intent was uncertain, we verified our understanding by asking yes/no questions.

Data Analysis

Variables of interest included participants' (a) initial selection of TTS support and feature settings, (b) comprehension accuracy in each experimental condition, (c) processing time in each experimental condition, (d) opinions about selected support and feature settings following exposure to stimuli in the TTS-supported condition, and (e) opinions about the use of TTS in functional contexts.

Participant Feature Preferences

We tallied the number of participants who selected each setting option for voice, speech output rate, highlighting type, and highlighting color during Session 1. We also totaled the number of participants who expressed a desire to change one or more preferences at the conclusion of Session 2. We recorded participant verbalizations and gestures generated to explain TTS support and feature setting preferences as well as any explanations provided about keeping or changing preference settings after exposure to the TTS-supported stimuli.

Statistical Treatment of Comprehension Accuracy and Processing Time Data

We performed Levene's Test for Equality of Variances to determine whether the population variances for comprehension accuracy and processing time were equal between the unsupported and supported conditions. On the basis of the Levene Test results, we performed either a paired-samples *t* test or Wilcoxon signed-ranks test to determine whether a significant difference existed between conditions. We further analyzed the group data by calculating and determining the significance of Pearson product–moment correlations among scores obtained on diagnostic tests, comprehension accuracy scores in both experimental conditions, and processing time durations in both experimental conditions.

Projected TTS Use in Functional Settings

We totaled the number of participants who expressed perceived uses in real-world settings for reading with TTS support, without TTS support, or sometimes with and sometimes without TTS support. We also recorded the types of reading materials spontaneously mentioned or identified in each condition along with a tally of the number of participants who mentioned each material. We recorded participant verbalizations and gestures to explain preferences about using TTS technology in functional settings as well as any explanations provided to support decisions to access certain materials with or without TTS support.

Results

Initial Feature Preferences

Participants made initial preference selections for TTS support and feature settings during Session 1. Of the 20 participants, 11 selected the male voice, and nine selected the female voice. The tendency was for people to select the voice that matched their gender (n = 15/20), but two men chose female voices and three women chose male voices. As a group, most participants preferred a TTS output rate near the middle of the options provided. Specifically, one participant selected a rate of 100 wpm, two selected 130 wpm, nine selected 160 wpm, six selected 190 wpm, and two selected 220 wpm. Regarding highlighting, 10 participants opted to have sentence highlighting, seven opted for word highlighting, and three did not want any highlighting. Participants with nonfluent aphasia chose word highlighting (n = 5) more often than sentence highlighting (n = 3), whereas participants with fluent aphasia chose sentence highlighting (n = 7) more often than word highlighting (n = 2); the three participants who opted to have no highlighting had fluent aphasia. Of the 17 participants desiring either sentence or word highlighting, seven opted for yellow, four opted for blue, two opted for green, two opted for pink, and two opted for gray. Table 2 shows participants' initial setting selections for each support and feature.

Table 2. Participant initial TTS support and feature preferences.

Participant	Initial preferences: Voice	Rate (wpm)	Highlighting type	Highlighting color
A	Male	160	Word	Blue
B	Male	160	Word	Blue
C	Female	160	Word	Yellow
D	Male	160	Word	Blue
E	Female	220	None	None
F	Male	160	Sentence	Yellow
G	Female	190	Sentence	Blue
H	Female	160	Sentence	Green
I	Male	190	Sentence	Gray
J	Male	160	Sentence	Yellow
K	Male	130	Sentence	Pink
L	Female	130	Sentence	Green
M	Male	160	Word	Yellow
N	Male	190	None	None
O	Male	160	Word	Yellow
P	Male	190	Sentence	Yellow
Q	Female	190	Sentence	Pink
R	Female	190	None	None
S	Female	100	Word	Yellow
T	Female	220	Sentence	Gray

Note. TTS = text-to-speech; wpm = words per minute.

Comprehension Accuracy

Participants achieved higher average percent correct comprehension scores in the unsupported condition (range: 36.11–91.67, $M = 66.53$, $SD = 16.12$) than in the TTS-supported condition (range: 30.56–83.33, $M = 64.03$, $SD = 14.18$). Figure 3 displays individual, average, and median comprehension accuracy scores for each condition. Performance of Levene's Test for Equality of Variances verified homogeneity of variance for comprehension accuracy between the two experimental conditions, $F(1, 19) = 0.519$, $p = .476$. Given this result, we performed a paired-samples t test to evaluate comprehension accuracy differences between the unsupported and TTS-supported reading conditions. Calculation of the paired-samples t test revealed no significant difference in comprehension accuracy, $t(19) = -0.972$, $p = .343$.

Processing Time

Participants spent less time reviewing articles presented in the TTS-supported condition (range: 362–864 s, $M = 576.75$ s, $SD = 120.95$) than in the unsupported reading condition (range: 225–2168 s, $M = 941.15$ s, $SD = 502.39$). Variability across participants was substantially greater in the unsupported than TTS-supported condition. Figure 4 presents individual, average, and median processing time durations for each condition. Performance of Levene's Test for Equality of Variances using the processing time data indicated heterogeneity of variance between the two experimental conditions, $F(1, 19) = 12.823$, $p = .001$. Hence, we performed a nonparametric Wilcoxon signed-ranks test to determine whether a significant difference in processing time existed between the unsupported and TTS-supported conditions. Computation of the Wilcoxon test revealed that the TTS-supported condition yielded significantly shorter processing times than the unsupported condition ($z = -2.912$, $p = .004$).

Correlations

Calculation and significance testing of the Pearson correlations appearing in Table 3 revealed significant positive correlations between standardized test results and TTS-supported and unsupported comprehension accuracy scores; thus, participants who achieved high scores on objective tests tended to respond more accurately to experimental task comprehension questions than participants who achieved low scores. A significant positive correlation also occurred between the TTS-supported and unsupported comprehension accuracy scores, thus indicating that strong performance in one experimental condition correlated with strong performance in the other experimental condition. In contrast, a negative correlation occurred between processing time in the TTS-supported condition and unsupported comprehension accuracy scores. This negative correlation suggested that longer articles—and, thus, ones requiring more time to present via TTS technology—were associated

Figure 3. Percentage of correct responses in TTS-supported and unsupported reading conditions. Letters reference participant identification codes. TTS = text-to-speech.

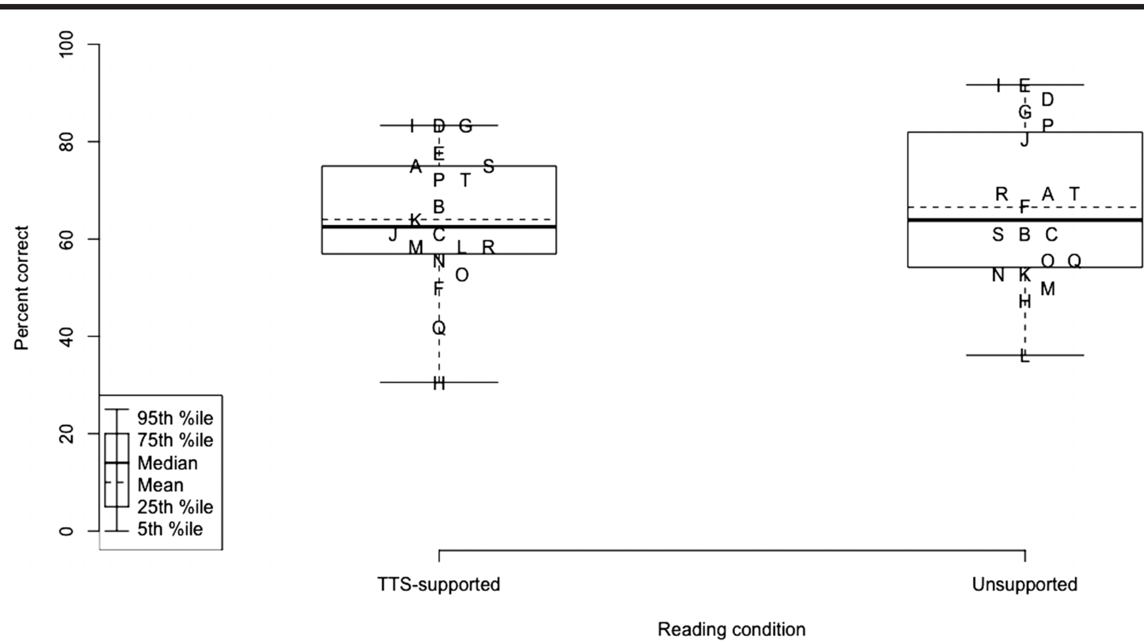
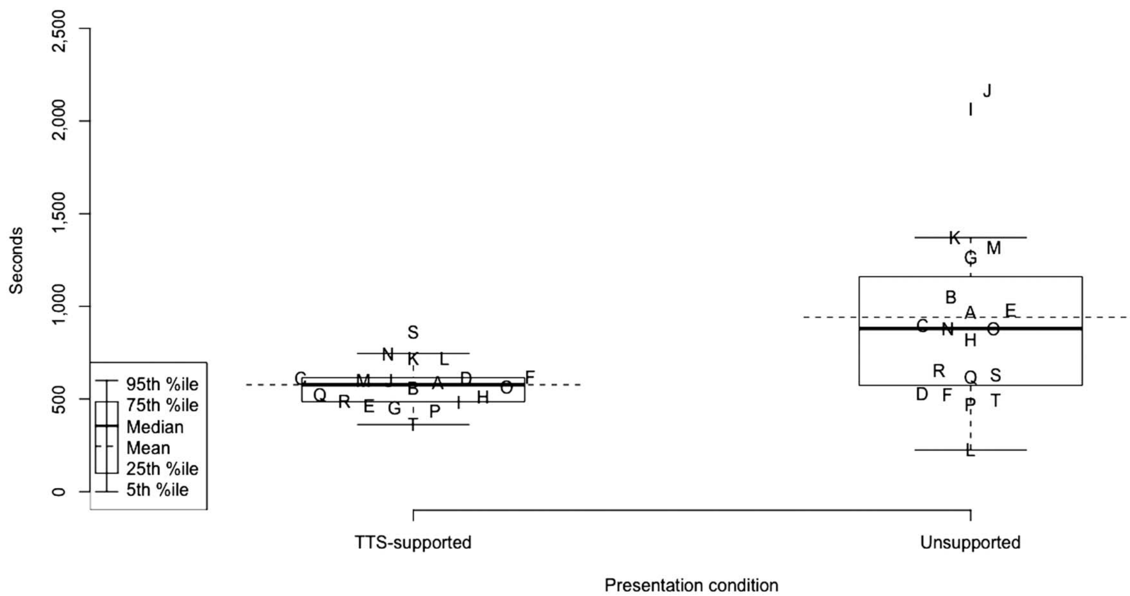


Figure 4. Length of time spent processing experimental articles in TTS-supported and unsupported conditions. Letters reference participant identification codes. TTS = text-to-speech.



with lower comprehension accuracy scores in the unsupported condition. However, given minimal length differences among experimental stimuli, functional implications of this negative correlation are unlikely.

TTS Versus Unsupported Reading Preferences and Perceived Understanding

Thirteen of the 20 participants (i.e., A, B, D, F J, K, L, M, O, P, Q, S, and T) expressed a preference for the TTS-supported condition, one (i.e., H) preferred the unsupported condition, and six (i.e., C, E, G, I, N, and R) preferred both conditions equally when performing the experimental tasks. Participant H explained that he preferred the unsupported condition, because it allowed him to alter his pace of reading throughout a passage.

Thirteen of the 20 participants (i.e., A, B, D, E, F, J, K, L, M, P, Q, S, and T) felt that they understood the experimental articles best in the TTS-supported condition, two (i.e., H, and I) felt that they understood best in the unsupported reading condition, and five (i.e., C, D, G, N, and R) felt that their understanding was the same in both conditions. Rationales for greater perceived comprehension in the TTS-supported condition included a greater ability to attend to (i.e., J and O) and remember (i.e., P) the material. Another participant (i.e., T) reported that the speech output of the TTS-supported condition helped her realize when she was reading words incorrectly. Rationales for greater comprehension in the unsupported condition included difficulty understanding synthetic speech word pronunciations (i.e., I) and feeling rushed given a set speech output rate (i.e., H and I).

Table 3. Pearson correlation coefficients among standardized test scores and experimental task performance.

Variable	1	2	3	4	5	6
1 WAB-R						
2 CAT	.624**					
3 RCBA	.778**	.680**				
4 TTS-supported comprehension accuracy	.612**	.670**	.567**			
5 Unsupported comprehension accuracy	.686**	.609**	.806**	.718**		
6 TTS-supported processing time	−.298	−.143	−.397	−.118	−.503*	
7 Unsupported processing time	.157	.156	.17	.211	.338	−.070

Note. WAB-R = Western Aphasia Battery–Revised; CAT = Comprehensive Aphasia Test; RCBA = Reading Comprehension Battery for Aphasia; TTS = text-to-speech; wpm = words per minute.

*$p < .05$. **$p < .01$.

Feature Preferences Following Experimental TTS Exposure

Participants re-evaluated their selected support and feature settings following multiple exposures to the TTS-supported trials in Session 2. None of the 20 participants wanted to change their voice or type of highlighting selection. By way of explanation, four expressed indifference about voice selection, and the remainder indicated satisfaction with their initial choice; all participants voiced satisfaction with their initial selection regarding highlighting type. However, five participants (i.e., A, I, L, P, and T) wanted to change their selected speech output rate. Of these, four wanted a slower rate than initially chosen because of expressed processing challenges, and one wanted a faster rate. Two also wanted to change their selected highlighting color (A: blue to green; L: green to yellow or blue).

Projected TTS Use in Functional Settings

Thirteen of 20 participants expressed a desire to use TTS technology during all real-world reading activities, three expressed a preference for reading unsupported (i.e., C, H, and R), and four wanted the option of utilizing both methods (i.e., G, I, N, and T). Of the 17 who desired access to TTS technology for at least some reading activities, 11 wanted it for reading books, and five wanted it for reading newspapers; less frequent desire for TTS technology access emerged for reading magazines or material on the Internet. Rationales for selecting specific materials centered on the advantage TTS technology provided for decreasing fatigue when reading lengthy texts. In contrast, two participants reported a wish to read newspapers and two reported wanting to read short materials (e.g., recipes and texts) without TTS support. Rationales from these participants focused on their feelings of satisfaction and competence when reading and understanding short texts or familiar materials.

Discussion

Adopting person-focused intervention approaches promotes clinician–client collaboration, client autonomy and motivation, and treatment saliency (Rathert et al., 2012). Technological supports for functional communication activities often provide opportunities for personalization that can improve accessibility and consistency of use (van de Sandt-Koenderman, 2004). Personalizing technology features is imperative, because every person with aphasia presents a unique profile of communication needs and preferences (Cistola et al., 2020). Examining the comprehension accuracy and processing time of PWA when performing TTS-supported reading with preferred settings versus unsupported reading was the primary purpose of this study. A secondary aim was to determine whether initial setting preferences changed following multiple exposures to TTS-supported reading. To obtain opinions about the potential benefits of TTS technology on functional reading tasks, we also queried PWA about everyday contexts in which they foresaw themselves using the technology. In combination, the study findings provide clinicians with information about the potential benefits and applications of TTS technology as a reading support for PWA.

Initial Feature Preferences

Historically, services for PWA have followed a medical model in which clinicians assume responsibility for determining and implementing a course of treatment based on deficits observed during assessment (Hofmann, 2005). Criticism that this model limits client autonomy and access to personalized care has prompted a shift toward person-centered approaches that foster greater client empowerment and participation in treatment development and implementation (Sacristán, 2013; White-Chu et al., 2009). In accordance with this philosophy, we implemented a person-centered decision-making model by allowing PWA to select preferred TTS supports and features from preselected options. We then measured their reading comprehension and processing time with the provision of personalized TTS support versus no support.

The TTS highlighting type and speech output rate settings initially selected by study participants were generally consistent with preferences reported in extant literature (Brown et al., 2021; Hux et al., 2020). Specifically, study participants' most preferred speech output rate of 160 wpm was comparable to the preferred "medium rate" of 154 wpm by participants in a study performed by Hux et al. (2020, p. 176). In both studies, rationales for preferring a rate around 160 wpm related to the importance of having sufficient time to decode words as they were being read and the desire to have a speed roughly comparable to conversational speech. In addition, most current study participants preferred either sentence or word highlighting rather than no highlighting—a finding comparable to that of participants in the study by Brown et al. (2021). Stated rationales included improved tracking of the text and a sense of enhanced concentration. Whether participants with fluent versus nonfluent aphasia differ regarding their preference for word or sentence highlighting remains uncertain. Regarding TTS feature preferences, highlighting color was variable across participants, and preference for a male versus female voice for speech output was roughly equivalent. A tendency was evident for people to select a voice matching their gender, but the relatively small sample size prevents generalization of this finding to PWA in general.

Comprehension Accuracy and Processing Time

No significant comprehension difference emerged between the TTS-supported and unsupported conditions. This is consistent with findings from previous researchers who have examined comprehension effects on PWA when manipulating isolated TTS features (Brown et al., 2021, Hux et al., 2017, 2020). However, a significant difference in the time participants took to process stimulus articles emerged between the two reading conditions; specifically, participants exhibited shorter processing time given TTS support than they did without support. This suggests that PWA are more efficient when they have access to personalized TTS technology than when they read without TTS support; comprehension accuracy does not suffer despite the shorter time spent processing materials. Similar findings have been observed by other researchers examining the effects of TTS technology on reading efficiency (Harvey et al., 2013; Knollman-Porter et al., 2019). This suggests a possible benefit of TTS technology is that it allows PWA to process written texts faster than they can otherwise. Because PWA often abandon reading tasks that are difficult or time consuming (Knollman-Porter et al., 2015), using TTS technology as a reading support warrants further investigation regarding engagement with challenging or lengthy materials.

Allowing participants to select a preferred synthetic speech output rate provides a possible explanation for finding a significant difference in processing time but not in comprehension accuracy. Most participants selected either 160 or 190 wpm as the desired rate despite evidence that comprehension improves when presentation occurs at rates slower than this (Hux et al., 2020; Pashek & Brookshire, 1982). Hence, having a presentation rate slower than 160 wpm may have yielded different comprehension accuracy results. The fact that most participants selected a medium or faster speech output rate suggests that they either (a) found the time spent reviewing written material was equally or more important than a high level of comprehension accuracy, (b) did not recognize the potential benefit associated with a slow presentation rate, or (c) desired to read at a rate comparable to that at which they read prior to acquiring aphasia or at a rate comparable to typical conversational speech. Perhaps, having a slow presentation rate fosters feelings of frustration or embarrassment (Webster et al., 2018). The fast pace of daily events with high demands for productivity and efficiency may contribute to these feelings.

Preference Changes Following TTS Exposure

Only five of the 20 participants indicated a desire to alter their initial preference selections following multiple exposures to written text with TTS support. Rationales for not modifying initial settings related to satisfaction with the support provided or the feature selected. Of the five participants desiring a change to their initial selections, all wanted to change the rate of speech output, with four of the five opting for a slower rate. Over- or underconfidence in perceived reading comprehension or a hope that TTS support would be adequate to facilitate a return to pre-aphasia reading ability are possible explanations for less-than-optimal initial selections. Alternately, participants may have misjudged the length and complexity of the experimental reading materials and, hence, found that their initial preferences were not optimal. We did not explicitly ask participants for rationales about their initial preferences, so we do not know the factors prompting their selections. However, the study findings support the notion that practitioners need to provide PWA with multiple opportunities to explore fully different TTS support and feature options. Adjustments to TTS settings may be appropriate as a person progresses through rehabilitation and learns to accommodate residual aspects of their aphasia or develops new goals related to reading speed or comprehension.

Another factor influencing participants' reluctance to alter TTS setting selections may have been our decision not to share comprehension accuracy information. This forced participants to make decisions about desired changes solely on the basis of self-perceptions about comprehension accuracy and reading efficiency. Prior researchers have found that decreased awareness of language abilities by PWA can interfere with motivation to use compensatory strategies (Cocchini et al., 2010; Rubens & Garrett, 1991). Given this phenomenon, providing feedback to PWA about their comprehension accuracy may be an appropriate clinical practice to promote selection of optimal settings. As suggested for evidence-based practice, integrating clinician and client perspectives with suggestions available in the extant literature is the best approach for designing effective interventions (American Speech-Language-Hearing Association, n.d.; Trinder & Reynolds, 2006).

Projected TTS Use in Functional Settings

An understanding of the contexts in which PWA are likely to utilize compensatory supports such as TTS augmentation is important when considering generalization to functional activities encountered during daily life. Given that PWA are more likely to maintain strategies they perceive as being relevant and effective in meeting salient needs (Lasker & Bedrosian, 2000), we questioned participants about the types of reading materials for which they thought support via TTS technology would be beneficial. Most participants (i.e., 17/20) expressed a desire to use

TTS technology for at least some routinely encountered situations; however, only a few (i.e., B, D, and J) anticipated using TTS technology with all encounters with written text. For example, eight participants expressed a preference for accessing TTS support only when reading lengthy or difficult materials (e.g., novels) or those with which they currently struggled; for short and easy materials (e.g., calendars and text messages), they preferred to rely on unsupported reading. For these participants, the support provided by TTS technology may promote success with a wider array of reading materials than currently exists. A desire to alternate between unsupported and TTS-supported reading based on situational demands was not uncommon. However, three participants had no desire to read with TTS support either because they were confident in their current reading ability, did not believe they would have access to the technology, or did not want to maintain a consistent reading rate throughout text engagement. Because of variability among PWA in reading ability and reading material preferences, considering contexts in which a person does and does not want TTS technology support is an important consideration.

Limitations

Limitations to this study concern our development of stimulus materials, selection of a TTS device for stimulus presentation, decision not to provide comprehension accuracy feedback, and sample population characteristics. Also, restrictions imposed because of the COVID-19 pandemic forced us to alter some procedural aspects of the research that may have affected outcomes. We address each of these issues separately.

We used edited newspaper articles as experimental reading passages. We opted for this type of written material, because it is similar to that which PWA are likely to encounter during functional reading activities. However, to enhance experimental control, we edited both the length and reading level of articles to make them relatively comparable. Although we included elements often present in actual newspaper articles—such as quotations and common abbreviations—and made modifications only by removing full sentences from the original articles, our changes resulted in the materials being representative of some, but not all, newspaper articles and other functional reading materials PWA might encounter.

Presentation of TTS support involved the use of Kurzweil 3000 software. We chose to use this software because it provided us with a way of manipulating the multiple TTS supports and features we wished to target for personalization. However, the Kurzweil system is one of the most expensive TTS systems available commercially, and it may be of better quality or have more adjustable features than other products. Still, even with the Kurzweil system, we occasionally had to alter story formatting to maintain appropriate text highlighting and smooth presentation of the TTS output. Many PWA are likely to lack the technological competency or language skills necessary to optimize TTS output in this manner. Hence, the experiences of PWA may differ depending on their use of Kurzweil 3000 software versus other TTS systems.

Another limitation stemmed from our decision not to provide feedback about comprehension accuracy or processing time after participants performed the experimental tasks in the TTS-supported or unsupported conditions. This procedural decision may have affected participants' decisions when asked whether they were satisfied with their initial TTS support and feature selections. Future researchers may wish to examine whether PWA use performance feedback to adjust TTS settings in an attempt to optimize reading comprehension and efficiency.

Another potential limitation is that we used convenience sampling to recruit study participants. This resulted in unequal representation of various aphasia types and severities. Unequal numbers of participants across subgroups prompted our decision to omit statistical analyses examining the effects of aphasia type and severity on reading comprehension, processing time, and preference selections.

A final limitation involves procedural adaptations made because of the COVID-19 pandemic. Specifically, we shifted from in-person data collection to remote administration of the experimental procedures. Overall, this adaptation was successful, but it may have affected the type of participants included in the study. In particular, participants had to have sufficient communication and computer navigation skills to use the provided laptop and materials binder to connect with us remotely. This added exclusionary criterion prevented some PWA from participating.

Future Directions

Several possible future research directions are possible. First, we presented short, edited newspaper articles as reading stimuli. The articles were consistent with some reading materials that PWA may encounter during daily life but certainly were not reflective of all such materials. Given that some participants expressed interest in using TTS technology to read short stories and books, determining the effect of personalized systems on reading comprehension and efficiency when engaged with these types of material is important clinically and with regard to quality of life questions. In fact, the benefits afforded by TTS technology may be more readily apparent when PWA attempt to process passages of greater length and difficulty than those included in the current and previous studies.

Another area of future research concerns the effects of experience and performance feedback on TTS support and feature selections. The results reported herein suggest that at least some PWA alter support and feature settings after gaining experience with the technology. Whether greater experience or the provision of performance feedback encourages additional adjustments remains unknown. We also do not know whether such adjustments result in actual changes in reading comprehension, efficiency, or engagement.

Yet another possibility for future research involves the monitoring of eye movements while PWA processes written materials with and without TTS support. We observed head and general eye gaze direction to monitor participant progress through the articles presented as experimental stimuli for this study. However, this observation did not allow us to measure the extent to which participants read along with the speech output provided in the TTS-supported condition. Hence, we do not know how much participants utilized the visual versus auditory modality of content presentation when provided with TTS support. Likewise, when presented with articles in the unsupported condition, we could not be certain that participants complied with our instructions to read a passage only 1 time. Using eye-tracking technology to capture and monitor eye gaze behaviors while reading in unsupported and TTS-supported conditions would foster greater understanding of the reading behaviors of PWA and the extent to which they rely on auditory and visual content when using TTS technology.

Conclusions

Allowing PWA to specify preferences to personalize TTS technology is relevant to the provision of person-centered interventions. Results from this study revealed no significant comprehension differences when PWA read passages without TTS support versus with TTS support and preferred settings, while a significant difference in processing time did occur. Specifically, participants spent less time processing newspaper articles while utilizing personalized TTS technology than when reading comparable articles without reading supports, corroborating similar results from past studies on the potential benefits of TTS use. This suggests that personalized TTS technology may improve the processing of written text by PWA without compromising comprehension. Similar to findings from past studies, the majority of study participants also preferred reading with TTS support and believed it aided their comprehension. Because self-perceptions about benefits associated with TTS support strategies and devices influence adoption and sustained use, clinicians should routinely include PWA to personalize reading supports in accordance with individual preferences.

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Appendix

Sample Comprehension Question Presentation Slides