

Research Article

Phonological Loop Functioning In Neuromuscular Disorders

Halil Tayyip Uysal¹, Mariam Kavakci²

¹Corresponding Author, Ankara Yıldırım Beyazıt University, Faculty of Health Sciences, Department of Speech and Language Therapy, Ankara, Türkiye, ORCID No: 0000-0001-7758-0785, htuysal@aybu.edu.tr

²Ankara Yıldırım Beyazıt University, Faculty of Health Sciences, Department of Speech and Language Therapy, Ankara, Türkiye, ORCID No: 0000-0001-6511-9203, mariamkavakci@gmail.com

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ABSTRACT

Purpose: The phonological loop is a key component of working memory, and subvocal rehearsal plays a critical role in its functioning. Individuals with neuromuscular disorders may experience cognitive effects due to motor system impairment, yet little is known about their phonological loop performance. This study aims to investigate the subvocal rehearsal rate as a measure of phonological loop functioning in patients with neuromuscular disorders using a novel, non-motor task.

Method: This cross-sectional study was conducted at the Neuromuscular Disorders Clinic of Ankara City's Hospital and included patients with neuromuscular disorders and age- and gender-matched healthy control participants. Thirty-eight patients with neuromuscular disorders and 38 age- and gender-matched healthy subjects completed a non-motor subvocal rehearsal task. Mean response times were compared between groups. Statistical analysis used: An independent t-test was used to compare response times. Effect size was calculated using Cohen's d.

Results: Patients with neuromuscular disorders demonstrated significantly slower response times than healthy controls on all items ($p < .05$), with a large effect size ($Cohen's d = 1.22$), indicating impaired subvocal rehearsal performance.

Conclusion: Subvocal rehearsal rate is significantly reduced in patients with neuromuscular disorders, suggesting disruption in the phonological loop system of working memory independent of motor impairment.

Keywords: neuromuscular disorders, phonological loop, working memory, subvocal rehearsal, cross sectional study



Araştırma Makalesi

Nöromusküler Hastalıklarda Fonolojik Döngü Fonksiyonu

GENİŞLETİLMİŞ ÖZET

Amaç: Çalışma belleği, dil işleme, öğrenme ve günlük bilişsel fonksiyonların yürütülmesinde merkezi bir rol oynayan dinamik bir sistemdir. Baddeley ve Hitch tarafından 1974'te önerilen çalışma belleği modeli, bu operasyonları açıklayan yaygın kabul görmüş bir teoridir. Bu model, tek ve statik bir kısa süreli bellek konseptinin yerini almak üzere geliştirilmiştir. Bu sistemle birlikte; merkezi yürütücü (central executive), görsel-mekânsal taslak (visuospatial sketchpad), fonolojik döngü (phonological loop) ve bölgesel arabellek (episodic buffer) süreçleri de ele alınır. Fonolojik döngü, işitsel-dilsel bilgiyi kısa süreliğine 'fonolojik depo'da muhafaza eden ve bu bilgiyi koruyan 'artikülâtör kontrol süreci' olmak üzere iki alt bileşenden meydana gelmektedir (Baddeley, 2000). İçsel tekrar (subvocal rehearsal) mekanizması, dilsel girdinin fonolojik depoda en fazla 2 saniye kalmasını sağlayarak yeni sözcüklerin öğrenilmesi, sözel akıcılık ve sözcük dağarcığının gelişiminde kritik rol oynamaktadır (Mahy ve ark., 2016; Jarrold & Tam, 2011). Nöromusküler bozukluklar (NMB), multipl skleroz, Amiyotrofik Lateral Skleroz (ALS), Miyastenia Gravis (MG), Multipl Skleroz (MS) gibi hastalıkları kapsamaktadır. Ayrıca birincil olarak kas-iskelet sistemi üzerinde etkili olmaktadır. Güncel nöropsikolojik çalışmalarda ise bu bozuklukların bilişsel süreçler üzerinde de belirgin etkileri olduğu gösterilmiştir (Abrahams ve ark., 2000; Strong ve ark., 2017). Özellikle ALS hastalarında, sözel akıcılık ve yürütücü işlevlerde gözlenen sorunlar motor problemlerle ve çalışma belleğinin üst düzey bileşenlerindeki bozukluklarla bağlantılı olabileceği öne sürülmüştür. Ancak, bu hastalarda fonolojik döngünün temel bileşenlerinden biri olan içsel tekrar hızını doğrudan ölçen, motor gereksinimi ortadan kaldıran görevlerle elde edilen veriler sınırlılık göstermektedir. Çalışmamızda motorik gereksinimleri minimize eden, tamamen motor hareket gerektirmeyen bir içsel tekrar görev modeli kullanılmıştır. Böylece, Bu literatürdeki sınırlılığın azaltılmasına katkı sağlanabilecek ve fonolojik döngü işleyişi daha ayrıntılı kavranabilecektir. Bu görevle elde edilecek ortanca tepki süreleri; NMB'li hastalar ile yaş ve cinsiyet açısından eşleşmiş sağlıklı bireylerde kıyaslanarak, fonolojik döngü sisteminin ne ölçüde etkilendiğinin incelenmesi hedeflenmiştir. Özellikle, içsel tekrar hızının ölçümü yoluyla; motor sistemden bağımsız bir bilişsel fonksiyon göstergesi olarak çalışma belleğinin bu alt bileşeninin performans bozukluğu derecesi değerlendirilmesi ve klinik değerlendirmeler ile müdahale stratejilerine yeni bir perspektif oluşturulması amaçlanmıştır.

Yöntem: Araştırma, Ankara Şehir Hastanesi Nöromusküler Bozukluklar Kliniği'nde yürütülen kesitsel tasarımlı bir çalışma olarak planlanmıştır. Çalışmaya, NMB tanısı almış 38 hasta (%40 multipl skleroz, %34 ALS, %26 miyastenia gravis; yaş ortalaması $55,7 \pm 10,4$ yıl) ile yaş ve cinsiyet (23 kadın, 15 erkek) eşleştirmeli 38 sağlıklı kontrol bireyi (yaş ortalaması $54,2 \pm 10,5$ yıl; 22 kadın, 16 erkek) dahil edilmiştir. Hem hasta grubu hem de kontrol grubu için katılımcı yaş aralığı 21–70'tir ve tüm katılımcıların ana dili Türkçe'dir. Çalışma, Ankara Yıldırım Beyazıt Üniversitesi Etik Kurulu'nun 15 Şubat 2023 tarihli ve 2023-31 onay kodlu kararı ile Helsinki Bildirgesi ilkelerine uygun yürütülmüş; katılımcılardan yazılı bilgilendirilmiş onam alınmıştır. Hasta grubuna alınma kriterleri: (a) nöromusküler bozukluk tanısının bulunması, (b) ek nörolojik patolojinin olmaması, (c) yaşın 21–70 aralığında olması ve (d) Türkçeyi ana dil düzeyinde konuşuyor olması olarak belirlenmiştir. Kontrol grubuna ilişkin kriterler ise: (a) nörolojik veya kronik hastalık öyküsünün olmaması, (b) ek tıbbi durumun olmaması, (c) yaşın 21–70 aralığında olması ve (d) Türkçeyi ana dil düzeyinde konuşuyor olması olarak belirlenmiştir. Çalışmaya dahil edilen hastalar ve sağlıklı bireyler öncelikle demografik bilgi formunu doldurmuştur. Ardından içsel tekrar görevini tamamlamıştır. Çalışmada kullanılan içsel tekrar görevi, dört dilsel uyaran setinden oluşan motor hareket gerektirmeyen bir testtir. Uyarılar; haftanın günleri, ardışık sayılar, rastgele sayılar ve karışık dizi gibi dört öğede sunulmuştur. Bu görev; fonolojik depoyu (2 saniyeye kadar sözel bilginin depolandığı iç 'kulak') ve artikülâtör kontrol sürecini (iç 'ses' aracılığıyla tekrar) aynı anda çalıştıracak şekilde tasarlanmıştır.

Katılımcılardan, artikülâtör hareket oluşturmadan, uyarınları yalnızca içsel (bilişsel) düzeyde ardışık biçimde tekrarlamaları istenmiştir. Araştırmacı, her bir öge için ‘başla’ işareti verdiğiğinde dijital kronometreyi çalıştırmış; katılımcı ‘bitti’ deyince kronometreyi durdurmuştur. Her öge üç kez tekrarlanmış ve ortanca tepki süresi hesaplanmıştır. Ortanca tepki süresi verilerinin normal dağılım koşulları Kolmogorov–Smirnov testi ile analiz edilmiştir. Tanımlayıcı istatistikler (*Ortalama ± SD*) sunulmuştur. Gruplar arası karşılaştırmalar için bağımsız örneklem t-testi; etki büyüklüğü değerlendirmesi için Cohen’s d kullanılmıştır. Anlamlılık düzeyi $\alpha = .05$ olarak belirlenmiş ve tüm analizler SPSS v.23 ile gerçekleştirilmiştir.

Bulgular: Hasta ve kontrol gruplarının tepki süreleri karşılaştırıldığında; Madde 1 (Haftanın günleri) için hasta grubunun ortalama tepki süresi 26,20 saniye ($SS = 9,98$) iken, kontrol grubunun ortalaması 15,10 saniye ($SS = 4,53$) olarak hesaplanmıştır ($p = .002$, Cohen’s $d = 1.18$). Madde 2 (Artan Sayılar) görevinde hasta grubu ortalama 20,85 saniyede ($SS = 8,21$) tepki verirken, kontrol grubunda bu süre 13,29 saniye ($SS = 4.04$) olarak bulunmuştur ($p = .03$, Cohen’s $d = 1.03$). Benzer şekilde, Madde 3 (Rastgele Sayılar) incelendiğinde hasta grubunun tepki süresi ortalaması 11.64 saniye ($SS = 4.65$), kontrol grubunun ise 7.52 saniye ($SS = 2.02$) olarak ölçülmüştür ($p = .01$, Cohen’s $d = 1.09$). Son olarak, Madde 4’te (Karışık Diziler) hasta grubu ortalama 10.05 saniyelik ($SS = 4.85$) bir tepki süresi gösterirken, kontrol grubunun ortalaması 6.00 saniye ($SS = 1,79$) olmuştur ($p = .01$, Cohen’s $d = 1.22$). Elde edilen bu bulgular doğrultusunda, tüm maddelerde gruplar arasında $p < .05$ düzeyinde istatistiksel olarak anlamlı bir farklılık görülmüş ve hesaplanan etki büyüklüklerinin tamamı "büyük" ($d > 0.8$) kategorisinde yer almıştır. Hasta grubundaki ortanca tepki süresi dağılımının kontrol grubuna göre daha değişken olması, bireyler arası performans farklılıklarının da belirginliğini göstermiştir.

Sonuç: Elde edilen bulgular, NMB’li hastaların motor hareket gerektirmeyen içsel tekrar görevlerindeki tepki sürelerinin sağlıklı bireylerden anlamlı şekilde daha uzun olduğunu ortaya koymuştur. Bu durum, fonolojik döngü alt bileşenlerinden içsel tekrar hızının, motor bozukluklardan bağımsız biçimde etkilendiğini desteklemektedir. ALS’li bireylerde de benzer bilişsel-yavaşlama belirten önceki çalışmalara paralellik göstermektedir (Abrahams ve ark., 2000). Ayrıca, görev esnasında artikülâtör hareketsiz kalma zorunluluğu, bulbar kas disfonksiyonunun sonuçları çarpıtmasını önleyerek gerçekten fonolojik sistem performansını izole etmiştir. Benzer şekilde, nöromusküler bozukluklarda bilişsel işlevlerin motor belirtilerden bağımsız olarak etkilenebileceğini gösteren çalışmalar, klinik değerlendirmelerin yalnızca motor performansa odaklanmasının yetersiz kalabileceğini vurgulamaktadır (Abrahams et al., 2000; Strong et al., 2017). Özellikle ALS ve Multipl Skleroz (MS) gibi hastalıklarda kısa süreli bellek, sözel akıcılık ve çalışma belleği bileşenlerinde gözlenen bozulmaların, hastalığın klinik seyri ve günlük yaşam işlevselliğini etkileyebileceği bildirilmiştir. Bu bağlamda, içsel tekrar hızının motor hareket gerektirmeyen görevlerle değerlendirilmesi, bilişsel-zamansal işlevlerin klinik izlemde daha sistematik biçimde ele alınmasına katkı sağlayabilir.

Fonolojik döngü ve kısa süreli belleğe ilişkin önceki çalışmalar, içsel tekrar mekanizmasının özellikle kelime öğrenimi, sözel akıcılık ve dilsel bilgilerin geçici olarak korunmasında kritik bir rol oynadığını ortaya koymuştur (Baddeley, 2000; Mahy et al., 2016). Bu nedenle, içsel tekrar hızındaki yavaşlamanın objektif olarak ölçülmesi, çalışma belleğinin fonolojik alt sistemine özgü bozuklukların erken dönemde saptanmasına olanak tanıyabilir. Motor gereksinimlerden arındırılmış değerlendirme paradigmatları, bilişsel bozulmaların hastalığın ileri evrelerine özgü ikincil sonuçlar mı yoksa erken dönem özellikleri mi olduğunu ayırt etmede önemli bir araç sunmaktadır.

Fonolojik benzerlik ve kelime uzunluğu etkilerinin, farklı nöromusküler bozukluk gruplarında nasıl bir örüntü sergilediğinin incelenmesi, fonolojik döngü alt bileşenlerinin hastalığa özgü profillerini ortaya koyarak kısa süreli bellek bozukluklarının ayırt edici tanılabilir göstergeler olarak kullanılmasına katkı sağlayabilir (Baddeley, 1997; Papagno, 2022). Gelecekte, fonolojik benzerlik ve kelime uzunluğu etkileri gibi diğer alt süreçlerin de aynı paradigma ile incelenmesi, bozukluk profilini daha ayrıntılı ortaya koyabilir.

Anahtar Sözcükler: nöromusküler bozukluk, fonolojik döngü, çalışma belleği, içsel tekrar, kesitsel çalışma

Introduction

Working memory serves as the foundational element for language and cognitive processes. It's essential function in the temporary storage and manipulation of information is evident in primates throughout their lifespan, from early development to advanced age. The Baddeley and Hitch model of working memory, proposed in 1974 by Alan Baddeley and Graham Hitch, is a widely accepted theory that explains working memory operations (Baddeley et al., 1974). This model was introduced to replace the earlier concept of a single, static short-term memory and consisted of three main components at conception, with the addition of a fourth component subsequently (Baddeley, 2000).

The central executive serves as the supervisory component of the model. It acts as a regulatory mechanism that oversees and organizes the functions of the other mechanisms involved in working memory. The visuospatial sketchpad handles visuospatial data and functions as a cognitive workspace for processing visual and spatial information. The phonological loop component of the model manages auditory-linguistic input and consists of two parts: 1) the phonological store (also known as the "inner ear"), which keeps information in a speech-related form for a maximum of 2 seconds, and 2) the articulatory control process (referred to as the "inner voice"), which is employed to rehearse and maintain the information in the phonological store by means of subvocal repetition (e.g., repeating a phone number in one's mind). Lastly, the episodic buffer integrates data from the central executive, phonological loop, visuospatial sketchpad, and long-term memory into a unified, multi-dimensional representation. This buffer is hypothesized to facilitate the processing of both new and previously stored information, acting as a link between working memory and long-term memory.

Not surprisingly, the phonological loop system plays a special role in language development. It has been linked to vocabulary development in early childhood (Papagno, 2022) and has been implicated in the acquisition of a second language (Karaousou & Nerantzaki, 2020). Subvocal rehearsal is a component of the phonological system known to play an important role in verbal working memory and is implicated in various cognitive functions (Mahy et al., 2016). In children, subvocal rehearsal does not fully develop until about 7 years of age (see Jarrold and Tam, 2011, for a review). In adults, this mechanism affects the ease with which new words are added to the existing lexicon, especially unfamiliar words (Kaushanskaya, 2011). Although

the exact nature of the relationship between subvocal rehearsal and verbal working memory is not fully understood, there is a consensus that subvocal rehearsal plays a significant role in the acquisition of verbal information.

A few noteworthy findings provide evidence for the phonological loop system in healthy subjects (Baddeley, 1997). The first is the phonological similarity effect, which refers to the finding that words that sound more dissimilar (e.g., cat and bug) are easier to remember than words that sound more similar (e.g., cat and rat) (Baddeley, 1966; Baddeley, 1997). The second is the articulatory suppression effect, which refers to the disruption of subvocal rehearsal processes by the production of irrelevant speech (Baddeley et al., 1984). Interestingly, the suppression effect is also found when subjects move their articulators for something other than speech (e.g., chewing gum). The third is the word length effect, which is evidenced by the finding that longer words are more difficult to recall than shorter words (Baddeley et al., 1974).

Neuropsychological evidence on patients with motor speech disorders also sheds light on phonological loop functioning. In a study examining articulatory rehearsal, researchers found evidence of disrupted rehearsal mechanisms in patients with apraxia of speech compared to healthy controls (Waters et al., 1992). Their study had two main findings. First, patients' verbal memory span was found to be significantly shorter than control subjects' verbal memory span. Second, patients' performance was not influenced by word length or phonological similarity effects. Thus, the researchers concluded that speech disorders involving deficits at the planning level such as apraxia of speech, are related to articulatory rehearsal mechanisms.

Another study investigated whether patients with dysarthria secondary to brain injury exhibit evidence of phonological coding and subvocal speech (Baddeley & Wilson, 1985). Phonological coding was assessed by asking the patients to evaluate homophony in both words and nonwords during a judgment task. Patients' performance was slow in both tasks; however, their accuracy was found to be within the normal range. Furthermore, patients' memory spans were also found to be normal, and the usual negative effect of phonological similarity was observed on their performance. Lastly, the presence of a word length effect in immediate recall showed that patients with dysarthria have functioning subvocal rehearsal systems. The authors concluded based on these findings that phonological coding and subvocal rehearsal can function centrally in the absence of vocal speech. Thus, patients with speech disorders stemming from a deficit in execution (i.e., dysarthria) in contrast to a deficit in planning and programming (i.e., apraxia of speech), appear to exhibit a normal capacity for rehearsal. Taken together, these

findings suggest that subvocal rehearsal mechanisms are crucial for the planning and configuration of accurate speech production.

Few studies have investigated the phonological loop component of working memory in neuromuscular disorders. In one study with amyotrophic lateral sclerosis (ALS) patients, results showed evidence of phonological similarity and the word length effects in ALS patients, despite also showing a marked decrease in working memory capacity (Abrahams et al., 2000). The authors interpreted these findings as suggesting that impairments in verbal fluency among ALS patients stem from a higher-level dysfunction, indicating issues with attentional or the central executive component, rather than being related to deficits in phonological loop functioning or language skills per se.

Previous studies on phonological loop functioning have relied mainly on behavioral tasks that require a motor response from patients. This is a significant limitation for studies on patients with neuromuscular disorders, whose primary deficit involves muscular functioning. As such, methods designed for exploiting the phonological system directly, especially those that control for motor skill, are needed. The purpose of this study was to use a non-motor task to examine subvocal rehearsal rate in patients with neuromuscular disorders and compare them to healthy control subjects.

Method

Design and Ethical Considerations

This study was approved by the ethics committee of Ankara Yıldırım Beyazıt University (Approval Code: 2023-31) on 02/15/2023. The research was carried out in line with the ethical guidelines established by the committee for human experimentation and in accordance with the Helsinki Declaration. All participants provided written informed consent prior to enrollment in the study after the procedures were fully explained. This research was completed as a cross-sectional study.

Participants

A total of 38 patients with neuromuscular disorders and 38 age- and gender-matched control subjects were recruited for this cross-sectional study. Patients were recruited from the Neuromuscular Disorders Clinic of Ankara City Hospital's Physical Medicine and Rehabilitation inpatient department. Control subjects were recruited through snowball sampling. Inclusionary criteria for the patient group were: 1) diagnosis of a neuromuscular

disorder, 2) no comorbid neurological condition, 3) age between 21-70 years, and 4) native Turkish speaker. Inclusionary criteria for the control group were: 1) no history of neurological or chronic illness, 2) no underlying medical conditions, 3) age between 21-70 years, and 4) native Turkish speaker. Exclusion criteria included 1) the presence of additional neurological disorders, 2) severe hearing impairment, 3) major psychiatric disorders, and 4) the use of medications known to significantly affect cognitive functioning.

Data Collection/Procedure

Prior to task administration, a demographic information form was filled out for each participant. The form included information about the subjects' gender, date of birth, medical history, education level, and cognitive status. Next, each participant was administered a novel linguistic generation task designed to measure subvocal rehearsal rate. The task was designed to engage the phonological store (holding a series of verbal information in memory) and rehearsal mechanisms (subvocally repeating verbal information). It consisted of four-items with various types of linguistic stimuli (e.g., days of the week, numbers) and included automatic and random sequences (see Appendix). Participants were explicitly instructed to complete each item as quickly as possible while maintaining accurate internal repetition of the stimuli. Emphasis was placed on both speed and correctness to ensure that response time reflected subvocal rehearsal efficiency rather than individual pacing preferences. After ensuring that the participant understood the task directions, the examiner cued the participant to begin the task and simultaneously started a digital stopwatch. The timer was stopped immediately upon cue (nodding or saying "done") from the participant to the examiner, indicating that the item had been completed. This process was repeated for each item of the task.

Data Analysis

Initial power analysis with a medium effect size of .50 and statistical power of .80 yielded a sample size of 35 patients and 35 control subjects. Data were evaluated through various statistical methods (e.g., Kolmogorov–Smirnov test) to confirm normal distribution. Descriptive statistics were presented as mean and standard deviation (*Mean ± SD*) for normally distributed variables. After verifying that the data followed a normal distribution, an independent sample t-test was performed to compare the parameters between groups. Response time was defined as the dependent variable. A significance level of 5% was set to assess statistical significance. SPSS software version 23 (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses.

Results

Data for 38 patients with neuromuscular disorders (23 female, 15 male) and 38 age- and gender-matched healthy subjects (22 female, 16 male) were obtained for this study. Of the 38 patients with neuromuscular disorders, 15 had a diagnosis of multiple sclerosis (40%), 13 had a diagnosis of amyotrophic lateral sclerosis (34%), and 10 had a diagnosis of myasthenia gravis (26%). Mean age of the patient group was 55.72 ± 10.42 and mean age of the control group was 54.20 ± 10.51 . Age and gender did not differ significantly between the patient and control groups ($p > .05$). See Table 1.

Table 1. The Demographic Characteristics of Patient and Control Subjects

Variable		Patient group		Control group	
		<i>n</i> = 38	%	<i>n</i> = 38	%
Gender	Male	15	40	16	42
	Female	23	60	22	58
Age	30-40	3	8	4	10
	41-50	13	34	12	32
	51-60	15	40	14	37
	61-70	7	18	8	21
Diagnosis	MS	15	40	-	-
	ALS	13	34	-	-
	MG	10	26	-	-

Note. MS: multiple sclerosis; ALS: amyotrophic lateral sclerosis; MG: myasthenia gravis.

Results showed that mean response times (RTs) were significantly higher for the patient group compared to the control group ($p < .05$) on all items of the task (see Table 2).

Table 2. Mean Response Times (RT) and Standard Deviations (SD) on Subvocal Rehearsal Task for Patient and Control Groups

Item	Mean RT (patients)	SD	Mean RT (controls)	SD	<i>p</i> -value
1	26.20	9.98	15.10	4.53	.002*
2	20.85	8.21	13.29	4.04	.03*
3	11.64	4.65	7.52	2.02	.01*
4	10.05	4.85	6.00	1.79	.01*

Note. *Indicates a significant statistical difference with $p < .05$

Cohen's d value was found to be 1.22, indicating a large effect size between the two groups. These findings indicate that patients with neuromuscular disorders performed significantly more slowly than healthy controls on the subvocal rehearsal task.

Standard errors were higher in the patient group compared to the control group, indicating greater variability in performance (see Figure 1). Error bars in Figure 1 represent standard errors of the mean.

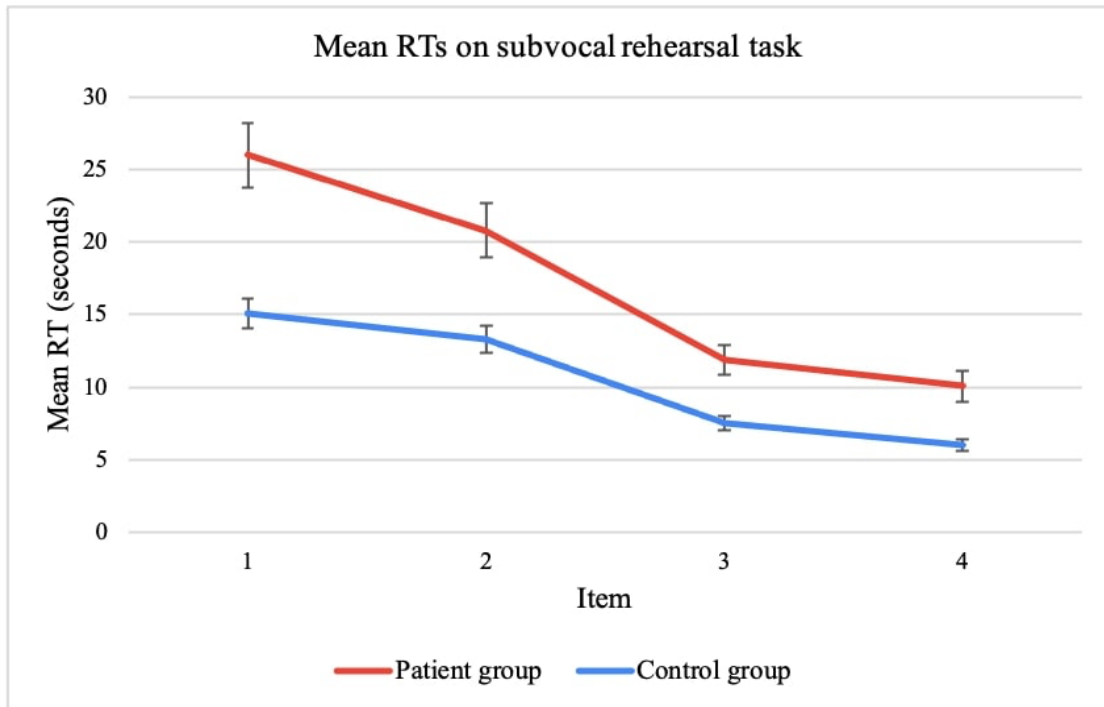


Figure 1. Mean RTs on Subvocal Rehearsal Task.

Discussion

Working memory is a restricted cognitive mechanism responsible for temporarily retaining and processing input, including linguistic information. The phonological loop component of working memory is specifically responsible for holding auditory information required for multiple aspects of language processing. Subvocal rehearsal mechanisms are a critical part of this system, maintaining auditory and linguistic memory traces that would otherwise be lost.

Previous studies have provided conflicting evidence regarding phonological loop functioning in neuromuscular and motor speech disorders (e.g., Baddeley & Wilson, 1985; Abrahams et al., 2000; Waters et al., 1992). Furthermore, quantifying phonological loop functioning, even in healthy subjects, presents its own challenges. Most research has considered the observation of phonological similarity and word length effects as indices of preserved phonological loop functioning. While this approach is valid from an inductive standpoint; differences may nevertheless underlie what otherwise appears to be an intact phonological loop system. The phonological loop mechanism is a temporal system by nature, therefore a proxy of it would ideally include a measure of response time or duration. Consequently, previous studies' evidence on phonological similarity and word length effects documented in patients with neuromuscular disorders does not preclude the possibility that these patients have an impairment in one or more aspects (e.g., temporal processing) of the subvocal rehearsal system.

The current research employed a new subvocal working memory task to examine if adults with neuromuscular disorders exhibit a deficit in a particular aspect of their phonological loop functioning, rehearsal rate. The findings indicated that individuals with neuromuscular disorders rehearse a sequence of verbal information subvocally at a significantly slower speed than healthy control participants.

A significant challenge in carrying out behavioral studies on neuromuscular disorders is controlling for the motor and muscular impairments experienced by these patients (Strong et al., 2017). In the case of subvocal rehearsal, bulbar deficits can easily confound the results on tests that require a speech-motor response. This is also the case for other motor tasks that may require manual responses to items. The task developed for the purposes of the present study aimed to address this challenge. Patients were not required to repeat items overtly and the task did not require any spontaneous linguistic generation. This is an important consideration because impairments in verbal fluency skills have been consistently documented in disorders such as ALS (Barker et al., 2024). Finally, the simplicity and conciseness of the task make it feasible for use with different patient populations and disease severities.

The present study examined only one aspect of subvocal rehearsal, which is rehearsal rate. An examination of several variables including articulatory suppression, phonological similarity and word length effects, verbal fluency, and rehearsal rate/response time, would help elucidate which subcomponents of phonological loop functioning, or linguistic ability more

generally, may be impaired. Future studies should include standardized assessments of motor severity, such as the Amyotrophic Lateral Sclerosis Functional Rating Scale–Revised, the Expanded Disability Status Scale, and the Myasthenia Gravis Foundation of America Clinical Classification, as well as comprehensive cognitive screening measures, including the Montreal Cognitive Assessment and the Mini-Mental State Examination. This integrated approach would allow a more precise examination of the interplay between motor impairment, cognitive status, and subvocal rehearsal processes in neuromuscular disorders. An investigation of the contribution of subvocal rehearsal to verbal working memory among these other factors may help consolidate the seemingly conflicting evidence in the existing literature. The specific nature of the phonological loop mechanism also remains a critical question. The rehearsal speed deficit observed in patients with neuromuscular disorders may be mediated by more general cognitive processes. The large variability documented in the performance of the patient group warrants further investigation. Although the present sample included patients with different neuromuscular diagnoses, subgroup comparisons were not conducted due to insufficient statistical power within each diagnostic category. This limitation should be considered when interpreting the findings, and future studies with larger, diagnosis-specific samples are warranted to clarify potential subgroup-specific differences in subvocal rehearsal functioning. Individual differences between patients can be determined to predict which patients may have difficulty with phonological functioning, and may potentially serve as a prognostic indicator.

Patients with neuromuscular disorders have slower performance rates on a novel, non-motor subvocal rehearsal task compared to healthy subjects, suggesting an impairment in the phonological loop system of working memory. These results reveal important insights into the linguistic and cognitive repercussions of neuromuscular pathology and open a new avenue for future research on phonological loop mechanisms in different patient populations.

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Appendix

Novel Linguistic Generation Task

“Ağzınızı hareket ettirmeden haftanın 7 gününü 5 defa İçinizden tekrarlayınız.” (Repeat the 7 days of the week silently 5 times without moving your mouth.)

Pazartesi-Salı-Çarşamba-Perşembe-Cuma-Cumartesi-Pazar

(Monday-Tuesday-Wednesday-Thursday-Friday-Saturday-Sunday)

Süre (Duration): _____

“Ağzınızı hareket ettirmeden 1’den 10’a kadar İçinizden sayınız. 5 defa aynı şeyi tekrarlayın.” (Count from 1 to 10 silently without moving your mouth. Repeat this 5 times.)

1-2-3-4-5-6-7-8-9-10

Süre (Duration): _____

“Dört kelime söyleyeceğim. Lütfen bunları İçinizden aynı şekilde tekrarlayınız. 5 defa ağzınızı hareket ettirmeden. (I will say four words. Please repeat them silently in the same way. Do this 5 times without moving your mouth.)

Kedi-ağaç-bardak-mavi

(Cat-tree-glass-blue)

Süre (Duration): _____

“Dört rakam söyleyeceğim. Lütfen bunları İçinizden aynı şekilde tekrarlayınız. 5 defa ağzınızı hareket ettirmeden.” (I will say four digits. Please repeat them silently in the same way. Do this 5 times without moving your mouth.)

2-1-4-3

Süre (Duration): _____