

Research Article

A Pilot Study of Listening Fatigue: Impacts of Pediatric Dysarthria on Adult Listeners

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ABSTRACT

Purpose: We sought to characterize fatigue of adults when listening to speech of children with cerebral palsy (CP).**Method:** Fifty-seven children with CP (19 without dysarthria and 38 with dysarthria) produced single-word and multiword speech samples. One hundred fourteen adult listeners completed transcription intelligibility tasks and provided listening fatigue ratings. Multiword utterances were analyzed in terms of speech rate and communication efficiency.**Results:** Intraclass correlations showed large individual differences for listening fatigue ratings. Pearson correlations showed negative relationships between listening fatigue and intelligibility; however, the magnitude varied depending upon utterance length and dysarthria status of child speakers. Pearson correlations between listening fatigue and speech rate and between listening fatigue and communication efficiency varied depending upon dysarthria status of child speakers. Welch's *t* test showed that listeners of children with dysarthria had higher fatigue ratings than listeners of children without dysarthria. Listeners of children with dysarthria were more fatigued following multiword utterances than single-word utterances. Best subset regression showed that the combined effect of dysarthria status, intelligibility, and speech rate best explained listening fatigue of adult listeners.**Conclusions:** Listeners had increased levels of fatigue when they heard dysarthric speech relative to nondysarthric speech. The needs of both speaker and listener should be considered when supporting children with CP and dysarthria to achieve successful communication.

Cerebral palsy (CP) is the most prevalent nonprogressive neuromotor condition in childhood (Christensen et al., 2014; Maenner et al., 2016). Although CP is considered a motor disorder, children with CP often have multiple co-occurring conditions or secondary challenges such as communication impairment, which negatively impacts social participation and academic performance (Bax et al., 2006; Fauconnier et al., 2009; Rosenbaum et al., 2007). Communication is a dyadic process, such that unique characteristics of a speaker (e.g., specific speech subsystem

impairments and their effects on the acoustic speech signal) and unique characteristics of a listener (e.g., listening effort and fatigue) mutually influence successful communication (Lindblom, 1990). That is, listeners are not passive receivers of messages but take an active role in understanding what they hear (Klasner & Yorkston, 2005). Thus, aside from characterizing the speech features of children with CP, quantifying what listeners contribute to the communication process is crucial to holistically understand communication impairment experienced by children with CP and to develop appropriate interventions.

Dysarthria is a chronic neuromotor speech disorder that affects the structures and functions of one or more of the speech subsystems (respiration, phonation, articulation, resonance, and prosody), impacting functional use of speech in daily communication (Darley et al., 1969;

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Yorkston et al., 2010). At least half of children with CP have dysarthria (Mei et al., 2020; Nordberg et al., 2013). Previous studies have reported that intelligibility, speech rate (i.e., words per minute), and communication efficiency (i.e., intelligible words per minute) are key functional speech metrics for differentiating children with CP who have dysarthria from those with CP who do not have dysarthria (Hustad, Sakash, Broman, & Rathouz, 2019; Hustad et al., 2023). Specifically, children with CP who have dysarthria present with lower intelligibility, slower speech rate, and lower communication efficiency compared to children with CP who do not have dysarthria (Braza et al., 2019; Darling-White et al., 2018; Hustad et al., 2023).

Many factors influence intelligibility of speech. Length of utterance, or in the most basic form, whether a speaker is producing single-word utterances or multiword utterances, is one such factor. Studies across different populations including children with neurotypical development, children with dysarthria, and adults with dysarthria have consistently shown an intelligibility advantage for multiword utterances over single-word utterances (Hodge & Gotzke, 2014; Hustad, 2007; Hustad, Sakash, Natzke, et al., 2019; Hustad et al., 2021, 2023; Mahr et al., 2020; O'Neill, 1957; Yorkston & Beukelman, 1978, 1981). This advantage is associated with the presence of linguistic-contextual information available within multiword utterances that may aid listeners in inferring the meaning of utterances. One caveat, however, is that the advantage for multiword utterances was not observed for adults with moderate-to-profound dysarthria (Hustad, 2007; Yorkston & Beukelman, 1978, 1981), likely because there may not be enough information in the speech signal to enable listeners to fully leverage their linguistic knowledge.

Listening Effort

The presence of dysarthria adds a layer of complexity to speech processing for listeners, particularly in the case of children who are still developing and therefore produce a speech signal that is both immature and impacted by underlying subsystem impairments. Thus, processing demands on listeners are greater than for non-dysarthric and/or mature speech (i.e., requiring more effort and cognitive resources). Fletcher et al. (2022) studied whether listeners require more cognitive resources when listening to dysarthric speech compared to neurotypical speech. They used speech samples from one adult female speaker with moderate spastic dysarthria and one age-matched neurotypical adult female speaker. Adult listeners transcribed speech samples while concurrently attempting to remember words that were given prior to the transcription task. Results showed that listeners were less likely to recall words produced by the speaker with

dysarthria than words produced by the neurotypical speaker, suggesting that dysarthric speech required more listening effort (i.e., more cognitive resources) than neurotypical speech.

Additionally, Klasner (2003) conducted focus group discussions with listeners who heard speech samples from adults with dysarthria to determine perceived barriers when understanding dysarthric speech. Thematic analysis showed four categories of barriers: (a) segmental barriers, which pertained to speech sounds (e.g., “Sounds were slurred together.”); (b) suprasegmental barriers, which pertained to rate, rhythm, and/or prosody (e.g., “Pauses occurred in the wrong places.”); (c) linguistic barriers, which pertained to extracting meaning (e.g., “I couldn’t understand the sentence without the context.”); and (d) cognitive barriers, which pertained to cognitive processing (e.g., “I lost interest in understanding the sentence.”).

Klasner and Yorkston (2005) used the results of the focus group discussion to develop a scale that quantifies listeners’ perceived barriers to understanding dysarthric speech. Listeners completed this scale after transcribing speech samples from adults with dysarthria. Results showed that the majority of barriers related to segmental and linguistic features of dysarthric speech; however, listeners also reported cognitive barriers, such as “It was hard to listen to this sentence” and “I got distracted by the way the speech sounded,” further illustrating that listening to dysarthric speech imposes added cognitive demands.

In addition, studies have shown that speech intelligibility scores and listening effort (as measured through rating scales) are moderately to highly negatively correlated. That is, as speech intelligibility decreases, listening effort increases for adult listeners of dysarthric speakers (Beukelman et al., 2011; Connaghan et al., 2021; Cote-Reschny & Hodge, 2010; Landa et al., 2014; T. L. Whitehill & Wong, 2006). There is a paucity of research on the relationship of speech rate and communication efficiency with listening effort.

Listening Fatigue

Listening fatigue is a concept related to listening effort. Listening fatigue (or mental exhaustion) is a by-product of sustained effort when listening (Adams et al., 2023; Holman et al., 2019; Hornsby, 2013; McGarrigle et al., 2014). Literature examining listening fatigue is limited; studies include listening fatigue of adults with hearing impairment (e.g., Alhanbali et al., 2017; Bess & Hornsby, 2014; Hornsby et al., 2016; McGarrigle et al., 2014, 2021) and listening fatigue of children with hearing impairment (Hick & Tharpe, 2002). Using experimental manipulations of listening conditions, studies demonstrated, generally, that when listening tasks were more difficult, adult listeners with

hearing impairment had slower response times as tasks progressed; listeners also reported difficulty focusing and attending to listening tasks (Hornsby, 2013; McGarrigle et al., 2017). Qualitative studies suggest that listening fatigue of adult listeners with hearing impairment is multifaceted (Davis et al., 2021; Holman et al., 2019). Participants of focus group discussions reported different listening fatigue experiences such as physical (e.g., low energy and exhaustion), cognitive (e.g., difficulty thinking, no longer engaging in listening, and difficulty remembering things), social (e.g., avoidance and withdrawal from communication and/or social events), and emotional (e.g., stress and frustration).

Given that the fidelity of a speech signal is one factor that affects listener performance (Pisoni, 1982, as cited in Beukelman et al., 2011), lower intelligibility, slower speech rate, and lower communication efficiency are likely to lead to listening fatigue. Extrapolating findings from the hearing impairment literature to the experience of listening to speech that is not fully intelligible, the experience of listening fatigue might also be expected to include changes in cognitive processing and potential communication disengagement. However, studies have not examined listening fatigue of neurotypical adults for speakers with reduced intelligibility such as children whose speech is not fully mature or children with dysarthria who have an added disadvantage of reductions in intelligibility beyond those that are developmental. As a result, we do not know the extent to which adults who listen to children experience fatigue and how dysarthria may exacerbate fatigue. Therefore, our ability to develop interventions that support both speakers and listeners in the communication process is limited. The overarching aim of the present study was to characterize listening fatigue of adult listeners of children with CP. The following specific research questions were addressed:

1. Within single-word utterances produced by children with CP, what is the correlation between listening fatigue of adults and single-word intelligibility scores? Is there a difference in fatigue level for adult listeners of children with CP who have dysarthria versus adult listeners of children with CP who do not have dysarthria?
2. Within multiword utterances produced by children with CP, what is the correlation between listening fatigue of adults and multiword intelligibility scores as well as multiword speech rate and communication efficiency? Is there a difference in fatigue ratings for adult listeners of children with CP who have dysarthria versus adult listeners of children with CP who do not have dysarthria?
3. Within children with dysarthria, is listening fatigue of adults greater for multiword utterances versus single-word utterances?

4. Which of the following factors best explain adult listening fatigue ratings for multiword utterances: (a) dysarthria status, (b) intelligibility scores, (c) speech rate, or (d) communication efficiency?

As the presence of dysarthria increases listening complexity and cognitive demands, we hypothesize that the correlation between fatigue of adult listeners and child speech intelligibility for both single-word and multiword utterances will be different. In addition, we expect that adult listeners of children with dysarthria will report higher fatigue ratings than listeners of children without dysarthria for both single-word and multiword utterances. For multiword utterances, we expect that lower intelligibility scores, slower speech rate, and lower communication efficiency, which are hallmarks of dysarthria, will be associated with higher listening fatigue ratings. As the combined influence of dysarthria and longer utterances further increases listening complexity and cognitive demands, we hypothesize adult listeners of children with CP and dysarthria will report higher fatigue ratings for multiword utterances versus single-word utterances. Lastly, we hypothesize that combined effects rather than individual effects of dysarthria status, intelligibility, speech rate, or communication efficiency will best predict listening fatigue of adults.

Method

The University of Wisconsin–Madison Institutional Review Board (Minimal Risk Research Institutional Review Board Committee: 2013-1258 and 2018-0855) granted ethical approval for this study. Informed consent was provided by or on behalf of all participants.

Participants

Child Speakers

Children in the current study are a subset of an ongoing longitudinal cohort of children with CP (Hustad, Sakash, Natzke, et al., 2019; Hustad et al., 2020; Mahr et al., 2020). The cohort of children with CP was recruited through medical clinics in the Upper Midwest region of the United States. The aim of the ongoing longitudinal project was to prospectively collect and quantify the speech, language, cognitive, oral–motor, and communication skills of children with CP. Children from this cohort who (a) were between 6;0 and 6;11 (years;months), (b) completed a sentence repetition task, and (c) had no co-occurring diagnosis of autism were included in the current study. Fifty-seven children, comprising 31 boys and 26 girls, met the inclusion criteria. For children with more than one complete visit in the target age range, the youngest visit was selected. Using video and audio recordings

and assessment notes of the selected data collection visit, the presence or absence of dysarthria was determined by a certified speech-language pathologist through perceptual assessment of each child's speech, visual evaluation for drooling and/or facial asymmetry at rest and during movement, and orofacial muscle tone. Thirty-eight of the children had evidence of dysarthria, whereas 19 children did not have evidence of dysarthria. The mean age across children was 6;2 ($SD = 2$ months). The age range was 6;0–6;7. Demographic characteristics of the children in the current study are presented in Table 1.

Adult Listeners

One hundred fourteen naive adult listeners orthographically transcribed for measurement of intelligibility and provided fatigue ratings (i.e., two listeners per child speaker). Listeners (a) had no identified language, learning, or cognitive disabilities per self-report; (b) had passed a standard pure-tone hearing screening; and (c) were native monolingual speakers of American English. The

mean age of listeners was 21;4 ($SD = 3;7$). Five listeners did not report their age. Adult listeners were predominantly undergraduate students. Demographic characteristics of the adult listeners are presented in Table 2.

Materials and Procedure

All participants (i.e., child speakers and naive adult listeners) completed data collection in person at the Waisman Center, University of Wisconsin–Madison. Specific procedures are described below.

Child Speech Samples

In a sound-attenuated suite, children repeated a pre-determined set of utterances from the Test of Children's Speech (Hodge & Gotzke, 2014), which included 38 single-word utterances and 60 multiword utterances (i.e., 10 utterances of two to seven words in length; available via open access in Hustad et al., 2021). All children completed single-word utterances ($n = 57$); however, only 54

Table 1. Demographic information for children with cerebral palsy ($N = 57$).

Characteristic	With dysarthria ($n = 38$)	Without dysarthria ($n = 19$)	Total ($N = 57$)
	Male–female ratio		
Sex (designated at birth)	17:21	14:5	31:26
	M (SD in months)		
Age in years;months	6;2 (2)	6;3 (2)	6;2 (2)
	Frequency		
Race			
White	31	18	49
Black	2	0	2
Guatemalan	2	0	2
Asian	1	0	1
Mixed	1	1	2
Not reported	1	0	1
Ethnicity			
Hispanic/Latino	3	1	4
Not Hispanic/Latino	33	16	49
Not reported	2	2	4
Cerebral palsy type			
Spastic	29	17	46
Diplegia	6	5	11
Hemiplegia (left)	3	10	13
Hemiplegia (right)	11	2	13
Triplegia	6	0	6
Quadriplegia	2	0	2
Not reported	1	0	1
Ataxic	3	1	4
Dyskinetic	1	0	1
Hypotonic	1	0	1
Mixed	1	0	1
Unknown	3	1	4

Table 2. Demographics of adult listeners ($N = 114$).

Characteristic	Frequency	Percentage
Gender		
Female	84	73.68%
Male	30	26.32%
Ethnicity		
Hispanic	6	5.26%
Not Hispanic	108	94.74%
Race		
White	94	82.46%
Black	4	3.51%
Asian	5	4.39%
Mixed	8	7.02%
Did not report	3	2.63%

children completed multiword utterances. Three children with dysarthria were not able to repeat multiword utterances. Children's speech samples were recorded at a 44.1-kHz sampling rate using professional quality equipment (i.e., Audio-Technica AT4040 condenser studio microphone, Mackie 12010 VLZ mixer, and Denon DN-500R SD audio recorder) while a research assistant monitored the recording quality of each production. Research assistants with background in acoustic analysis segmented the recorded speech samples from each child participant into individual utterances. Segmented utterances were peak amplitude normalized to control for differences in distance between the microphone and child's mouth due to head movement. This automated process involves using the highest peak value as an anchor reference for normalizing the speech sample. The subsequent normalized speech sample retains the original contours of the child's speech. For each child participant, we used segmented utterances to collect single-word and multiword transcription intelligibility scores and listening fatigue ratings from adult listeners. Only multiword utterances were used for computing speech rate and communication efficiency.

Transcription Intelligibility Scores

Speech intelligibility scores quantify how well a listener understands a speaker and is an indicator of overall speech performance (Beukelman & Yorkston, 1979; Perez, 1983; T. Whitehill et al., 2011). To obtain intelligibility scores, utterances from each child participant were presented in two blocks based on type of utterance: single-word utterances versus multiword utterances. The two blocks of utterance types were counterbalanced such that half of the listeners for each child received the single-word block first and half received the multiword block first. Within each block, the sequence of utterances was randomized for each listener. Listeners completed the transcription task in a sound-attenuating booth. In-house software was used to present individual utterances. Individual

utterances were played only once through an external speaker, which was calibrated to a peak output level of 75 dB SPL from the seat of the listener.

Two listeners orthographically transcribed speech samples for each child speaker ($n = 114$). For each listener, orthographic transcriptions of individual words in each utterance were scored as correct when (a) all phonemes matched the target word or (b) the transcribed word phonemically matched the spoken version (i.e., homonym). Transcription intelligibility scores for the 38 single-word utterances and the 60 multiword utterances were computed separately. For single-word utterances, transcription intelligibility scores were computed by dividing the total number of words correctly identified by the total number of intended words. For multiword utterances, transcription intelligibility scores were computed by (a) dividing the total number of words correctly identified by the total number of intended words across each utterance length (i.e., two to seven words) and (b) averaging scores across each utterance length. The individual listener data for each child were used for analyses.

Intelligibility Intraclass Correlation Coefficient

As we used individual ratings of the two listeners for each child speaker, we estimated the interrater reliability of intelligibility scores and fatigue ratings using intraclass correlation coefficient (ICC). The ICCs for intelligibility and fatigue ratings were computed using the irr R package (Version 0.84.1; Gamer et al., 2019). The descriptive categories of Koo and Li (2016) for ICC were used. That is, ICC estimate with a 95% confidence interval (CI) lower than .5 is poor, that between .5 and .75 is moderate, that between .75 and .95 is good, and that above .95 is excellent reliability.

Using an average-score, agreement-based, one-way random-effects model, there was excellent interrater agreement among single-word intelligibility scores, $ICC(2) = .98$, 95% CI [.97, .99]. The average of the absolute value of the difference between the two listeners for single-word intelligibility was 0.05 (on a continuous scale ranging from 0 to 1), and the SD was 0.05. Likewise, there was excellent interrater agreement among multiword intelligibility scores, $ICC(2) = .99$, 95% CI [.98, .99]. The average of the absolute value of the difference between the two listeners for multiword intelligibility was 0.05, and the SD was 0.05.

Listening Fatigue Ratings

Listeners rated their fatigue level twice: (a) after they transcribed all single-word utterances and (b) after they transcribed all multiword utterances. Note that the order of the blocks of single-word versus multiword utterance types was counterbalanced. Listeners responded to the prompt "I felt fatigued from trying to understand this child" using a hybrid visual analog scale with integers marked from 1 to 7. Anchors were 1 = *strongly disagree*

and 7 = *strongly agree* (see Figure 1). The rating scale used in this study was adapted from the rating scale used by Beukelman et al. (2011) for measuring perceived attention allocation (i.e., listening effort). The individual listener data for each child were used for analyses.

Listening Fatigue ICC

Using an average-score, agreement-based, one-way random-effects model, there was poor to moderate interrater agreement among single-word listening fatigue ratings of adults, $ICC(2) = .40$, 95% CI $[-.01, .65]$. The average of the absolute value of the difference between the two listeners for fatigue ratings of single-word utterances was 1.51, and the *SD* was 1.37. Similarly, there was poor-to-moderate interrater agreement among multiword listening fatigue ratings of adults, $ICC(2) = .51$, 95% CI $[.16, .71]$. The average of the absolute value of the difference between the two listeners for fatigue ratings of multiword utterances was 1.49, and the *SD* was 1.33.

Speech Rate

Speech rate is the number of speech units produced over time, such as the number of words per minute including pauses (Huici et al., 2016). To determine speech rate inclusive of pauses, the duration of each multiword utterance from start to end was measured using the Montreal Forced Aligner (Version 2.0; McAuliffe et al., 2017). See Mahr, Berisha, et al. (2021) and Mahr, Soriano, et al. (2021) for more information. For each multiword utterance, speech rate was computed as the number of words spoken per minute and was averaged across the 60 multiword utterances produced by each child.

Communication Efficiency

Communication efficiency measures the combined influence of intelligibility and speech rate on the communication process and is quantified as the number of words correctly understood over a specific unit of time (i.e., intelligible words per minute; Hustad, Sakash, Broman, & Rathouz, 2019; Yorkston & Beukelman, 1981). Communication efficiency for each child speaker was computed by multiplying the multiword intelligibility score and speech rate in words per minute, resulting in an intelligible words per minute value.

Statistical Procedure

To answer the first three research questions addressing the relationship of listening fatigue and speech features of child speakers (i.e., intelligibility, speech rate, communication efficiency, and dysarthria status), we computed Pearson correlations across individual listeners (for single-word utterances: $n = 76$ for children with dysarthria and $n = 38$ for children without dysarthria; for multiword utterances: $n = 70$ for children with dysarthria and $n = 38$ for children without dysarthria). Given that speech features and listening fatigue are different constructs, we used the following descriptive categories for level of correlation. We considered $r = .1-.29$ as small, $r = .3-.49$ as medium, and $r = .5$ and above as large, based on Cohen (1988, as cited in MacKinnon et al., 2002).

To determine if there was a difference in fatigue level for listeners of children with CP who have dysarthria versus listeners of children with CP who do not have dysarthria, we used unequal variances *t* test (Welch's *t* test). To determine if listening fatigue was greater for multiword utterances versus single-word utterances, we used a paired *t* test. Pearson correlations were completed using the DescTools package (Version 0.99.54; Signorell et al., 2024). Welch's *t* test and paired *t* test were completed using the stats package (Version 3.3.3; R Core Team, 2024).

To determine which factors (i.e., dysarthria status, multiword intelligibility scores, multiword speech rate, and/or multiword communication efficiency) best explain listening fatigue level for multiword utterances, we pursued a "best subset regression" approach (i.e., implementing linear regression for all possible models with individual factors and combinations of factors), specifying Mallows' C_p as the comparative fit index across models (Rawlings, 1988). Using Hocking's (1976, as cited in Rawlings, 1988) selection criteria, we computed Mallows' $C_p - 2p' + t$, where p' is the number of factors of the model including the intercept and t is the total number of factors under consideration (i.e., 4). A subset model with the most negative value, excluding the subset model that contained all possible factors ("Best Subsets Regression," n.d.), was considered to be the best subset of predictors that explained listening fatigue. Subset regression and computation of Mallows' C_p was completed using the

Figure 1. Listening fatigue rating scale.

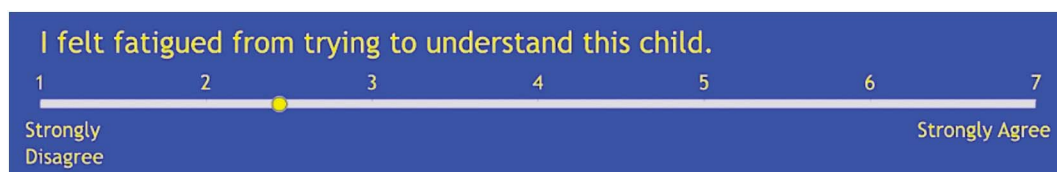


Table 3. Descriptive statistics of study variables.

Variable	<i>n</i>	<i>M</i>	<i>SD</i>	Range
Single word: listening fatigue of adults				
Children with dysarthria	76	3.55	1.65	1.00–7.00
Children without dysarthria	38	2.06	1.14	1.00–6.43
Single word: intelligibility scores				
Children with dysarthria	76	0.46	0.25	0.00–0.82
Children without dysarthria	38	0.81	0.08	0.62–0.95
Multiword: listening fatigue of adults				
Children with dysarthria	70	4.05	1.58	1.00–7.00
Children without dysarthria	38	2.31	1.42	1.00–5.74
Multiword: intelligibility scores				
Children with dysarthria	70	0.50	0.29	0.00–0.95
Children without dysarthria	38	0.90	0.06	0.77–0.98
Multiword: speech rate (words per minute)				
Children with dysarthria	35	133.07	25.25	72.23–185.77
Children without dysarthria	19	150.01	16.91	119.55–185.47
Multiword: communication efficiency				
Children with dysarthria	35	69.43	42.85	0.00–136.12
Children without dysarthria	19	135.55	16.93	102.97–161.25

Note. All children completed single-word utterances ($n = 57$); however, only 54 children completed multiword utterances. There were two adult listeners per child ($N = 114$).

leaps R package (Version 3.1; Lumley, 2020). Data analysis was executed in R (Version 3.3.3; R Core Team, 2024) and R studio (Version 2023.12.1 + 402; Posit Software, PBC, 2022).

Results

Descriptive Results

Table 3 summarizes descriptive statistics of the study variables. In general, children with dysarthria had lower single-word and multiword intelligibility scores, speech rate, and communication efficiency than children without dysarthria. Adults who listened to children with dysarthria reported higher fatigue than adults who listened to children without dysarthria.

Research Question 1: Within Single-Word Utterances Produced by Children With CP, What Is the Correlation Between Listening Fatigue of Adults and Single-Word Intelligibility Scores? Is There a Difference in Fatigue Level for Adult Listeners of Children With CP Who Have Dysarthria Versus Adult Listeners of Children With CP Who Do Not Have Dysarthria?

Figure 2 shows a scatter plot of adult listening fatigue ratings and single-word intelligibility scores grouped by dysarthria status of child speakers. Table 4 summarizes the Pearson correlation values of the relationship between

listening fatigue ratings and single-word intelligibility scores. Results indicated a medium-sized negative correlation between adult listening fatigue ratings and single-word intelligibility scores of children with dysarthria. In contrast, this same relationship for children without dysarthria was a very small negative correlation, nearly zero. Mean fatigue ratings for adult listeners of children with dysarthria ($M = 3.55$, $SD = 1.65$) were significantly higher, $t(100.74) = 5.6$,

Figure 2. Scatter plot of listening fatigue ratings and single-word intelligibility scores grouped by dysarthria status of child speakers.

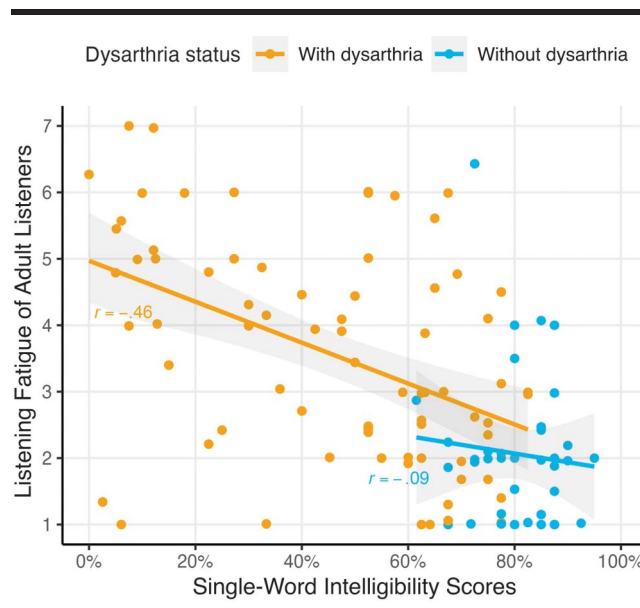


Table 4. Pearson correlation values of the relationship of listening fatigue ratings of adults and single-word intelligibility scores.

Participant	n	r	95% confidence interval	
			Lower boundary	Upper boundary
Children with dysarthria	76	-.46	-.62	-.26
Children without dysarthria	38	-.09	-.40	.24

$p < .001$, than that for adult listeners of children without dysarthria ($M = 2.06$, $SD = 1.14$).

Research Question 2: Within Multiword Utterances Produced by Children With CP, What Is the Correlation Between Listening Fatigue of Adults and Multiword Intelligibility Scores as Well as Multiword Speech Rate and Communication Efficiency? Is There a Difference in Fatigue Ratings for Adult Listeners of Children With CP Who Have Dysarthria Versus Adult Listeners of Children With CP Who Do Not Have Dysarthria?

Figure 3 shows scatter plots of adult listening fatigue ratings and multiword speech features (i.e., intelligibility scores, speech rate, and communication efficiency) grouped by dysarthria status of child speakers. Table 5 summarizes the Pearson correlation values of the relationship between adult listening fatigue ratings and multiword speech features of child speakers.

For the relationship between adult listening fatigue ratings and multiword intelligibility scores, results showed a medium-sized negative correlation for children with dysarthria; however, the correlation was small and negative

for children without dysarthria. The relationship between adult listening fatigue ratings and speech rate was a very small negative correlation (nearly zero) for children with dysarthria and a small positive correlation for children without dysarthria. For the relationship between adult listening fatigue ratings and communication efficiency, results showed a medium negative correlation for children with dysarthria; however, the relationship was a very small positive correlation (nearly zero) for children without dysarthria. Mean fatigue ratings for listeners of children with dysarthria ($M = 4.05$, $SD = 1.58$) were significantly higher, $t(83.59) = 5.9$, $p < .001$, than those for listeners of children without dysarthria ($M = 2.31$, $SD = 1.42$).

Research Question 3: Within Children With Dysarthria, Is Listening Fatigue of Adults Greater for Multiword Utterances Versus Single-Word Utterances?

Results of paired t test showed a significant listening fatigue effect between types of utterances, $t(69) = 3.33$, $p < .001$. That is, mean fatigue ratings of adults for multiword utterances ($M = 4.05$, $SD = 1.58$) were significantly higher than those for single-word utterances ($M = 3.55$, $SD = 1.65$). However, results showed no significant

Figure 3. Scatter plots of listening fatigue ratings with multiword intelligibility scores, speech rate, and communication efficiency grouped by dysarthria status of child speakers.

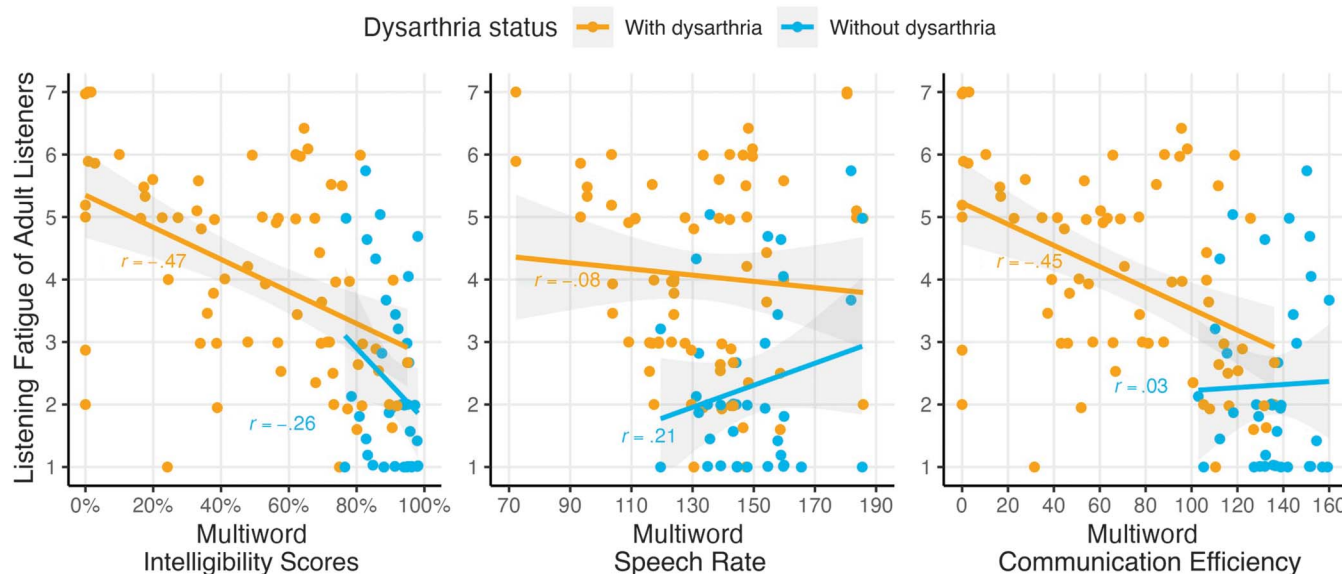


Table 5. Pearson correlation values of the relationship of listening fatigue ratings of adults and multiword intelligibility scores, speech rate, and communication efficiency.

Variable	<i>n</i>	<i>r</i>	95% confidence interval	
			Lower boundary	Upper boundary
Multiword intelligibility scores and listening fatigue ratings				
Children with dysarthria	70	-.47	-.63	-.26
Children without dysarthria	38	-.26	-.53	.07
Multiword speech rate and listening fatigue ratings				
Children with dysarthria	70	-.08	-.31	.16
Children without dysarthria	38	.21	-.12	.49
Communication efficiency and listening fatigue ratings				
Children with dysarthria	70	-.45	-.62	-.24
Children without dysarthria	38	.03	-.29	.34

intelligibility effect between types of utterances, $t(69) = 0.99$, $p = .16$. For both types of utterances, mean intelligibility scores were low (for multiword utterances: $M = 0.50$, $SD = 0.29$; for single-word utterances: $M = 0.46$, $SD = 0.25$; see Table 3 for ranges).

Research Question 4: Which of the Following Factors Best Explain Adult Listening Fatigue Ratings for Multiword Utterances: (a) Dysarthria Status, (b) Intelligibility Scores, (c) Speech Rate, or (d) Communication Efficiency?

Table 6 summarizes the Mallows' C_p of all possible linear regression models with individual factors and combinations of factors. Results indicate that the combined effect of dysarthria status, intelligibility, and speech rate best explains listening fatigue of adult listeners for multiword utterances using the " $C_p - 2p' + t$ " criteria to select the best-fitting model.

Table 6. Mallows' C_p of subset regression.

Variables in the model	p'	C_p	$C_p - 2p' + t$
Dysarthria status, intelligibility, and speech rate	4	3.043	-0.957
Dysarthria status, intelligibility, and communication efficiency	4	3.162	-0.838
Dysarthria status and intelligibility	3	1.851	-0.149
Dysarthria status, speech rate, and communication efficiency	4	4.783	0.783
Intelligibility, speech rate, and communication efficiency	4	6.808	2.808
Intelligibility and speech rate	3	5.017	3.017
Intelligibility and communication efficiency	3	5.358	3.358
Intelligibility	2	3.394	3.394
Dysarthria status and communication efficiency	3	5.799	3.799
Speech rate and communication efficiency	3	6.695	4.695
Communication efficiency	2	8.094	8.094
Dysarthria status	2	22.593	20.593
Dysarthria status and speech rate	3	20.604	20.604
Speech rate	2	53.681	53.681

Note. p' = number of regression parameters of the model including intercept; C_p = Mallows' C_p ; t = total number of variables under consideration, which is 4.

Discussion

This study examined adult listeners' experience of fatigue when listening to the speech of children with CP (including children who had dysarthria as well as children who did not have dysarthria). Adult listeners were asked to rate their level of fatigue using the prompt "I felt fatigued from trying to understand this child" using a continuous scale from 1 to 7. Fatigue ratings were provided by two different listeners for each of 57 child speakers following each of two counterbalanced orthographic transcription tasks, one for single-word utterances and one for multiword utterances. Key findings were that (a) there were considerable individual differences among listeners in the experience of fatigue and (b) listening fatigue was influenced by dysarthria status, intelligibility, and speech rate of children with CP. These findings are discussed in detail below.

Individual Differences Among Listening Fatigue Ratings

Klasner and Yorkston (2005) advocated for considering what listeners contribute to the speaker–listener interaction because communication is dyadic. Subsequently, researchers have examined different variables related to perceptual processing and learning by listeners of dysarthric speech (Borrie et al., 2017, 2023; Borrie & Lansford, 2021; Borrie, McAuliffe, & Liss, 2012; Borrie, McAuliffe, Liss, Kirk, et al., 2012; Borrie, McAuliffe, Liss, O’Beirne, & Anderson, 2012); however, to date, no studies have examined how fatigued listeners report feeling after listening to dysarthric speech from adults or children. Results of the current study showed that individual listeners who heard the same child in the same listening task can have quite different listening experiences with regard to how fatigued they report feeling after listening (resulting in poor-to-moderate interrater agreement). Even more interesting is the fact that these same listeners had similar intelligibility scores for the same child (resulting in excellent interrater agreement). These findings suggest that adult listeners were able to process speech with almost identical levels of accuracy, and yet they varied substantially in how fatigued they felt afterwards. This finding is consistent with the results of qualitative studies (focus group discussions) on the perspective of adults with hearing loss on listening fatigue (Davis et al., 2021; Holman et al., 2019), which showed that the majority of the participants (but not all) experienced listening fatigue to varying degrees, secondary to different personal factors (e.g., motivation and coping strategies). This finding highlights the importance of understanding listener variability or individual differences among listeners (similar to understanding individual differences among speakers) and the impact of these differences on the success of the speaker–listener interaction. Moreover, studies that have examined the relationship between how well a speaker was understood and listener variables such as familiarity with the speaker (Flipsen, 1995; Holmes et al., 2018; Levi et al., 2011) and proficiency with the language being used (Kilman et al., 2014; Rimikis et al., 2013; Shi, 2011, 2013) suggest that unique listener characteristics influence how well listeners understand a speaker. However, there is a paucity of studies that investigate the relationship between unique listener characteristics and listening fatigue associated with dysarthric speech. To develop optimal assessment and intervention for children with dysarthria that takes into account the role of listeners in the communication process, studies on how individual differences of listeners influence their performance are needed. To do this, future studies should examine fatigue ratings from more than two listeners per child speaker to capture a fine-grained understanding of listener variability.

In the present study, listening fatigue was measured using a continuous rating scale from 1 to 7. One of the advantages of using a rating scale is that it is quick and easy to complete, particularly in a clinical setting. However, listeners rely on their own interpretation of rating scale prompts and anchors on the scale (Ishikawa et al., 2021; Miller, 2013; Schiavetti, 1992). Moreover, listeners may have had different baseline levels of listening fatigue. These factors may have contributed to the variability in listening fatigue ratings, in addition to unique listener variables. Future studies should consider developing operational definitions of listening fatigue to facilitate a similar understanding of the construct across listeners and collecting listening fatigue rating before a listening task to understand baseline status.

Listening Fatigue Is Influenced by Dysarthria Status, Intelligibility, and Speech Rate of Children With CP

A key finding of the current study was that listening fatigue was best explained by the combined effect of dysarthria status, intelligibility, and speech rate of children with CP. Furthermore, communication efficiency did not uniquely contribute to listening fatigue, likely because the metric itself is based on both intelligibility and speech rate. The individual relationships of listening fatigue with dysarthria status, listening fatigue with intelligibility, and listening fatigue with speech rate are discussed in detail below.

Listening Fatigue and Dysarthria Status

The majority of studies on children with CP have focused on the impact of dysarthria on the speech motor characteristics of the speaker (e.g., Allison & Hustad, 2018a, 2018b; Chen et al., 2018; DuHadway & Hustad, 2012; Lee et al., 2014; Patel et al., 2012) and functional speech performance of the speaker (e.g., Braza et al., 2019; Haas et al., 2021, 2022; Hustad, Sakash, Broman, & Rathouz, 2019; Hustad et al., 2023). These studies have established that the speech signal from children with dysarthria is affected by development and by the impacts of underlying subsystem impairments, which result in a distorted acoustic signal (as compared to neurotypical speech), in turn, affecting intelligibility and speech rate. In addition, studies on the relationship of listening effort of adult listeners and intelligibility of children with CP and dysarthria showed higher listening effort ratings for less intelligible words (Cote-Reschny & Hodge, 2010; Landa et al., 2014). In other words, attempting to understand distorted acoustic signals required more effort and cognitive resources from listeners. Results of the current

study extend existing literature, showing that listening to and then orthographically transcribing single-word utterances and multiword utterances led to increased listening fatigue for dysarthric speech (relative to nondysarthric speech). This suggests that prolonged exposure to and processing of dysarthric speech, which likely involved exerting more effort and using more cognitive resources, resulted in greater listening fatigue. Considering the likely connection between listening effort and listening fatigue, studies that measure listening effort in conjunction with listening fatigue are needed to better quantify the perceptual load for listeners.

A unique challenge with studying children with disabilities is disentangling the impact of disability from the impact of developmental immaturity on daily performance. Specifically, determining the impact of dysarthria from the impact of speech development on listening fatigue is an important theoretical and clinical question. This line of research inquiry can aid with determining how much fatigue results from listening to dysarthric speech above and beyond any fatigue associated with listening to developmentally immature speech that is not fully intelligible. Results of the present study provide some insight into this question based on data from children with CP who did not have dysarthria. Although these children were not neurotypical, they did not show clinical evidence of speech motor impairment, and previous studies from our lab have suggested that they do not differ significantly in terms of speech intelligibility from neurotypical peers (Hustad et al., 2023). In the present study, we found that adult listeners who heard children without dysarthria, on average, reported a mean listening fatigue rating of 2.06 and 2.31 (on a continuous scale from 1 to 7) for single-word utterances and multiword utterances, respectively. Listeners who heard children with dysarthria, on average, reported higher listening fatigue ratings (mean ratings of 3.55 and 4.05 for single-word utterances and multiword utterances, respectively). A tentative conclusion based on these findings is that for children in our study, who were 6 years of age, a mean rating of 3.0 or lower may reflect fatigue effects of developmental immaturity for children who are at or above 80% intelligible. On the other hand, an average fatigue rating higher than approximately 3.0 may reflect the added impacts of processing dysarthric speech for 6-year-old children. Given the poor-to-moderate interrater agreement between the two adult listeners on their fatigue ratings, studies with more listeners per child speaker are needed to validate this tentative conclusion. In addition, these results are specific to the children in this study who were homogenous with regard to their age; however, future studies should seek to quantify the extent to which dysarthria, across the continuum of severity levels, adds to listening fatigue for listeners of children.

Listening Fatigue and Intelligibility

In this study, we found that there was a negative correlation between intelligibility and fatigue, with listeners experiencing more fatigue for children who were less intelligible. This finding is consistent with existing literature on listening effort across different speaker populations including children and adults with dysarthria, adults with head and neck cancer, and adults using electrolarynx (Beukelman et al., 2011; Connaghan et al., 2021; Cote-Reschny & Hodge, 2010; Eadie et al., 2021; Landa et al., 2014; Nagle & Eadie, 2018; T. L. Whitehill & Wong, 2006). That is, higher listening effort is associated with lower intelligibility scores. Note, however, that studies on listening effort and intelligibility of speakers with dysarthria did not include speakers without dysarthria; thus, there was no comparison between dysarthric versus nondysarthric speech. In the current study, results showed that the effect of intelligibility on listening fatigue was greater for children with dysarthria compared to children without dysarthria (see Tables 4 and 5), suggesting that children with dysarthria were at a greater risk of experiencing a negative impact of listening fatigue. A noteworthy factor to consider is the interconnection of intelligibility and dysarthria. That is, more severe dysarthria led to lower intelligibility scores. From the present study, we do not know the extent to which dysarthria itself is associated with listener fatigue or whether reduced intelligibility, regardless of the origin, might be the driving force behind listener fatigue. Studies that include children with lower intelligibility scores associated with development as well as different underlying etiologies are needed to explore this possibility.

For children with dysarthria, listening fatigue was higher for multiword utterances than for single-word utterances by about 0.5 points, whereas intelligibility scores did not differ for the two types of utterances. One tentative explanation for this finding is that the presence of dysarthria limited listeners from utilizing the linguistic-contextual information available within multiword utterances. As a result, listeners may have needed to exert more effort to process each individual word, thereby increasing fatigue. Studies examining both effort and fatigue may provide insight into this possibility. Specifically, studies should examine the extent to which increased effort may be associated with processing longer utterances, which in turn may lead to fatigue. In addition, studies need to examine how these cognitive impacts interact with intelligibility.

Listening Fatigue and Speech Rate

Compared to the effect of intelligibility on listening fatigue, the effect of speech rate on listening fatigue was considerably smaller, particularly for children with

dysarthria. Although the magnitude of the correlation between listening fatigue and speech rate was similar to our findings for the correlation between listening fatigue and intelligibility in children without dysarthria (see Table 5), the correlation was in the opposite direction, indicating that as rate increased, fatigue ratings also increased.

Generally, results from the present study are in line with the findings of Hustad, Sakash, Broman, and Rathouz (2019), who found that speech intelligibility measures separated among children with CP who did and did not have dysarthria more strongly than rate measures. In the present study, this finding may manifest as intelligibility being a primary source of fatigue and speech rate as a secondary source for listeners. In addition, results of the current study may suggest a U-shaped relationship between speech rate and listening fatigue (see middle panel of Figure 3) wherein the majority of the child speakers fell within the middle range (contributing to the lower effect size for speech rate). Descriptively, our data suggest that listeners who heard speech that was either very slow or very fast (relative to the group of speakers examined in this article) reported higher listening fatigue ratings. One implication may be that listening fatigue is not limited to speech disorders associated with slow speech rate (e.g., dysarthria) but may also include speech disorders associated with faster speech rate (e.g., cluttering). Studies examining the relationship of listening fatigue and speech rate associated with other speech disorders are needed to further examine the effect of speech rate on listening fatigue.

Clinical Implications

Increased listening fatigue is a potential barrier to successful communication exchanges, particularly if listening fatigue leads to increased cognitive processing load (Hornsby, 2013; McGarrigle et al., 2017) and communication disengagement (Davis et al., 2021; Holman et al., 2019). This highlights the potential usefulness of quantifying listening fatigue and considering the reduction of listening fatigue as a valued intervention outcome for speech treatment. Indeed, addressing only functional speech performance of a speaker, without regard for impacts on communication partners/listeners, is addressing only one side of the dyadic communication process.

The International Classification of Functioning, Disability and Health (ICF; World Health Organization, 2007) provides a framework that can help clinicians take into consideration the needs of both speaker and listener in the communication process. In particular, examination of the social environment as a contextual factor of the ICF may help clinicians take into consideration the active role of communicative partners. For example, asking communication partners about their listening fatigue during

assessment of a speaker may provide a broader picture of how children are functioning in their environment. It may also aid with developing and implementing appropriate strategies to manage listening fatigue. Although studies focused on developing and testing interventions and strategies for alleviating listening fatigue are needed, various intervention approaches could be considered.

Yorkston et al. (1996) recommended strategies for facilitating comprehensibility of dysarthric speech, which may serve to reduce listening fatigue. For example, they suggest maximizing visual speech information, watching the face of the speaker, and conversing when the speaker is not eating or drinking. They also suggest environmental management, such as being in a quiet and well-lit room as a way to lessen distraction and/or additional challenges in understanding dysarthric speech. In addition, the use of augmentative communication or speech supplementation strategies, such as alphabet supplementation and/or topic supplementation, has been shown to help improve intelligibility, in part by providing linguistic cues to listeners (Hustad & Beukelman, 2001, 2002). Given the relationship of intelligibility and listening fatigue, augmentative communication or speech supplementation strategies may alleviate listening fatigue; low-tech tools such as topic boards and alphabet boards are readily available and easy to implement and may reduce listening burden and subsequently listening fatigue. Studies are needed to quantify the impact of such strategies on listening fatigue and enable evidence-based recommendations.

Lastly, research on perceptual processing and learning by listeners of dysarthric speech has shown the benefit of perceptual learning paradigms on improving speech intelligibility of dysarthric speech (Borrie et al., 2017, 2023; Borrie & Lansford, 2021; Borrie, McAuliffe, & Liss, 2012; Borrie, McAuliffe, Liss, Kirk, et al., 2012; Borrie, McAuliffe, Liss, O'Beirne, & Anderson, 2012). The use of perceptual learning paradigms, which includes exposing listeners to dysarthric speech and providing different kinds of feedback regarding what speakers are saying, may hold promise for reducing listening fatigue. Again, studies are needed to support evidence-based recommendations.

Limitations and Future Directions

The results of the current study expand our knowledge regarding the impact of dysarthria on listeners. However, the study has several variables that limit ecological validity and generalization of the results to different populations. The study was conducted in a sound-attenuating room, and speech samples were presented in a controlled manner. This is very different from conversations that occur in real communicative contexts, which typically involve some level of noise and availability of gestural

cues and topic cues that interact with the speaker's speech. The presence of noise may exacerbate listening fatigue; on the other hand, additional conversational context cues may inhibit listening fatigue. Studies that occur in real environments with real communicative contexts are needed.

A significant limitation of the present study is that the experience of fatigue was highly variable among listeners even in the idealized listening environment utilized in this study, even for listeners of the same child, and even when intelligibility scores had a very strong ICC. This preliminary study provides a starting point for large-scale studies needed to further advance our understanding of listening fatigue. That is, future studies that include more listeners are needed to explore factors that contribute to listener variability. In addition, more studies are needed to examine the utility of different approaches for measuring fatigue.

The data set included monolingual child speakers and adult listeners, which limits the generalizability of the results to other populations such as bilingual child speakers and adult listeners. Studies that include bilingual child speakers and adult listeners are needed to better support speakers and listeners in a pluralistic society such as the United States.

Lastly, adult listeners in the current study were predominantly undergraduate students who passed a hearing screening. Considering that individuals with hearing loss experience listening fatigue (particularly older adults; McGarrigle et al., 2021) and children with CP interact with older adults with hearing impairments (e.g., grandparents), studies that examine the listening fatigue of adults with a wider range of hearing abilities are crucial.

Conclusions

The impact of dysarthria is undeniably felt by listeners and is not limited to speakers alone. The present study documented the wide variability among listeners in the experience of fatigue and the association of listening fatigue with dysarthria status and functional speech metrics. Given the neurological nature of dysarthria, children with conditions such as CP that are present from birth experience the effects of reduced intelligibility and speech rate throughout their development. Focusing on improving functional speech performance of a speaker, without addressing the potential needs of a listener, is addressing only one side of the dyadic communication process. Speech-language pathologists should consider the needs of both speaker and listener to holistically support children with CP and dysarthria in achieving successful communication.

Data Availability Statement

The data are not publicly available due to human subject privacy restrictions. The data used for the analyses presented in this study may be made available upon request.

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