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Facing phonological complexity as an autistic adult: An exploratory study

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Abstract

Background and aims: While it has been suggested that phonology is relatively spared in autism, some studies have shown that many autistic children and adolescents exhibit severe phonological impairment, of which syllabic complexity is a reliable index. However, although autism is a lifelong disorder, no such evidence exists for adults. The aim of the present study is to bridge this knowledge gap by investigating how autistic adults deal with phonological complexity.

Method: Phonological abilities were assessed in 48 autistic adults aged 18 to 56 years and 50 controls matched on age and sex/gender. A linguistically motivated Nonword Repetition (NWR) task manipulating syllabic complexity, LITMUS-QU(Quasi Universal)-FR(ench)-NWR-Adults, was used to distinguish participants with and without a phonological impairment. In addition to the NWR task, additional tests were conducted to examine potential factors influencing phonological performance. These measures included morphosyntax, vocabulary, nonverbal IQ (NVIQ), short-term memory, working memory, and autism severity, providing a comprehensive understanding of variables affecting phonological abilities in autistic adults.

Results: Global performance on NWR was significantly lower and spanned a wider range in the autism group than that in the control group. By looking at individual results across the structures and substructures included in NWR, which presented varying degrees of syllabic complexity, it was possible to uncover great variability among autistic individuals with a phonologicalimpairment. Phonological proficiency appeared to be related to morphosyntax rather than to lexical knowledge and nonverbal cognition, including memory. Moreover, phonological skills did not correlate with autism severity.

Conclusions: This study represents a first step towards understanding how to characterize phonological skills in autistic adults. Our findings indicate that syllabic complexity prompts diverse behaviors among autistic individuals with impaired phonology. Further research is required to gain insight into the cause(s) underlying the detected difficulties.

Keywords
Autism, adulthood, phonology

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that is increasingly diagnosed worldwide (with an estimated prevalence of 1 in 36 eight-year-olds; Maenner et al., 2023). It is defined by the presence of persistent deficits in social interaction and communication coexisting with a range of restricted and repetitive behaviors and interests (DSM-5-TR, American Psychiatric Association [APA], 2022; ICD-11, World Health Organization [WHO], 2023).

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Although no longer part of the diagnostic criteria, the presence/absence of any accompanying language impairment (LI) in those receiving an autism diagnosis must be specified (APA, 2022; WHO, 2023). Great heterogeneity exists in the language phenotypes associated with autism and while all autistic individuals show impairment in at least some aspects of pragmatics, many also have difficulties with structural language, including phonology.

Research on phonology in autism is limited, partly due to the fact that phonology has been regarded by some as relatively spared in the autistic population (Rapin & Dunn, 2003). However, several recent studies have shown that a higher proportion of autistic children have impaired phonology compared to typically developing (TD) children (McCleery et al., 2006) and that almost a quarter of autistic children present with severely impaired phonology (Rapin et al., 2009). For some of those children, difficulties emerge when syllabic complexity comes into play. Consonant clusters are a well-attested source of complexity (i.e., two-segment consonant groups) as well as internal codas (i.e., optional syllabic constituents following a vowel). Processes leading to a simplification of complex syllabic structures, including cluster reduction (e.g., *spoon* → [bu]) and final consonant deletion (e.g., *green* → [wi]), have been observed in spontaneous language samples of some autistic children with phonological difficulties. Such processes are common in typical development, but they are found beyond the expected age in autism (Wolk & Brennan, 2013; Wolk & Edwards, 1993; Wolk & Giesen, 2000). The effect of complexity on phonological production in autism was also reported by Tuller et al. (2017) based on a word repetition task requiring participants to repeat real words varying in syllable length and phonological complexity. Language-impaired autistic children (ASD-LI) aged 6–12 years failed to produce liquids in final cluster positions (e.g., /tɛʁmomɛtʁ/ 'thermometer') and internal coda positions (e.g., /ɔʁlɔʒ/ 'clock'), and obstruents in internal coda positions (e.g., /tʁaktœʁ/ 'tractor'), although they had little to no difficulty producing branching liquids (e.g., the second /ʁ/ in /ʁefʁiʒeratœʁ/ 'fridge'), as well as /s/ in initial clusters (e.g., /splɪt/ 'split') and in final clusters (e.g., /kask/ 'helmet'). Strategies of complexity avoidance mostly consisted in phonemic substitution and omission.

In addition to spontaneous speech sample analysis and word repetition, Nonword Repetition (NWR) tasks have been used to characterize the phonological profiles of autistic children. There is abundant evidence that NWR is one of the most reliable tools to screen structural language impairment and is a reliable measure of phonological abilities in autism (Schaeffer et al., 2023). However, since most NWR tasks assess different phonological structures via items of varying syllabic lengths, they have been used as a measure of phonological short-term memory as well as of phonology (Coady & Evans 2008). In order to tap specifically into phonology, NWR needs to be designed by manipulating syllabic complexity, to which (autistic and non-autistic) individuals displaying LI seem to be particularly sensitive, and by limiting the length of the items, so as to control for the effect of short-term memory. In a recent study on the phonological abilities of Arabic-speaking children with and without autism, Abd El-Raziq et al. (2024) examined the effects of length (1–4 syllables) and phonological complexity (presence or absence of consonant clusters/sequences) on the NWR accuracy scores of TD and autistic children aged 5–11 years. Neither length nor phonological complexity were found to impact performance: while TD and autistic children with normal language (ASD-LN) accurately repeated nonwords (henceforth NWs) regardless of their length and complexity, ASD-LI children showed profound difficulties in repeating short and multi-syllabic phonological structures, including complex structures.

Given their attested sensitivity to LI (Conti-Ramsden et al., 2001), NWR tasks have been extensively used in studies comparing ASD and Developmental Language Disorder (DLD). One recent example is the study of Georgiou and Spanoudis (2021), who investigated potential discrepancies in the performance of autistic children with and without LI and children with DLD aged 6–12 years. Their NWR task included NWs of four different lengths, ranging from two to five syllables, with low wordlikeness (unlikely to be rated as real words in Greek). Both language-impaired groups were reported to perform significantly worse than age-matched TD children. This finding is consistent with several previous studies, supporting that children with ASD-LI and those with DLD have similarly poor NWR performance (see Durrleman & Delage, 2016; Taylor et al., 2014). Using an NWR task including items two to five syllables long, Tager-Flusberg (2015) showed that ASD-LI ($M = 10;1$ years) and DLD children ($M = 11;2$ years) displayed analogous error patterns, specifically substitutions and omissions. Other studies found that children with ASD-LI differ from those with DLD. In the study of Hill et al. (2015), ASD-LI and DLD children listened to pre-recorded NWs of two to four syllables with low wordlikeness and low complexity (no consonant clusters). The authors showed that children with DLD produced significantly more phoneme errors compared to autistic children in response to two- and three-syllable NWs. Along the same lines, for example, Williams et al. (2013) assessed phonological abilities in language-impaired autistic preadolescents and in peers with DLD via an experimental NWR task manipulating a range of phonological characteristics (i.e., length, wordlikeness, and cluster position). Quantitative and qualitative error analysis showed that the participants with DLD performed lower than those with ASD-LI or with TD (matched on verbal mental age). In addition, preadolescents with DLD were found to make errors changing the structural integrity of the cluster and its segmental content more frequently than ASD-LI and TD participants. According to the authors, these findings indicate that the phonological impairment exhibited by autistic individuals are less pervasive than those displayed by individuals with DLD, in that they are delayed rather than deviant (see also Botting & Conti-Ramsden, 2003; Riches et al., 2011; Whitehouse et al., 2008). The same hypothesis was put forward by Nadig and Mulligan (2017), who compared the performance of kindergarten-aged autistic children with language delays to younger language-matched TD children on an NWR task involving a limited set of early-acquired phonemes. The authors extended evidence of delayed but qualitatively typical nonword repetition to young autistic children ($M = 5$ years) by showing that, for very simple four-syllable stimuli, they had better repetition accuracy than a language-matched TD group. Taken together, these results suggest that, despite differences in the early acquisition stages, the phonological system of autistic children with a language delay develops in a typical fashion. However, existing studies are inconclusive as to whether phonology is delayed or deviant. To answer this question, it is necessary to assess phonological skills across the lifespan, including in autistic adults, a population that has historically been largely neglected in studies on language in autism (Happé & Frith, 2020).

To our knowledge, Pijnacker et al. (2009) is the only study that explored phonological abilities in autistic adults. Using the Auditory Discrimination Task—subtest C (ADIT-C; Crul & Peters, 1976) as a measure of phonological abilities, they compared the performance of three groups of participants: autistic individuals with a history of language delay (so-called *High Functioning Autism*), autistic individuals without a history of language delay (Asperger's syndrome in the DSM-IV; APA 1994), and age-matched controls. The three groups did not differ significantly, which hints to an overall absence of phonological difficulties in autism. However, as the name of the test suggests, ADIT-C was designed to assess the auditory discrimination and phonetic sound differences in words, rather than expressive phonology. Very little is thus known about the phonological capacities of autistic adults.

Building on this gap in knowledge, the main objective of our study is to provide insight into the phonological skills of autistic adults via the use of a linguistically motivated NWR task.

This is important for theoretical and clinical reasons. A better theoretical understanding of phonological skills in this population would help shed light on the mechanism(s) underlying phonological impairment. In this respect, exploring the relationship between phonology and autism severity is particularly important, since one major hypothesis in autism research holds that LI in autistic individuals is a direct result of pervasive autism features. Whitehouse et al. (2008) showed that weak performance on an NWR task, considered by the authors as assessing phonological short-term memory, tended to co-occur with increased autistic symptomatology in autistic children. The authors claimed that poor performance on such tasks might be explained by autism-related difficulties such as attending to others' speech and imitating others. However, significant correlations between low NWR rates and autism severity measures have not consistently been found in either child (see Hill et al., 2015) or adult studies. Girolamo and Rice (2022), who conducted a study aimed at understanding how to better identify LI in autistic adolescents and young adults, found no correlation between a syllable repetition task, considered by the authors to be an NWR task assessing verbal working memory, and autism severity, as measured by the total score of the Social Responsiveness Scale, Second Edition (SRS-2, Constantino & Gruber, 2012). Therefore, sufficient evidence has not yet been provided to support the hypothesis of a potentially causal association between autistic symptoms and NWR performance.

Definitive answers are also lacking regarding the potential link between NWR performance and extra-linguistic abilities such as (short-term and working) memory and nonverbal (NV) intelligence, which are below age expectations or impaired in many autistic individuals (Maenner et al., 2023; Merchán-Naranjo et al., 2016). Understanding what role memory plays in the phonological performance of individuals on the autism spectrum is far from straightforward, as the answer to this question depends on the specific properties of the tasks used to measure these abilities, which are sometimes difficult to disentangle (see the discussion above on the different uses of NWR tasks). As for NV intellectual abilities, childhood studies are inconclusive. While some studies provided evidence for a potential association between NWR and NV intelligence (Abd El-Raziq et al., 2024), others did not. In the latter case, phonological impairment has been found to be present despite normal intelligence, and normal phonological abilities have been reported despite intellectual disability (Bartolucci & Pierce, 1977; Kjelgaard & Tager-Flusberg, 2001; Silleresi et al., 2020; Tuller et al., 2017). Most autism studies, including the only adult study on phonology reviewed in this section, involve autistic individuals with average or above average intelligence (Russell et al., 2019), which limits the possibility of exploring the impact of NV intelligence on language development. From a clinical perspective, given the continuing evolution of the concept of autism (Mottron & Gagnon, 2023) and the increasing prevalence of this disorder (Maenner et al., 2023), there is a persistent need to enhance our understanding of ASD and refine our plans for intervention, including speech-language therapy. Information on the phonological behaviors of autistic individuals is essential for improving prognostic accuracy for individuals with language difficulties who are diagnosed with autism in either childhood or adulthood, as well as for designing treatment programs that, if tailored to individual needs, can lead to better long-term prognosis (Baghdadli et al., 2019).

The overarching aim of the current study is to provide a picture of the phonological skills of verbal autistic adults via the use of a repetition task including NWs involving different degrees of syllabic complexity and structures known to be challenging for individuals with language impairment, including DLD. We sought to answer the following research questions:

RQ1: What are the phonological abilities of verbal autistic adults?
RQ2: What is the effect of complexity on NWR performance among autistic adults?
RQ3: Which variables can explain NWR performance in verbal autistic adults?

Although this study is, to our knowledge, the first to explore phonological abilities in autistic adults, a hypothesis was formulated for each research question:

H1: We expected to identify the same variability in NWR performance that has been reported in childhood studies, with some autistic adults showing phonological impairment and others showing intact phonological abilities.

H2: Drawing on previous literature on autistic children and children with DLD, we expected to detect an effect of complexity on NWR performance, with adults showing more difficulties in repeating complex rather than simple syllabic structures.

H3: No clear hypotheses could be formulated regarding the role of autism severity and NV abilities in the phonological performance of our autistic participants, as previous literature on children is inconclusive and that on adults is virtually nonexistent. In broad terms, we expected phonological performance to be better explained by linguistic cognitive variables than by extra-linguistic cognitive variables.

Methods

Participants

The population sample was composed of two groups of adults: 48 verbal autistic adults (henceforth the ASD group) and 50 age-matched individuals without a prior diagnosis of neurodevelopmental disorder (henceforth, the CONT group). None of the adults who participated in the study had a hearing disorder. All autistic participants were verbal (i.e., typically producing at least three-word utterances) and they were aged 18–56 years old ($M=32.7$; $SD=10.7$). The ASD group included 17 women (35.4%) and 31 men (64.6%). They were recruited from different autism-related services and organizational structures in France (the Autism Centre at the Regional University Teaching Hospital in Tours and four residential care facilities in the Cher, île-de-France, and Indre-et-Loire districts), as well as through the communication channels of the University of Tours and self-help associations for autistic people. All autistic participants met the criteria for a formal DSM-5-TR/ICD-11 diagnosis of ASD. Diagnosis was made by psychiatrists and documented when possible using the Autism Diagnostic Observation Schedule (ADOS, Lord et al., 2003), the Autism Diagnostic Interview-Revised (ADI-R, Le Couteur et al., 2003) and/or the Child Autism Rating Scale (CARS, Schopler et al., 2010). One-third of the participants (14/48) had received a diagnosis of autism as children. Similarly, one-third of our autism group (17/48) had a diagnosis of co-occurring Developmental Intellectual Disorder (DID). The Mini-Mental State (MMS, Kalafat et al., 2003) confirmed that none of our participants over 40 years of age and without co-occurring DID had ongoing cognitive decline at testing time.[1] None of the participants in the CONT group had an (NV)IQ < 70 or an ongoing cognitive decline at the time of the testing session. The main characteristics of our population are presented in Table 1.

The present study received approval from the Ethical Committee for Research on humans of Tours-Poitier, France (CER-TP-2020–10-01). Written informed consent was obtained from all participants.

Material and procedures

Phonology: LITMUS-QU-NWR-FR-Adults. One of the most appropriate tools for evaluating phonology in autistic individuals is NWR (Schaeffer et al., 2023). Consequently, participants' phonological abilities were assessed using an adult version of LITMUS (Language Impairment Testing in Multilingual Settings)-QU(Quasi-Universal)-NWR-FRENCH (dos Santos & Ferré, 2018). The original instrument was built to assess complex phonology in children and has been shown to be suitable for autistic children (Silleresi et al., 2020). The adult version, LITMUS-QU-NWR-FR-Adults (Ferré et al., 2022), consists of two modules: a child module including the 31 items of the original task and an adult module including 22 items designed to target an adult population. The child and the adult modules were designed following the same constraints (for more details on the development of the child version of the task, see the study of dos Santos & Ferré, 2018). All items ($n=53$) resulted from the manipulation of syllabic structure (whose complexity depended on the presence of different types of consonant clusters and word-final consonants). The child module, which is phonologically simpler, allows for the assessment of the phonological abilities of severely impaired participants, regardless of their age. A stop criterion can be used for those who fail to repeat items in the child module (see below). In addition, having participants start by repeating simple items can serve as positive reinforcement for the examinee and can inform the examiner about the relevance of proposing more difficult items. All NWs were limited in length (not exceeding three syllables for the child module and two syllables for the

Table 1. Participant characteristics.

Variable		ASD group ($n = 48$)	CONT group ($n = 50$)	Inter-group comparison
Sex/gender	Female	17 (35.4%)	18 (36%)	$\chi^2 = .004$
	Male	31 (64.6%)	32 (64%)	
Mean age in years (SD) [range]		32.7 (10.7) [18.2–56.8]	34.6 (14.1) [18.1–73.8]	$U = 1170$ $r = -.021$
Educational level[a]	Primary	2 (4.17%)	0	$\chi^2 = 23.9$*
	Secondary	17 (35.4%)	11 (22%)	
	Post-secondary	17 (35.4%)	39 (78%)	
	No regular schooling	10 (20.8%)	0	
Diagnosis of co-occurring DID		17 (35.4%)	-	-
When diagnosed	Childhood/adolescence[b]	14 (29.2%)	-	-
	Adulthood	34 (70.8%)	-	-

[a] $df = 96$ (due to two missing data points for the ASD group).
[b] The only one who was diagnosed with autism after age 13 was diagnosed at age 17.
*$p < .02$ (significance threshold obtained after Bonferroni correction).

Table 2. Phonological structures and substructures in the LITMUS-QU-NWR-FR-Adults task with examples for the child and adult modules.

Structure	Substructure	Example item: Child module	Example item: Adult module
Vowel (V)		/pl**u**/	/skil.f**a**/
Head of onset (HO)		/**f**uk/	/**f**is.palk/
Branching onset (BO)		/**pl**u/	/k**l**i.fap/
Medial & final obstruent (MFO)	Final consonant (FC)	/ka.fi**p**/	/plif.ku**p**/
	/s/ as a final consonant (FS)	/fa.pu**s**/	/spu.kla**s**/
	Medial obstruent consonant (M2C)	/fli**p**.ka/	(-)
	/s/ in coda medial position (M2S)	/pa.fu**s**.ki/	/fa**s**.klip/
Medial & final liquid (MFL)	/l/ as a final consonant (FL)	/pla**l**/	(-)
	/l/ as a coda in medial position (M2L)	/pi**l**.fu/	/ku**l**.faps/
Consonant + /s/ in final position & /s/ + consonant in final position (sFC)	Consonant + /s/ in final position (FCS)	/fi**ps**/	/pil.fu**ps**/
	/s/ + consonant in final position (FSC)	/ku**sp**/	(-)
/s/ in #sC initial position (AppS)		(-)	/**s**pu.klas/

adult module) and did not bear any resemblance to French words (as ascertained through the collection of information about wordlikeness). This was meant to limit the influence of short-term memory and lexical knowledge respectively. Moreover, NWs were built from two elementary stacks (i.e., segments and syllables) that were combined and attuned for phonological assessment. The selected phonemes are acquired early during development and are not articulatory too close to each other, as to avoid errors due to articulatory problems. The vocalic segments included in the task are the most common ones across the languages of the world, namely /a/, /i/, and /u/ for vowels and /p/, /k/, /f/, /s/ , and /l/ for consonants (Maddieson et al., 2011). The phonological structures and substructures targeted by the task are presented in Table 2 (with examples). The complete list of items is provided in Appendix A. Note that Vowel, Head of onset and Branching onset were considered to be simpler than the other structures.

Audio recorded NWs were presented on a laptop computer in a PowerPoint document along with a video showing the face of the French native speaker who had recorded the stimuli while producing the NWs. This contributed to making the task ecological while enabling participants to complete the task without any need for social interaction with the examiner. Items were played through external speakers to improve the quality of the auditory presentation. The loudness level was adjusted according to the participant's requests so as to avoid sensory disturbance. Participants were instructed to repeat each NW exactly as they had heard it. Unless external interruptions occurred, NWs were played only once. Test items were preceded by two warm-up items (/cholnɛd/ and /telodeuch/) for

Table 3. Language and extra-linguistic measures in autistic and control participants – Mean (*SD*) and range.

Variable	ASD ($n = 48$)	CONT ($n = 50$)	Inter-group comparison
Morphosyntax (SR)	25.72 (12.13) [0–36]	32.31 (3.27) [21–36]	$U^a = 789.5$ $r = -.251$
Vocabulary (EVIP)	56.67 (43.73) [0.1–98]	92.04 (4.18) [80–97]	$U^b = 750$ $r = -.362$*
NVIQ (PRI)	91.48 (24.36) [50–128]	103.2 (15.79) [70–136]	$U^c = 794$ $r = -.244$
vSTM (FDS)	5.51 (1.9) [2–9]	6.38 (1.36) [3–9]	$U^d = 704.5$ $r = -.277$
WM (BDS)	4.1 (2.5) [0–9]	4.86 (1.20) [2–7]	$U^d = 789.5$ $r = -.190$
Autism severity (SRS-2)	73.28 (10.3) [50–91]	53.42 (9.78) [40–76]	$U^e = 1805.5$ $r = .806$*

[a] $df = 43$ for ASD (due to five individuals not being able to complete SR) and 49 for CONT (due to missing data on SR for one person).
[b] $df = 47$ for ASD (due to missing values on EVIP for one person) and 50 for CONT.
[c] $df = 42$ for ASD (due to missing data on PRI for one person and five persons being excluded because they completed the WISC rather than the WAIS) and 50 for CONT.
[d] $df = 38$ for ASD (due to missing data on FDS and BDS for three participants and five persons being excluded because they completed the WISC rather than the WAIS) and 50 for CONT.
[e] $df = 40$ for ASD (due to missing values on the SRS-2 for eight individuals) and 50 for CONT.
*$p < .008$ (significance threshold obtained after Bonferroni correction).

which participants were given corrective feedback, and the adult module was systematically proposed after the child module. The following stop criterion was defined: if participants were not able to complete the child module, the adult module was not proposed. Repetitions were audio-recorded via a high-quality digital microphone (ZOOM H4™) and then played back, transcribed, and coded by the last author, who is a phonologist with extensive experience in speech transcription. Productions were scored as correct (score = 1) or incorrect (score = 0) according to whether they were verbatim repetitions of the target NW. The only exceptions were voicing substitutions (e.g., [p] repeated as [b]) and substitution of similar vowels (e.g., [e] repeated as [ɛ]), which were not counted as errors. If participants did not repeat the NW despite the absence of interruption, a score of 0 was assigned.

Other linguistic and extra-linguistic cognitive tasks. In addition to phonology, two other language skills were tested: expressive morphosyntax and receptive vocabulary. The former was assessed via the LITMUS-SR(Sentence Repetition)-FR-Adults task (Manenti et al., 2023) and the latter via the *Échelle de Vocabulaire en Images Peabody* (EVIP; Dunn et al., 1993), the French version of the Peabody Picture Vocabulary Test.

NV intellectual abilities were estimated through the Block Design and Matrix Reasoning subtests of the Wechsler Adult Intelligence Scale–Fourth Edition (WAIS-IV; Wechsler, 2008). The results from these subtests were combined into a Perceptual Reasoning Index (PRI), which was used as a proxy for NVIQ. Verbal short-term memory (vSTM) and working memory (WM) were also assessed, via the Forward and Backward Digit Span subtests (FDS and BDS) of the WAIS-IV. Five adults (all within the low intellectual range) had NV scores (Block Design, Matrix Reasoning and Digit Span) from the Wechsler Intelligence Scale for Children–Fifth Edition (WISC-V; Wechsler, 2014) since this battery was considered more appropriate by the neuropsychologist who conducted a clinical assessment prior to our testing session.

The SRS-2, (translated into French) was used to obtain information about the severity of autistic symptoms. Two additional measures were used, provided by two subscales of the SRS-2: Social Communication and Interaction (SCI), mirroring the first diagnostic dimension of autism, and Restricted Interests and Repetitive Behavior (RRB), reflecting the second dimension.

Performance on language and extra-linguistic measures in autistic and control participants is presented in Table 3. As can be seen, no statistically significant differences were found between the ASD and the CONT groups except for a difference in vocabulary and autism severity.

Each participant was tested individually in a quiet room, in one, two or three sessions whose durations varied from 15 min to more than 2 h.

Statistical analyses. Out of 48 autistic participants, only two (4.2%) failed to complete NWR in its entirety, as the adult module was not proposed to them. Statistical analyses were only carried out on individuals who completed both modules ($n = 46$). Due to compromised NWR audio recording, one control participant was also excluded from the analyses.

Since the data distribution for NWR and most other measures was nonnormal (Shapiro-Wilk test), non-parametric tests were used. To assess participants' performance on NWR and determine whether NWR performance was influenced by phonological complexity (difference between the child and adult modules, less and more complex, respectively) or syllabic length (difference between one, two-, and three-syllable items), we used a binomial generalized linear mixed-effects model (GLMER) followed by a Type II ANOVA and pairwise post-hoc comparisons with Tukey-adjusted significance levels. To explore the effect of complexity on the production of autistic adults, we performed Friedman ANOVAs on performance (expressed as a percentage of exact repetition) on phonological structures within the ASD group. Pairwise comparisons using a Conover's all-pairs test adjusted with Holm correction were conducted to understand the origin of the effects. Finally, Spearman's rank correlations were performed between each linguistic and extra-linguistic measure and NWR performance in each group to observe how this task related to cognitive abilities in the different population samples at stake. For the same reason, a correlation between autism severity and NWR performance was conducted. Correlation analyses (corrected to avoid Type I error) were preferred to a more complex statistical approach such as Structural Equation Modeling (SEM) because of the size of our group, the presence of missing data across measures and the non-normality of the data.

All statistical analysis and graphics were performed with R version 4.1.0 (R Core Team, 2021) and R-Studio version 2023.3.0.386 (Posit Team, 2023) using the following packages: *car* (Fox & Weisberg, 2019), *fmsb* (Nakazawa et al., 2024), *ggplot2* (Wickham, 2016), *ggradar* (Bion, 2020), *lme4* (Bates et al., 2015), *Matrix* (Bates et al., 2024), *multcomp* (Hothorn et al., 2008), *patchwork* (Pedersen, 2024), *PMCMRplus* (Pohlert, 2024), *ppcor* (Kim, 2015), *rcompanion* (Mangiafico, 2024) and *tidyverse* (Wickham et al., 2019).

Results

Global phonological performance

Mean NWR performance in the ASD group was 79.4% ($SD = 22.1$), compared to 91.7% ($SD = 6.7$) in the CONT group.

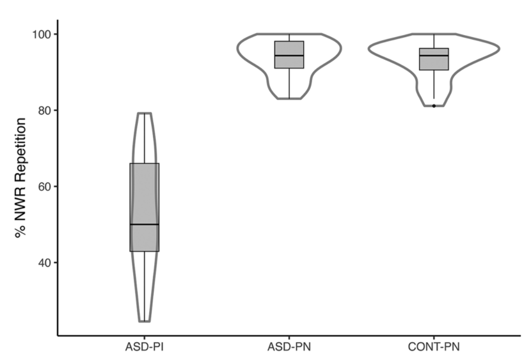

Figure 1. Global NWR performance (%) in the ASD-PI, ASD-PN and CONT-PN subgroups.

Based on a cut-off for impaired performance established at −1.65 *SD* (Ramus, 2003) in the CONT group, we found that 30/46 (65.2%) autistic adults had a normal phonological performance (henceforth ASD-PN), while the performance of 16/46 (34.8%) autistic participants suggested the presence of a phonological impairment (henceforth ASD-PI). In the CONT group, only 4/49 (8.2%) participants were considered PI (henceforth CONT-PI), while the remaining 45/49 (91.8%) were considered PN (henceforth CONT-PN). As our aim was to describe the phonological profiles of autistic adults and to understand how, if at all, they differed from those characterizing control participants without phonological difficulties, individuals in the CONT-PI subgroup were excluded from the analyses. Figure 1 illustrates NWR repetition rates in the ASD-LN, ASD-LI and CONT-PN subgroups.

A generalized linear mixed-effects model (GLMER) with a binomial distribution and a logit link was used to explore the effect of subgroup (three levels: ASD-PI/ASD-PN/CONT-PN), module (two levels: child module/adult module), and syllable length (three levels: one syllable/two syllables/three syllables) on NWR performance. Random intercepts were included for the individuals who completed NWR and for the items included in the task. The output of the model is presented in Table 4. A Type II ANOVA was conducted on the model output to test the significance of each predictor. This revealed an effect of subgroup ($\chi^2(2) = 151.91$, $p < .001$) and module ($\chi^2(1) = 10.13$, $p = .001$), but not of syllabic length ($\chi^2(2) = 4.177$, $p = .12$). A pairwise comparison with a Tukey adjustment performed for the subgroup variable revealed that the PI subgroup was significantly different from both PN subgroups (ASD-PN: $p < .001$; CONT-PN: $p < .001$), which did not differ ($p = .97$).

Phonological complexity

To identify which structures were the most difficult to reproduce for our autistic participants, we compared performance on the different structures within the two ASD subgroups. A significant effect of syllabic structure was observed in both groups (ASD-PI: $\chi^2(6) = 32.9$, $p < .001$; ASD-PN: $\chi^2(6) = 29.2$, $p < .001$). In the ASD-PI subgroup, four pairwise comparisons survived correction (Head of onset vs. Medial and final liquid, Branching onset vs. Vowel, Medial final obstruent vs. Vowel, and Medial final liquid vs. Vowel), while three pairwise comparisons survived correction in the ASD-PN subgroup (Branching onset vs. /s/ in initial #sC position, Branching onset vs. /s/ associated with final consonants, and Branching onset vs. Vowel). No clear pattern emerged from these analyses for either group, as the structures considered to be simpler (Vowel, Head of onset and Branching onset) did not show systematic differences with the structures considered to be more complex (Medial final obstruent, Medial final liquid, /s/ associated with final consonants, /s/ in initial #sC position), and no structure stood out as particularly easy or

Table 4. Results from the GLMER Model of NWR performance.

		Estimate	SE	z	p
Intercept		.9624	.3233	2.977	.00291
Subgroup					
	ASD-PN	2.9162	.2758	10.573	<.001
	CONT-PN	2.9703	.2557	11.617	<.001
Length					
	Two-syllable items	−.4216	.3657	−1.153	.24896
	Three-syllable items	−.8002	.3948	−2.027	.04265
Module	Adult module	−1.0073	.3164	−3.183	.00146
Random Effects		σ^2			*SD*
Participant-code		.59			.77
Item-number		.58			.76
Grouping variables		Number			ICC
Participant-code		91			.27
Item-number		53			.27
Model fit					
Observations		4823			
R^2 (fixed effects)		.26			
R^2 (total)		.46			
AIC		2922.5			
BIC		2974.4			

Model: NWR Score ~ Subgroup + Module + Syllable length + (1 | Participant-code) + (1 |Item-number).

particularly difficult to repeat. Performance by syllabic structure for each ASD subgroup is illustrated in Figure 2.

At a descriptive level, we observed that Medial final liquid was the structure showing the lowest repetition rate in both subgroups, with a lower mean in the ASD-PI subgroup (56.9%) than in the ASD-PN subgroup (95.7%). Between and within structures, the performance of ASD-PI individuals appeared to be characterized by greater variability. Intra-group correlations revealed larger group variability ($W = 289$, $p < .01$), indexed by a lower mean Spearman rho in the ASD-PI subgroup (mean = .33; $SD = .41$) than in the ASD-PN subgroup (mean = .20; $SD = .47$), indicating that successful repetition rates were more similar across autistic participants without a phonological impairment than across autistic participants with a phonological impairment.

To understand how autistic individuals presenting with a phonological impairment differed in their performance across syllabic structures, we decided to complement quantitative analyses with a description of individual profiles in the ASD-PI subgroup for each structure and substructure, which are illustrated in Figure 3.

Some participants displayed difficulties on certain (sub) structures, such as final consonants (P4, P15) and medial clusters (P12, P16), while others showed high repetition rates on nearly all (sub)structures (P1, P2). The reason why P1 and P2 were classified as ASD-PI is that their productions were characterized by what we labeled *non-target addition*s, namely, the addition of phonological material in the items to be repeated, (e.g., /pilfu/ → [pilifu] for P1; /pisfluk/ → [pisflupk] for P2). Finally, many participants (P5, P7, P14, P9, P11, P8, P6, P3, P10, P13) were found to display low repetition rates on a number of highly complex (sub)structures, notably final liquid (FL) and internal coda (M2L). This is attested by the fact that, at the group level, the only structures exhibiting repetition rates never falling below 70% were the simplest ones. There was great inter-individual variability as to the number of incorrectly repeated items for these participants, which resulted in repetition rates ranging from 0% to 50% within and across (sub)structures.

Variables explaining phonological performance

Correlations between NWR performance and linguistic and extra-linguistic cognitive abilities were conducted on the subgroup of 41 autistic participants with complete NWR data who completed WAIS-IV subtests.

Correlation analyses (corrected for multiple correlations) showed that NWR performance was significantly related to all the other variables in the ASD group (see Table 5). In contrast, NWR did not correlate with any variable in the CONT-PN group. To explore in more detail the relationships between the different variables in the ASD group, partial correlations were conducted. Findings revealed that when controlling for extra-linguistic cognitive variables (NVIQ on the

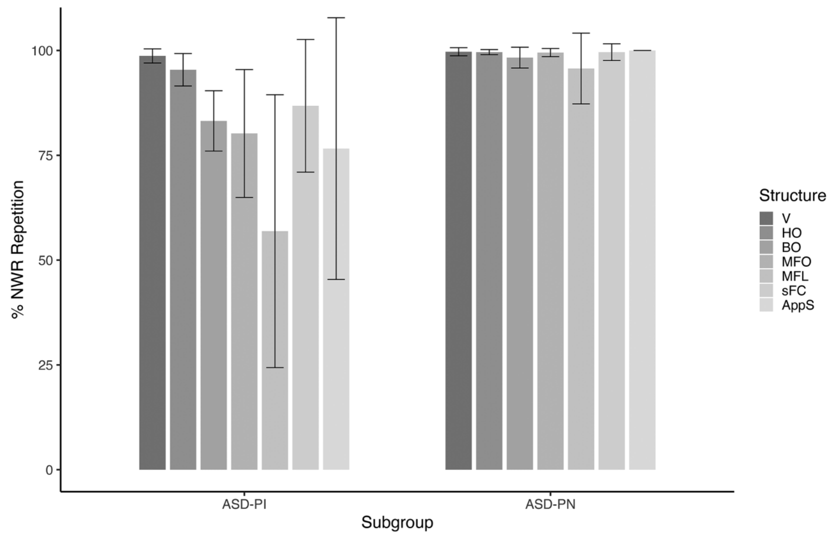

Figure 2. Performance by syllabic structure (%) in the ASD-PI and ASD-PN subgroups.

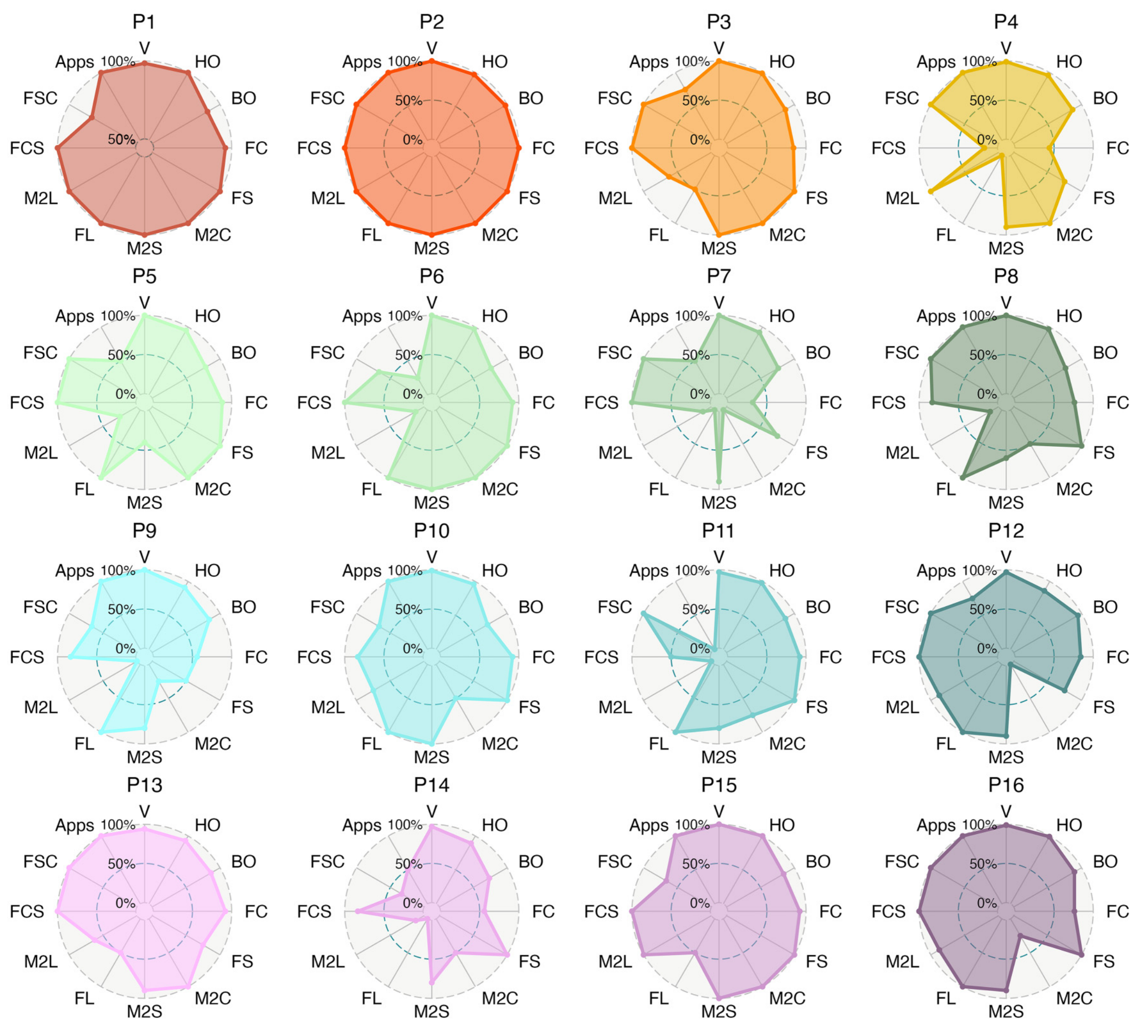

Figure 3. Individual profiles of ASD-PI subgroup participants for each syllabic (sub)structure.

one hand and vSTM and WM on the other hand), correlations between NWR and the other linguistic variables (i.e., morphosyntax and vocabulary) remained significant, except for the correlation between NWR and vocabulary, which did not survive correction when memory variables were controlled for. In contrast, when controlling for linguistic variables (i.e., morphosyntax and vocabulary), the correlation between NWR and extra-linguistic variables (i.e., NVIQ, vSTM, and WM) disappeared, even before correcting for multiple correlations. These results are reported in Table 6.

Since we were also interested in exploring the potential relationship between NWR and autism severity (as measured by SRS-2), correlation analyses were performed between NWR performance and the main SRS-2 scores. For the SRS-2 Total score, correlations were nonsignificant for both autistic ($r_s = -.067$, $p = .708$) and control participants ($r_s = .145$, $p = .342$). These tendencies did not change when correlation analyses were run on the SRS-2 SCI score (ASD: $r_s = -.014$, $p = .939$; CONT-PN: $r_s = .166$, $p = .274$) or the RRB score (ASD: $r_s = -.048$, $p = .790$; CONT-PN: $r_s = .059$, $p = .698$).

Finally, note that global NWR performance was not correlated with age in either the ASD group ($r_s = .095$, $p = .519$) or the CONT-PN group ($r_s = .143$, $p = .348$).

Table 5. Results of correlation analyses between NWR performance and both language and extra-linguistic measures in each group.

	ASD		CONT-PN	
Correlations with NWR	r_s	p	r_s	p
Morphosyntax (SR)[a]	.727	<.001	.224	.143
Vocabulary (EVIP)[b]	.655	<.001	.160	.292
NVIQ (PRI)[c]	.659	<.001	.083	.586
vSTM (FDS)[d]	.651	<.001	.361	.015
WM (BDS)[d]	.579	<.001	.203	.180

[a] $df = 39$ for ASD (due to two individuals not being able to complete SR) and 44 for CONT (due to missing data on SR for one person).
[b] $df = 40$ for ASD (due to missing data on EVIP for one person) and 45 for CONT.
[c] $df = 40$ for ASD (due to missing data on PRI for one person) and 45 for CONT-PN.
[d] $df = 38$ for ASD (due to missing data on FDS and BDS for three participants) and 45 for CONT.
The significance threshold after Bonferroni correction was $p < .005$.

Discussion

The present study investigated phonological abilities in verbal autistic adults via the use of LITMUS-QU-NWR-FR-Adults. This task, which includes syllabic structures of varying degrees of complexity, allowed us to explore the variety of difficulties that emerge when autistic adults are confronted with computational complexity. Three research questions were asked:

RQ1: What are the phonological abilities of verbal autistic adults?
RQ2: What is the effect of complexity on NWR performance among autistic adults?
RQ3: Which variables can explain NWR performance in verbal autistic adults?

What are the phonological abilities of verbal autistic adults?

Autistic adults had poorer phonological abilities compared to controls and showed greater variability in their overall performance. Some of our autistic participants exhibited intact phonological skills (ASD-PN), while others displayed clear and sometimes severe phonological impairment (ASD-PI). Participants in the ASD-PI subgroup had significantly lower NWR repetition rates than participants in the PN subgroups, which did not differ from each other. These results are in line with evidence from childhood research, which has shown that while some autistic children have typical phonological skills, others display mild to

Table 6. Results of partial correlation analyses between NWR performance and both language and extra-linguistic masures in the ASD group.

	Conditioned on language		Conditioned on NVIQ		Conditioned on memory	
Correlations with NWR	r_s	p	r_s	p	r_s	p
Morphosyntax (SR)	-	-	.558	<.001	.464	.006
Vocabulary (EVIP)	-	-	.474	.003	.392	.020
NVIQ (PRI)	.284	.099	-	-	-	-
vSTM (FDS)	.177	.324	-	-	-	-
WM (BDS)	.128	.478	-	-	-	-

[a] $df = 35$ (due to two individuals not being able to complete SR, one missing data on PRI and missing data on FDS and BDS for three participants).
[b] $df = 36$ (due to missing data on EVIP for one person, on PRI for another person, and FDS and BDS for three participants).
[c] $df = 37$ (due to missing data on PRI for one person and on EVIP for another person, and two individuals not being able to complete SR).
[d] $df = 35$ (due to missing data on FDS for three participants and on EVIP for one person, and two individuals not being able to complete SR).
The significance threshold after Bonferroni correction was $p < .007$.

severe phonological impairment (see the Introduction section). Our first hypothesis is thus confirmed. At the same time, our findings are at odds with what was reported by Pijnacker et al. (2009), whose results indicated an absence of impairment in autistic individuals.

As mentioned earlier, LITMUS-QU-NWR-FR-Adults includes both simple and relatively more phonologically complex items. In parallel, simpler items are one- to three-syllables long (child module) and more complex items are two-syllables long (adult module). Difficulties were related to phonological complexity, as indicated by the fact that performance was lower for items in the adult module than for items in the child module. In contrast, the task used by Pijnacker et al. did not tap specifically into syllabic complexity. Instead, as seen in the Introduction section, the task they used (the Auditory Discrimination Task) does not target phonology. The difference between our results and Pijnacker's is thus presumably due to methodological decisions.

What is the effect of complexity on NWR performance among autistic adults?

With the purpose of exploring the effect of complexity on NWR performance among autistic adults, performances on the different syllabic structures involved in NWR were compared. No statistically significant pattern emerged for either the ASD-PI or the ASD-PN subgroup, since simple structures were not systematically better repeated than more complex ones and the success rate of complex structures did not consistently differ from those of simpler structures, contrary to our expectations. This might be due to large variability in the ASD-PI subgroup and little variability in the ASD-PN subgroup. Inspection of individual scores revealed that the heterogeneity characterizing the overall performance of the former group resulted from autistic adults with a phonological impairment displaying different individual profiles. The existence of phonologically impaired autistic adults who have particular difficulties with final consonants suggests that, for some individuals, final position remains a sensitive area for consonant production well beyond childhood and adolescence (Ferré et al., 2012). Further investigation should be conducted on autistic adults who exhibit selective difficulties with structures that are yet to be explored in both children and adults, such as obstruent consonants in medial position, to understand the origin of this difficulty, which could be articulatory rather than phonological in nature. This distinction is particularly relevant, since there is a general lack of clarity within autism research about the difference between phonological and articulatory abilities (see Silleresi, 2023 for a review). Combining results from these two different areas clearly has a negative impact on designing therapeutic plans for individuals presenting with impaired language production and on developing underlying models of phonological impairment. Evidence for autistic adults making non-target additions to NWs that they had otherwise repeated accurately is also relevant. This is reminiscent of what has been referred to as *chaotic disturbances* (Ferré et al., 2012) or *novel cluster creation* (Williams et al., 2013) in studies performing qualitative analysis of word and nonword repetitions by children and adolescents with ASD and by children and adolescents with DLD. One hypothesis that has been put forward is that, in the face of high-level complexity, compensatory strategies such as segment omission and substitution are no longer sufficient, and participants with a phonological impairment, especially older ones, engage in structure processing instead of structure avoidance (see Ferré et al., 2012). To test the validity of this hypothesis, an in-depth analysis of error patterns across different structures in adult participants should be conducted. Many autistic adults were found to display low repetition rates across complex syllabic structures, which illustrates rather clearly that phonological complexity related to syllable structure is a source of difficulty for some individuals, as further attested by the fact that none of the participants performed poorly on the simplest syllabic structures. This supports our hypothesis and extends the results of Tuller et al. (2017), who showed that the difficulties observed in children with language impairment, both with and without ASD, systematically involved phonological complexity. Tuller and colleagues observed that /s/ in final clusters and #sC in initial position were challenging for children with DLD but not for children with ASD. While final /s/ was overall successfully repeated also by our autistic participants, with only one person scoring 50% and most participants scoring at ceiling, the picture for /s/ in #sC position is more nuanced. This syllabic structure proved to be a source of difficulty for half of the autistic adults who showed sensitivity to phonological complexity, with the other half performing almost uniformly at ceiling. This discrepancy alongside the contrast with what was reported for children warrants further research. Among the complex structures particularly affected in this group, it is worth mentioning the internal coda (M2L), which seems to cause difficulties even for autistic adults who show otherwise relatively high repetition rates. This result is reminiscent of what has been reported for DLD, as some scholars suggested that internal coda may be a reliable clinical index for phonological impairment in this population (Ferré et al., 2015).

Which variables can explain NWR performance in verbal autistic adults?

In addition to documenting phonological abilities in autistic adults, our study aimed to determine which linguistic and extra-linguistic cognitive variables explained phonological performance in this population. To this end, we recruited participants with a wide range of cognitive levels and included measures of morphosyntax, vocabulary, NVIQ, verbal short-term and working memory.

In the ASD group, significant correlations were found for all linguistic and extra-linguistic variables. However, partial correlations revealed that when language (i.e., morphosyntax and vocabulary) was controlled for, correlations with extra-linguistic cognitive variables were no longer significant. In particular, the correlation between phonology and morphosyntax remained significant after controlling for extra-linguistic variables and using post-hoc correction. This indicates that, in this population, structural language abilities are (at least partly) independent of lexical knowledge and nonverbal cognitive abilities, confirming results from studies on autistic children (Schaeffer et al., 2023). In contrast, correlations between NWR and other linguistic variables remained significant after controlling for extra-linguistic variables, suggesting that the correlations between phonological abilities and extra-linguistic skills might be mediated by language.

We also investigated the potential link between phonology and autism severity. No significant correlations were found between NWR repetition rate and SRS-2 scores, regardless of which and how many diagnostic dimensions were being considered. This argues against the hypothesis that difficulties in structural language stem from the degree of severity of autism symptoms, whether related to social interaction and communication skills or to repetitive and restricted behaviors and interests. Once again, this mirrors recent findings on autistic children (Tuller et al., in press) and goes against Whitehouse et al. (2008), who found an association between poor NWR performance and most severe autistic traits. Furthermore, our results are in line with the nonsignificant correlation between NWR and the SRS-2 total score observed by Girolamo and Rice (2022). However, it should be noted that, while the NWR tasks included in the studies by Whitehouse et al. and Girolamo and Rice were used to assess phonological short-term memory and verbal working memory, respectively, LITMUS-QU-NWR-FR-Adults was designed in such a way as to specifically tap phonology.

Finally, the wide age range of our participants warranted exploration of the potential effect of age on phonological performance. No significant difference emerged, neither for autistic adults nor for controls, which might be due to the fact that our sample does not include many elderly people. Alternatively, although language typically evolves rapidly in early infancy and undergoes a gradual decline in older age (Marini & Andreetta, 2016), some language skills, including phonological abilities, may remain stable across late adulthood. This is not the case for other linguistic and cognitive functions, notably processing speed, working memory, and cognitive plasticity, which tend to decline in (healthy) ageing (Sánchez-Izquierdo & Fernández-Ballesteros, 2021). These factors may play a more significant role in determining adult language performance, masking age-related effects. Note that the way advancing age affects the cognitive (thus also linguistic) abilities of autistic adults is a particularly important issue to address, as it is currently unknown whether and how autism might add layers of complexity to age-related changes in terms of either accelerated or slowed cognitive decline (Tse et al., 2022). For all these reasons, future studies on autism in adulthood should explore a broader age range and examine additional cognitive abilities.

Limitations and future perspectives

The results presented in this study should be interpreted in the context of some important limitations. The group of participants that was recruited was small and cognitively heterogeneous, thus caution should be used in generalizing our findings, which need to be replicated in larger samples. In addition, because our study was both clinical and population based, there was variability in the quantity and quality of information we had on the clinical profiles of participants. Working on a more comprehensive database would allow researchers to explore and account for interindividual differences in more detail. Note also that most autistic participants were younger or middle-aged. As the lack of elderly individuals could mask any potential age-related effects on cognitive performance, studies covering a wider age range are needed.

The distinction between PI and PN subgroups was based on an experimental task, meaning that what we accounted for was the divergence of language ability from the norm established based on our control group rather than from a standardized norm. This notwithstanding, there is a dearth of tests normed on adults and existing batteries are often ill-adapted to autistic individuals, whereas LITMUS-NWR-QU-FR-Adults specifically targets phonological abilities while being autism-friendly (as attested by the high completion rate in our ASD group – 95.8%).

Our findings further confirm that going beyond quantitative analysis by exploring individual results proves necessary to uncover the variability of ability profiles. We plan to investigate phonological productions in more detail by performing a qualitative analysis of errors, in both autistic and control participants, with and without phonological impairment. This should allow us to determine what strategies are implemented by adults to avoid computational complexity, provided that complexity avoidance occurs. The phonological abilities of autistic adults should also be compared to the phonological abilities of adults with DLD, as the nature of the phenotypic overlap between disorders primarily affecting language (e.g., DLD) and disorders that do not primarily affect language (e.g., autism) is the subject of ongoing debate. While some studies have provided evidence for shared linguistic deficits in individuals with DLD and individuals on the autism spectrum (e.g., Kjelgaard & Tager-Flusberg, 2001), others have not (e.g., Whitehouse et al., 2007; Williams et al., 2013). In parallel, family and twin studies have been conducted to understand whether the phenotypic overlap described in the literature was accompanied by a biological overlap. Both autism and DLD have been shown to have a strong genetic component and high heritability estimates. An elevated risk of autism has been identified among family members of DLD probands (Tomblin et al., 2003) and there is a well-documented history of language delay and impairment among family members of probands with autism (Piven & Palmer, 1997). Linkage peaks for language impairment in families with both language impairment and autism have also been detected (Bartlett et al., 2012). Some DLD candidate genes seem to be implicated in other neurodevelopmental disorders, including autism (e.g., *CNTNAP2*, Alarcón et al., 2008), although the genetic overlaps across these disorders might not be purely additive in nature (Nudel et al., 2020). Given the current paucity of research on language in autism and DLD after childhood and adolescence, comparing adult phonological competence in these two disorders would help uncover similarities and/or group specificities that would greatly contribute to the debate around the etiology of language impairment in different clinical populations.

Conclusion

To our knowledge, this is the first study that investigated phonological abilities in autistic adults, using an autism-friendly and linguistically motivated task and describing results at both a global and individual level. Taken together, our findings provide compelling grounds for suggesting that phonological impairment in verbal autistic adults varies greatly in terms of the degree of impairment and the number of affected structures. Moreover, no strong link could be established between phonological impairment and extra-linguistic cognition (NVIQ and memory skills) and autism severity. We believe that this type of knowledge is fundamental to advancing research and clinical practice, helping to set priorities for future studies and guide the design of care support tailored to the specific needs of individuals, based on their (dis)ability profiles. Our results also have important implications regarding the assessment of autistic people's language abilities. In particular, no assumptions about the linguistic competence of these individuals should be made based on the degree of severity of the main autistic symptoms. This particular result has further important theoretical implications, since it casts doubt on the validity of the hypothesis that communication (universally impaired in autism) is the driving force behind language development and functioning (see Tomasello, 2000). In addition, the absence of a correlation between phonology and autism severity seems to suggest that language impairment in autism should not be considered as a consequence of autism itself, thus discarding the "no comorbidity" hypothesis that can be advanced when trying to characterize the profile of autistic individuals with language difficulties (Schaeffer et al., 2023).

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Data availability statement

The participants of this study and their caregivers did not give written consent for their data to be shared publicly. For this reason, data is unavailable.

Declaration of conflicting interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval and informed consent statements

The present study received approval from the Ethical Committee for Research on humans of Tours-Poitiers, France (CER-TP-2020-10-01). Written informed consent was obtained for all participants.

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Note

1. One autistic participant obtained an MMS score below the cut-off due to extremely poor arithmetic skills. As no other cognitive weakness was observed, we decided not to exclude this person from our sample.

References

Abd El-Raziq, M., Meir, N., & & Saiegh-Haddad, E. (2024). Non-word repetition in Arabic-speaking children with and without autism spectrum disorder (ASD): A closer look into accuracy and error patterns. *Clinical Linguistics & Phonetics*, 1–25. https://doi.org/10.1080/02699206.2024.2391904

Alarcón, M., Abrahams, B. S., Stone, J. L., Duvall, J. A., Perederiy, J. V., Bomar, J. M., & Geschwind, D. H. (2008). Linkage, association, and gene-expression analyses identify CNTNAP2 as an autism-susceptibility gene. *The American Journal of Human Genetics*, *82*(1), 150–159. https://doi.org/10.1016/j.ajhg.2007.09.005

American Psychiatric Association (APA). (1994). *Diagnostic and statistical manual of mental disorders* (4th edn).

American Psychiatric Association (APA). (2022). *Diagnostic and statistical manual of mental disorders* (5th edn, text rev.).

Baghdadli, A., Rattaz, C., Michelon, C., Pernon, E., & Munir, K. (2019). Fifteen-year prospective follow-up study of adult outcomes of autism spectrum disorders among children attending centers in five regional departments in France: The EpiTED cohort. *Journal of Autism and Developmental Disorders*, *49*(6), 2243–2256. https://doi.org/10.1007/s10803-019-03901-9

Bartlett, C. W., Flax, J. F., Fermano, Z., Hare, A., Hou, L., Petrill, S. A., & Brzustowicz, L. M. (2012). Gene × gene interaction in shared etiology of autism and specific language impairment. *Biological Psychiatry*, *72*(8), 692–699. https://doi.org/10.1016/j.biopsych.2012.05.019

Bartolucci, G., & Pierce, S. J. (1977). A preliminary comparison of phonological development in autistic, normal, and mentally retarded subjects. *International Journal of Language & Communication Disorders*, *12*(2), 137–147. https://doi.org/10.3109/13682827709011317

Bates, D., & Maechler, M., & Matrix contributors. (2024). Matrix: Sparse and dense matrix classes and methods. *R package version*. https://CRAN.R-project.org/package=Matrix

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bion, R. (2020). ggradar: Create radar charts using ggplot2. *R package version*. https://github.com/ricardo-bion/ggradar

Botting, N., & Conti-Ramsden, G. (2003). Autism, primary pragmatic difficulties, and specific language impairment: Can we distinguish them using psycholinguistic markers? *Developmental Medicine & Child Neurology*, *45*(8), 515–524. https://doi.org/10.1111/j.1469-8749.2003.tb00951.x

Coady, J. A., & Evans, J. L. (2008). Uses and interpretations of non-word repetition tasks in children with and without specific language impairments (SLI). *International Journal of Language & Communication Disorders*, *43*(1), 1–40. https://doi.org/10.1080/13682820601116485

Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness scale: SRS-2*. Western Psychological Services.

Conti-Ramsden, G., Botting, N., & Faragher, B. (2001). Psycholinguistic markers for specific language impairment (SLI). *Journal of Child Psychology and Psychiatry*, *42*(6), 741–748. https://doi.org/10.1111/1469-7610.00770

Crul, T. A. M., & Peters, H. F. M. (1976). *Auditieve discriminatie test*. Swets & Zeitlinger.

dos Santos, C., & Ferré, S. (2018). A nonword repetition task to assess bilingual children's phonology. *Language Acquisition*, *25*(1), 58–71. http://www.tandfonline.com/loi/hlac20. https://doi.org/10.1080/10489223.2016.1243692

Dunn, L. M., Theriault-Whalen, C. M., & Dunn, L. M. (1993). Adaptation française du Peabody Picture Vocabulary Test-Revised. Manuel pour les formes A et B. Éditions Psycan.

Durrleman, S., & Delage, H. (2016). Autism spectrum disorder and specific language impairment overlaps in syntactic profiles. *Language Acquisition*, *23*(4), 361–386. http://www.tandfonline.com/loi/hlac20. https://doi.org/10.1080/10489223.2016.1179741

Ferré, S., dos Santos, C., & de Almeida, L. (2015). Potential clinical markers for SLI in bilingual children. In E. Grillo, & K. Jepson (Eds.), *BUCLD 39: Proceedings of the 39th annual Boston university conference on language development* (pp. 152–164). Cascadilla Press. https://shs.hal.science/halshs-02475952v1.

Ferré, S., Mahé, O., Manenti, M., Pimenta, H., & Prévost, P. (2022). Détecter un déficit phonologique chez les adultes—un module adulte pour LITMUS-QU-NWR-FR. In *Proceedings of XXXIVe Journées d'Études sur la Parole—JEP 2022* (pp. 280–288). https://www.researchgate.net/publication/366458930

Ferré, S., Tuller, L., Sizaret, E., & Barthez, M. A. (2012). Acquiring and avoiding phonological complexity in SLI vs. Typical development of French: The case of consonant clusters. In *Consonant clusters and structural complexity* (pp. 285–308). De Gruyter Mouton.

Fox, J., & Weisberg, S. (2019). *An {R} Companion to Applied Regression* (3rd ed.). Sage Publications, Inc. https://socialsciences.mcmaster.ca/jfox/Books/Companion/

Georgiou, N., & Spanoudis, G. (2021). Developmental language disorder and autism: Commonalities and differences on language. *Brain Sciences*, *11*(5), 589. https://doi.org/10.3390/brainsci11050589

Girolamo, T., & Rice, M. L. (2022). Language impairment in autistic adolescents and young adults. *Journal of Speech, Language, and Hearing Research*, *65*(9), 3518–3530. https://doi.org/10.1044/2022_JSLHR-21-00517

Happé, F., & Frith, U. (2020). Annual research review: Looking back to look forward—Changes in the concept of autism and implications for future research. *Journal of Child Psychology and Psychiatry*, *61*(3), 218–232. https://doi.org/10.1111/jcpp.13176

Hill, A. P., Van Santen, J., Gorman, K., Langhorst, B. H., & Fombonne, E. (2015). Memory in language-impaired children with and without autism. *Journal of Neurodevelopmental Disorders*, *7*(1), 1–13. https://doi.org/10.1186/s11689-015-9111-z

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*(3), 346–363. https://doi.org/10.1002/bimj.200810425

Kalafat, M., Hugonot-Diener, L., & Poitrenaud, J. (2003). Standardisation et étalonnage français du "Mini Mental State" (MMS) version GRECO. *Revue de Neuropsychologie*, *13*(2), 209–236.

Kim, S. (2015). ppcor: Partial and semi-partial (part) correlation. *R package version*. https://CRAN.R-project.org/package=ppcor

Kjelgaard, M. M., & Tager-Flusberg, H. (2001). An investigation of language impairment in autism: Implications for genetic subgroups. *Language and Cognitive Processes*, *16*(2-3), 287–308. https://doi.org/10.1080/01690960042000058

Le Couteur, A., Lord, C., & Rutter, M. (2003). *The autism diagnostic interview-revised (ADI-R)* (pp. 659–685). Western Psychological Services.

Lord, C., Rutter, M., DiLavore, P. S., & Risi, S. (2003). *Autism diagnostic observation schedule: ADOS*. Western Psychological Services.

Maddieson, I., Flavier, S., Marsico, E., & Pellegrino, F. (2011). LAPSyD: Lyon-albuquerque phonological systems databases, Version 1.0. http://www.lapsyd.ddl.ish-lyon.cnrs.fr/

Maenner, M. J., Warren, Z., Williams, A. R., Amoakohene, E., Bakian, A. V., Bilder, D. A., & Shaw, K. A. (2023). Prevalence and characteristics of autism spectrum disorder among children aged 8 years—Autism and Developmental Disabilities Monitoring Network, 11 sites, United States, 2020. *MMWR. Surveillance Summaries*, 72. https://doi.org/10.15585/mmwr.ss7202a1

Manenti, M., Tuller, L., Houy-Durand, E., Bonnet-Brilhault, F., & Prévost, P. (2023). Assessing structural language skills of autistic adults: Focus on sentence repetition. *Lingua. International review of general linguistics. Revue Internationale De linguistique Generale*, *294*, 103598. https://doi.org/10.1016/j.lingua.2023.103598

Mangiafico, S. (2024). rcompanion: Functions to support extension education program evaluation. *R package version*. https://CRAN.R-project.org/package=rcompanion

Marini, A., & Andreetta, S. (2016). Age-related effects on language production. In *Cognition, language and aging* (pp. 55–79). John Benjamins.

McCleery, J. P., Tully, L., Slevc, L. R., & Schreibman, L. (2006). Consonant production patterns of young severely language-delayed children with autism. *Journal of Communication Disorders*, *39*(3), 217–231. https://doi.org/10.1016/j.jcomdis.2005.12.002

Merchán-Naranjo, J., Boada, L., Del Rey-Mejías, A., Mayoral, M., Llorente, C., Arango, C., & Parellada, M. (2016). La función ejecutiva está alterada en los trastornos del espectro autista, pero esta no correlaciona con la inteligencia. *Revista de Psiquiatría y Salud Mental*, *9*(1), 39–50. https://doi.org/10.1016/j.rpsm.2015.10.005

Mottron, L., & Gagnon, D. (2023). Prototypical autism: New diagnostic criteria and asymmetrical bifurcation model. *Acta Psychologica*, *237*, 103938. https://doi.org/10.1016/j.actpsy.2023.103938

Nadig, A., & Mulligan, A. (2017). Intact non-word repetition and similar error patterns in language-matched children with autism spectrum disorders: A pilot study. *Journal of Communication Disorders*, *66*, 13–21. https://doi.org/10.1016/j.jcomdis.2017.03.003

Nakazawa, M., et al. (2024). fmsb: Functions for medical statistics book with some demographic data. *R package version*. https://CRAN.R-project.org/package=fmsb

Nudel, R., Christiani, C. A., Ohland, J., Uddin, M. J., Hemager, N., Ellersgaard, D. V., & Werge, T. (2020). Language deficits in specific language impairment, attention deficit/hyperactivity disorder, and autism spectrum disorder: An analysis of polygenic risk. *Autism Research*, *13*(3), 369–381. https://doi.org/10.1002/aur.2211

Pedersen, T. L. (2024). patchwork: The composer of plots. *R package version*. https://CRAN.R-project.org/package=patchwork

Pijnacker, J., Hagoort, P., Buitelaar, J., Teunisse, J. P., & Geurts, B. (2009). Pragmatic inferences in high-functioning adults with autism and Asperger syndrome. *Journal of Autism and Developmental Disorders*, *39*(4), 607–618. https://doi.org/10.1007/s10803-008-0661-8

Piven, J., & Palmer, P. (1997). Cognitive deficits in parents from multiple-incidence autism families. *Journal of Child Psychology and Psychiatry*, *38*(8), 1011–1021. https://doi.org/10.1111/j.1469-7610.1997.tb01618.x

Pohlert, T. (2024). PMCMRplus: Calculate pairwise multiple comparisons of mean rank sums extended. *R package version*. https://CRAN.R-project.org/package=PMCMRplus

Posit Team. (2023). RStudio: Integrated development environment for R. Posit Software, PBC, Boston, MA.

Ramus, F. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain*, *126*(4), 841–865. https://doi.org/10.1093/brain/awg076

Rapin, I., & Dunn, M. A. (2003). Update on the language disorders of individuals on the autistic spectrum. *Brain and Development*, *25*(3), 166–172. https://doi.org/10.1016/S0387-7604(02)00191-2

Rapin, I., Dunn, M. A., Allen, D. A., Stevens, M. C., & Fein, D. (2009). Subtypes of language disorders in school-age children with autism. *Developmental Neuropsychology*, *34*(1), 66–84. https://doi.org/10.1080/87565640802564648

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Riches, N. G., Loucas, T., Baird, G., Charman, T., & Simonoff, E. (2011). Non-word repetition in adolescents with specific language impairment and autism plus language impairments: A qualitative analysis. *Journal of Communication Disorders*, *44*(1), 23–36. https://doi.org/10.1016/j.jcomdis.2010.06.003

Russell, G., Mandy, W., Elliott, D., White, R., Pittwood, T., & Ford, T. (2019). Selection bias on intellectual ability in autism research: A cross-sectional review and meta-analysis. *Molecular Autism*, *10*(1), 1–10. https://doi.org/10.1186/s13229-019-0260-x

Sánchez-Izquierdo, M., & Fernández-Ballesteros, R. (2021). Cognition in healthy aging. *International Journal of Environmental Research and Public Health*, *18*(3), 962. https://doi.org/10.3390/ijerph18030962

Schaeffer, J., El-Raziq, A., Castroviejo, E., Durrleman, S., Ferré, S., Grama, I., & Tuller, L. (2023). Language in autism: Domains, profiles and co-occurring conditions. *Journal of Neural Transmission*, *130*(3), 433–457. https://doi.org/10.1007/s00702-023-02592-y

Schopler, E., Reichler, R. J., & Renner, B. R. (2010). *The Childhood Autism Rating Scale (CARS)*. WPS.

Silleresi, S. (2023). *Developmental Profiles in autism spectrum disorder: Theoretical and methodological implications*. John Benjamins.

Silleresi, S., Prévost, P., Zebib, R., Bonnet-Brilhault, F., Conte, D., & Tuller, L. (2020). Identifying language and cognitive profiles in children with ASD via a cluster analysis exploration: Implications for the new ICD-11. *Autism Research*, *13*(7), 1155–1167. https://doi.org/10.1002/aur.2268

Tager-Flusberg, H. (2015). Defining language impairments in a subgroup of children with autism spectrum disorder. *Science China Life Sciences*, *58*(10), 1044–1052. https://doi.org/10.1007/s11427-012-4297-8

Taylor, L. J., Maybery, M. T., Grayndler, L., & Whitehouse, A. J. O. (2014). Evidence for distinct cognitive profiles in autism spectrum disorders and specific language impairment. *Journal of Autism and Developmental Disorders*, *44*(1), 19–30. https://doi.org/10.1007/s10803-013-1847-2

Tomasello, M. (2000). Do young children have adult syntactic competence? *Cognition*, *74*(3), 209–253. https://doi.org/10.1016/S0010-0277(99)00069-4

Tomblin, J. B., Hafeman, L. L., & Brien, M. (2003). Autism and autism risk in siblings of children with specific language impairment. *International Journal of Language and Communication Disorders*, *38*(3), 235–250. https://doi.org/10.1080/1368282031000086363

Tse, V. W., Lei, J., Crabtree, J., Mandy, W., & Stott, J. (2022). Characteristics of older autistic adults: A systematic review of literature. *Journal of Autism and Developmental Disorders*, *9*(2), 184–207. https://doi.org/10.1007/s40489-021-00238-x

Tuller, L., Ferré, S., Prévost, P., Barthez, M. A., Malvy, J., & Bonnet-Brilhault, F. (2017). The effect of computational complexity on the acquisition of French by children with ASD. In *Innovative Investigations of Language in Autism Spectrum Disorder* (pp. 115–140). Walter de GruyterGmbH. https://doi.org/10.1037/15964-007

Tuller, L., Silleresi, S., & Prévost, P. (in press). Autism and language modularity. In M. Arche, J.-W. Zwart, H. Demirdache, & N. Hyams (Eds.), *Footprints of phrase structure: Studies in syntax in honour of Tim Stowell*. John Benjamins.

Wechsler, D. (2008). *Wechsler adult intelligence scale–Fourth edition (WAIS–IV)*. NCS Pearson.

Wechsler, D. (2014). *Wechsler intelligence scale for children–Fifth edition (WISC-V)*. Pearson.

Whitehouse, A. J., Barry, J. G., & Bishop, D. V. (2007). The broader language phenotype of autism: A comparison with specific language impairment. *Journal of Child Psychology and Psychiatry*, *48*(8), 822–830. https://doi.org/10.1111/j.1469-7610.2007.01765.x

Whitehouse, A. J., Barry, J. G., & Bishop, D. V. (2008). Further defining the language impairment of autism: Is there a specific language impairment subtype? *Journal of Communication Disorders*, *41*(4), 319–336. https://doi.org/10.1016/j.jcomdis.2008.01.002

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag. https://ggplot2.tidyverse.org.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., & Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Williams, D., Payne, H., & Marshall, C. (2013). Non-word repetition impairment in autism and specific language impairment: Evidence for distinct underlying cognitive causes. *Journal of Autism and Developmental Disorders*, *43*(2), 404–417. https://doi.org/10.1007/s10803-012-1579-8

Wolk, L., & Brennan, C. (2013). Phonological investigation of speech sound errors in children with autism spectrum disorders. *Speech, Language and Hearing*, *16*(4), 239–246. https://doi.org/10.1179/2050572813Y.0000000020

Wolk, L., & Edwards, M. L. (1993). The emerging phonological system of an autistic child. *Journal of Communication Disorders*, *26*(3), 161–177. https://doi.org/10.1016/0021-9924(93)90006-V

Wolk, L., & Giesen, J. (2000). A phonological investigation of four siblings with childhood autism. *Journal of Communication Disorders*, *33*(5), 371–389. https://doi.org/10.1016/S0021-9924(00)00021-6

World Health Organization. (2023). International Classification of Diseases (ICD)-11. https://icd.who.int

Appendix A

LITMUS-QU-FR-NWR-Adults

Module	Item number	Item	Syllabic structure	Syllable length
Child module	1	[kip]	CVC	1
	2	[fapus]	CV.CVs	2
	3	[kusp]	CVsC	1
	4	[paklu]	CV.CCV	2
	5	[plusk]	CCVsC	1
	6	[kupalfi]	CV.CVL.CV	3
	7	[plu]	CCV	1
	8	[fupli]	CV.CCV	2
	9	[plal]	CCVL	1
	10	[piklafu]	CV.CCV.CV	3
	11	[fips]	CVCs	1
	12	[kifapu]	CV.CV.CV	3
	13	[flaplu]	CCV.CCV	2
	14	[klifak]	CCV.CVC	2
	15	[piks]	CVCs	1
	16	[kufalpi]	CV.CVL.CV	3
	17	[plifu]	CCV.CV	2
	18	[flukif]	CCV.CVC	2
	19	[klil]	CCVL	1
	20	[plaklu]	CCV.CCV	2
	21	[pufaki]	CV.CV.CV	3
	22	[klups]	CCVCs	1
	23	[pafuski]	CV.CVs.CV	3
	24	[filpa]	CVL.CV	2
	25	[pusk]	CVsC	1
	26	[fikuspa]	CV.CVs.CV	3
	27	[pliks]	CCVCs	1
	28	[kuspa]	CVs.CV	2
	29	[kuflapi]	CV.CCV.CV	3
	30	[pilfu]	CVL.CV	2
	31	[kis]	CVC	1
Adult module	32	[pluflak]	CCV.CCVC	2
	33	[kliflap]	CCV.CCVC	2
	34	[fasklip]	CVs.CCVC	2
	35	[plifkup]	CCVC.CVC	2
	36	[spuklas]	sCV.CCVs	2
	37	[fluplak]	CCV.CCVC	2
	38	[klisfup]	CCVs.CVC	2
	39	[pusfilk]	CVs.CVCC	2
	40	[fispalk]	CVs.CVCC	2
	41	[klupki]	CCVC.CV	2
	42	[flaklup]	CCV.CCVC	2
	43	[kulfaps]	CVL.CVCS	2
	44	[skaplis]	sCV.CCVs	2
	45	[pisfluk]	CVs.CCVC	2
	46	[skilfa]	sCVL.CV	2
	47	[plafki]	CCVC.CV	2
	48	[klaplif]	CCV.CCVC	2
	49	[spalku]	sCVL.CV	2
	50	[flispuk]	CCVs.CVC	2
	51	[kaspluk]	CVs.CCVC	2
	52	[pilfups]	CVL.CVCS	2
	53	[flipka]	CCVC.CV	2