Endurance and fatigue characteristics in the neck muscles during sub-maximal isometric test in patients with cervical radiculopathy

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Abstract

Purpose The aim of the study was to compare myoelectric manifestation in neck muscle endurance and fatigue characteristics during sub-maximal isometric endurance test in patients with cervical radiculopathy and asymptomatic subjects. An additional aim was to explore associations between primary neck muscle endurance, myoelectric fatigability, and self-rated levels of fatigue, pain and subjective health measurements in patients with cervical radiculopathy.

Methods Muscle fatigue in the ventral and dorsal neck muscles was assessed in patients with cervical radiculopathy and in an asymptomatic group during an isometric neck muscle endurance test in prone and supine. 46

patients and 34 asymptomatic subjects participated. Surface electromyography signals were recorded from the sternocleidomastoid, cervical paraspinal muscles and upper and middle trapezius bilaterally during the endurance test. Subjective health measurements were assessed with questionnaires.

Results The results showed altered neck muscle endurance in several of the muscles investigated with greater negative median frequency slope, greater variability, side imbalance, lower endurance time and higher experience of fatigue among the cervical radiculopathy patients compared with healthy subjects. Endurance times were significantly lower in both prone and in supine positions between the patients compared to asymptomatic subjects. During the neck muscle endurance test, fatigues in the upper trapezius muscles during the prone test and in the sternocleidomastoid muscles during the supine test were of more importance than self-perceived pain, fatigue, disability and kinesiophobia in predicting neck muscle endurance (NME).

Conclusion NME testing in the primary neck muscles seems to be an important factor to take into consideration in rehabilitation.

Keywords Cervical radiculopathy · Electromyography · Endurance · Fatigue · Neck muscles · Pain

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Introduction

Most signs and symptoms associated with CR from degenerative disorders can resolve spontaneously [1]. However, with persisting symptoms, chronic functional impairments and activity limitations can occur [2].

A growing number of studies have found changes in the structure of cervical muscles and muscle behavior in chronic neck pain patients compared to healthy subjects [3]. Chronic neck pain patients have also shown to have implications for cervical muscle function with regard to decreased physical measures of strength, endurance, efficiency and repositioning acuity as well as decreased levels of self-perceived functioning [3]. There is, however, a lack of knowledge regarding neck muscle function in patients with CR.

Surface electromyography (EMG) is a non-invasive technique for assessing muscle function. The most commonly used index to quantify muscle fatigue is the change of the median frequency (MF) of the power spectrum of the EMG signal. During sustained muscular contraction, a compression of the MF EMG power spectrum towards lower frequencies has been observed to follow a linear relationship with muscular fatigue [4].

To our knowledge, no previous studies have investigated potential differences between patients with CR and an asymptomatic reference group with regard to myoelectric fatigability during primary neck muscle endurance testing. It is also unknown to what extent CR patient primary neck muscle endurance is associated with myoelectric fatigability and self-rated level of fatigue, pain, disability and psychological factors. A potential link between these variables may suggest the possible utility of specific training of neck muscle endurance in the treatment of CR.

The aim of the present study was, therefore, to investigate neck muscle endurance and fatigue characteristics in patients with CR compared to an asymptomatic reference group. An additional aim was to explore associations between primary neck muscle endurance, myoelectric fatigability, and self-rated levels of fatigue, pain, disability and psychological factors in patients with CR.

Methods

Subjects

Forty-six patients (26 women and 20 men) with CR and pathology of relevance for CR verified by Magnetic resonance imaging (MRI) and clinical examination including Spurling sign participated in the study. The patients were recruited from a Neurosurgery Clinic for selection to surgery. Patients who did not match the criteria for surgery or denied surgery ($N = 2$) were also asked to participate. Patients were excluded if they had earlier fracture or luxation of the cervical spine, myelopathy, malignity or spinal tumor, spinal infection or previous surgery in the cervical column. All patients were diagnosed with MRI. Neurological examination confirmed 1 level ($N = 13$), 2 levels ($N = 22$) and

multiple levels ($N = 11$) of radiculopathy. Patients with cervical disc herniation ($N = 23$) and/or spondylosis (foraminal stenosis) ($N = 23$) were diagnosed and clinical findings were in accordance with the MRI findings. MR imaging confirmed the clear presence of cervical root compression in 32/46 patients. All patients had clinical findings of neurological symptoms (sensibility disturbances, motor weakness and reflex disturbances) in the arm/hand. One patient underwent neurophysiology examination.

An additional 34 asymptomatic volunteers (21 women and 13 men) with no history of neck pain during the last 6 months were recruited as a sample of convenience from university staff and friends to form a reference group in the present study. After receiving verbal and written information about the study, each participant signed an informed consent form. Ethical approval for the study was granted by the regional Ethics Committee.

Neck muscle endurance test

An isometric neck muscle endurance test (NME test) was performed until exhaustion in all participants. In the

Fig. 1 Neck muscle endurance test

prone and supine positions, measurements of static endurance time (in seconds) were performed until the subjects were unable to hold their head in the correct position (chin retracted and head elevated from the bench) [5, 6]. A load of 2 kg for women and 4 kg for men was applied around the head, respectively. The weight was applied standardized above the ear on the participants (Fig. 1). After a 5-min recovery period after the prone test, the NME test was performed for the supine position.

EMG

During the prone and supine NME tests, surface EMG was used for recording the rate of muscle fatigue measured by the slope of MF (Myoresearch XP 1.06.68, Noraxon, USA). Surface EMG electrodes were placed bilaterally over the cervical paraspinal muscle (CPS), upper trapezius (UT), middle trapezius (MT) and sternocleidomastoid muscle (SCM) following areas according to the SENIAM guidelines [7]. An inter-electrode distance was maintained at >20 mm [6] and a ground electrode was placed on the right clavicle (Blue-Sensor N-00-S, Medicotest A/S, Denmark) was applied pairwise on the muscle, while the subject was sitting erect. EMG signals from eight channels were transmitted telemetrically (Myo Research XP, Master edition, Noraxon, USA). The raw EMG signals were recorded at a sampling rate of 1,000 Hz, band pass filtered (10–500 Hz), analogue to digitally converted and stored in a database. Fast Fourier Transformation (FFT) analysis was undertaken and MF was calculated for every second.

Rating of neck muscle fatigue and pain

All participants rated their perceived fatigue on a Borg 11 item CR-10 and the neck pain on the 100 mm Visual Analogue Scale (VAS) before and immediately after the NME test [8].

Questionnaires

Upon recruitment to the study, all participants completed the following questionnaires: EuroQol Health Survey (EQ-5D) [9], The International Physical Activity Questionnaire (IPAQ) short form [10] and The Self Efficacy Scale (SES) [11].

The CR group completed the following additional questionnaires: The Neck Disability Index (NDI) [12], Hospital Anxiety and Depression Scale (HADS) [13] and the Tampa Scale of Kinesiophobia (TSK) [14].

Data analysis

To coordinate the offset of time between the EMG muscle activation recordings and the NME test start and stop times, the following calculations were used:

1. Total EMG recorded time – total NME test clock time = Start time difference.
2. Start time difference + 2 s = EMG recorded data time withdrawn from start for analyses.
3. NME test Clock time stop – 1 s = EMG recorded data stop time used in analyses.

Linear regression analysis was then used to determine the EMG MF slope during the prone and supine NME tests.

Mean and standard deviation were used to describe subject's demographic characteristics and questionnaire data. Due to skewness, median and inter-quartile ranges (IQR) were reported for the NME test holding times. MF EMG was recorded for individual muscle groups during the NME tests.

Independent *t* tests or Mann–Whitney *U* tests were used for continuous or discrete data while χ^2 test was used for categorical data when comparing groups. Within-group statistical comparisons in right and left side MF EMG slope were conducted using Wilcoxon signed rank tests. Imbalance between left and right side MF EMG slope was also calculated as a ratio for every recorded second (“division of” right side value/left side value). Each of the ratio values was then transformed according to the following procedure to provide corrected ratios (*R*) with symmetrical properties centered on 0 [15].

For ratio values ≥ 1 (*R*) = (ratio – 1) $\times$ 100

For ratio values < 1 (*R*) = –((1/ratio) – 1) $\times$ 100.

The mean of all the transformed ratios was then used to represent the imbalance behavior in muscle groups. For example, a value of 20 would mean that the right side was 20 % larger than the left side, whereas a value of –20 would mean that the left side was 20 % larger than the right side. These ratios provided a symmetrical relative comparison between right-and left-sided differences in the underlying EMG parameters [15].

A categorical regression (CATREG) method was used to analyze nonlinear relations between NME test time (dependent variable), mean of the bilateral right and left side slope (MB-MF slope) for each muscle group during the NME test, NDI, pain VAS, TSK and self-rated fatigue at the end of the NME test for the CR group. CATREG modeling applies a transformation approach and optimal scaling methodology. The assumptions of linearity between variables, normality of residuals and ratio of cases to variables in standard linear or logistic regression do not apply to CATREG [16].

Table 1 Patient demographics and questionnaire data ($n = 80$)

Patient characteristics	Asymptomatic group ($n = 34$)	Cervical radiculopathy ($n = 46$)
Sex ^a		
Male	13 (38)	20 (43)
Female	21 (62)	26 (57)
Age—mean in years $\pm$ SD		
Whole group	43.4 SD 9.7	47.5 SD 9.2
Height—mean cm	169.6 SD 9.1	171.4 SD 10.4
Weight—mean kg	68.2 SD 11.2	75.4 SD 13.9
Hand dominance ^a		
Left	1 (3)	4 (9)
Right	33 (97)	42 (91)
Radiculopathy side ^a		
Left		24 (52)
Right		17 (37)
Both		5 (11)
Pain duration (months)		
Neck		21.7 SD 38.1
Arm		20.7 SD 35.0
Neck pain VAS (0–10)—mean score		3.5 SD 2.5
EQ5D (0–1)—mean score	0.97* SD 0.1	0.52* SD 0.4
EQVAS (0–100)—mean score	87.4* SD 12.0	57.1* SD 23.8
IPAQ		
Vigorous activity—mean days/week	2.8* SD 2.0	1.0* SD 1.8
Vigorous activity—mean minutes/day	40.9* SD 32.3	27.0* SD 63.4
Moderate activity—mean days/week	2.5 SD 2.5	1.9 SD 2.5
Moderate activity—mean minutes/day	36.3 SD 43.3	54.6 SD 93.4
Walking—mean days/week	4.6 SD 2.5	4.7 SD 2.1
Walking—mean minutes/day	43.0 SD 36.5	58.1 SD 56.7
Sitting—mean minutes/day	231.6 SD 172.5	313.7 SD 227.2
SES (0–200)—mean score	180.5* SD 35.5	134.8* SD 56.6
NDI (0–50)—mean score		19.1 SD 12.5
TSK (0–64)—mean score		37.4 SD 8.7
HADS		
Anxiety (0–21)—mean score		6.3 SD 5.8
Depression (0–21)—mean score		5.2 SD 4.6

EQ5D & EQVAS EuroQol Health Survey, IPAQ The International Physical Activity Questionnaire, SES Self Efficacy Scale, NDI Neck Disability Index, TSK the Tampa Scale of Kinesiophobia, HADS Hospital Anxiety and Depression Scale

* Group comparison of means $p < 0.05$

^a Number of patients (Percent of patients)

For all statistical analyses, a value of $p < 0.05$ was considered as an indicator of two-tailed statistical significance.

Fig. 2 Box-plot of the prone and supine neck muscle endurance tests. Group differences in median and interquartile range in prone and supine NME test time. Endurance time in seconds was measured during the tests. A significant difference between the groups was seen in endurance time for the NME test in prone ($p < 0.001$) and supine ($p = 0.017$)

Results

The CR group and the asymptomatic group were well match demographically (Table 1). Significantly lower levels ($p < 0.001$) of health related quality of life, SES and IPAQ were seen in the CR group compared to the asymptomatic group. The CR group's mean score of 37.4 on the TSK indicates the border line presence of kinesiophobia [14]. The score of the HADS, however, showed no indication of anxiety or depression co-morbidities.

The clinical messages of the results are that the NME test itself does not only provide answers due to impairment levels, but also reflects on activity limitations. An understanding of the physiological aspects of the muscle endurance capacity is for the concerned training and for the CR group's evaluation important. The endurance test itself is a way of measuring neck muscle fatigue. The results of this study highlight the importance of measuring sub-maximal endurance time and the experience of fatigue among patients with CR.

NME test time

The endurance time for the prone NME test in the CR group was significantly shorter ($p < 0.001$) than in the asymptomatic groups. The endurance time for the supine NME test in the CR group was significantly shorter

Fig. 3 Results of the group differences in Borg CR10 rating of fatigue (Borg CR 10 scale, 0–10) during prone and supine NME tests. Group differences between the cervical radiculopathy group ($n = 46$) and the asymptomatic group ($n = 34$). Histogram shows the fatigue rating at baseline ($p < 0.001$), at 15 s ($p < 0.001$), at 30 s ($p < 0.001$) and at the end of the extension test ($p < 0.001$). Fatigue after 5-min recovery ($p = 0.021$) and fatigue rating after the flexion test ($p < 0.001$)

($p = 0.017$) than in the asymptomatic groups. Both groups terminated the NME test in prone and supine due to self-reported neck muscle exhaustion (Fig. 2).

Rating of neck fatigue, pain VAS, NDI and TSK

The CR group rated significantly more fatigue than the asymptomatic group at all time points during the NME tests ($p < 0.001$), except for at the end of the prone test, where the asymptomatic group rated more fatigue ($p < 0.001$). The CR patients experienced significantly more remaining fatigue ($p = 0.021$) than the asymptomatic group after the 5-min rest interval between the prone and supine NME tests. Both the CR and asymptomatic groups had significantly lower ratings of fatigue ($p < 0.001$) after the supine NME test compared to the end of the prone NME test (Fig. 3).

EMG MF slope

During the prone NME test, the slope of the right CPS muscles had significantly more negative slope ($p = 0.035$) than the left side in the CR group. Furthermore, the right CPS muscles slope was significantly more negative ($p = 0.004$) in the CR group than in the asymptomatic group. Additionally, both the right and left MT muscle slope were more negative ($p = 0.005$, $p < 0.001$ respec-

tively) in the CR group than in the asymptomatic group (Fig. 4).

During the supine NME test, the slope of the right CPS muscles had significantly more negative slope than the left side in CR group ($p = 0.001$) and in the asymptomatic group ($p = 0.028$). Slope decline in the left CPS muscles was significantly greater in the asymptomatic group than in the CR group during the supine NME test ($p = 0.039$). During both the prone and supine NME tests, the slope of the right UT muscle had a significantly more negative ($p < 0.001$) than the left side in the asymptomatic group (Fig. 4).

Moderate correlation between test time and NDI was found in both prone and supine NME tests (Table 2).

Multivariate associations in the CR group

Non-Linear regression testing showed a strong significant multivariate association for variation in prone NME test time ($p < 0.001$) and supine NME test time ($p < 0.001$) explained by variables such as muscle MB-MF slope, NDI, pain VAS, TSK and fatigue. For the prone NME test, no individual variable played a statistical significant individual role in predicting variability in test time. Considering the importance of the predictors additively MB-MF slope decline for the UT muscles had the most important association with variability in prone NME test time (0.68) (Table 3).

For the supine NME test, MB-MF slope was more negative for the SCM muscles and was specifically significant among other independent variables in this association with variation in test time ($p = 0.001$). Borderline-specific significance was also observed for self-rated fatigue ($p = 0.055$). Considering the importance of the predictors additively (product of the regression coefficient and zero-order correlation), self-rated fatigue had the most important association with variability in supine NME test time (0.75) followed by MB-MF slope, which was more negative for the SCM muscles (0.68) (Table 4).

Discussion

To our knowledge, this is the first study to combine the NME test with measures of self-rated fatigue and EMG neck muscle fatigue on patients with CR compared to an asymptomatic group. The study showed that the CR group had a much shorter endurance time than the asymptomatic group in both prone and supine NME tests. The CR group had a larger amount of variability in NME test time than the asymptomatic groups during both tests, which was more evident during the NME test in the prone position.

Fig. 4 Box-plot of the median and interquartile range for median frequency (Hz/s) EMG slope of the left and right dorsal and ventral muscles SCM, CPS, UT and MT during prone and supine NME tests

Table 2 Correlation (Spearman rho bivariate) between mean bilateral Median Frequency slope decline in muscle groups

	CPS	UT	MT	Test time	Fatigue	VAS	NDI	TSK
Prone neck muscle endurance test								
Prone								
SCM	−0.14	−0.15	0.02	0.14	0.30*	0.07	0.15	0.14
CPS		0.31*	0.52**	0.06	−0.03	0.05	0.18	−0.10
UT			0.39**	0.03	−0.06	0.05	−0.11	0.14
MT				0.28	0.35*	0.05	0.01	0.03
Test time					0.25	−0.28	−0.54**	−0.17
Fatigue						0.19	0.21	0.36*
VAS							0.62**	0.20
NDI								0.35*
Supine neck muscle endurance test								
Supine								
SCM	0.38*	−0.07	−0.03	0.30	0.01	−0.11	−0.25	−0.12
CPS		0.29	0.15	0.19	−0.12	−0.08	0.09	−0.24
UT			0.36*	−0.03	−0.05	0.27	0.14	0.13
MT				0.16	−0.01	−0.03	−0.07	−0.15
Test time					−0.37	−0.34*	−0.54**	−0.39**
Fatigue						0.43**	0.33*	−0.17
VAS							0.62**	0.20
NDI								0.35*

0.00–0.25 little, if any correlation; 0.26–0.49 low correlation; 0.50–0.69 moderate correlation; 0.70–0.89 high correlation

(SCM sternocleidomastoid, CPS cervical paraspinal muscles, UT upper trapezius, MT middle trapezius), Test time, self-rated fatigue, pain intensity VAS Visual Analogue Scale, and NDI Neck Disability Index and TSK Tampa Scale of Kinesiophobia for test in prone and supine position in CR group ($n = 46$)

* <0.05 , ** <0.01

Table 3 Categorical regression analyzing the multivariate relationship between the prone NME test time (dependent variable) and mean bilateral MF EMG slope decline in muscles

Prone	Standardized coefficients		Importance ^a	d.f.	F	Significance
	Beta	SE				
SCM	0.45	0.60	0.23	1	0.58	0.453
CPS	−0.09	0.77	−0.01	1	0.01	0.911
UT	−1.14	0.78	0.68	2	2.13	0.136
MT	0.76	0.62	−0.11	3	1.51	0.232
Fatigue	0.16	0.12	0.05	2	1.89	0.169
VAS	−0.18	0.16	0.07	2	1.27	0.294
NDI	−0.16	0.24	0.06	2	0.46	0.634
TSK	−0.20	0.24	0.03	1	0.68	0.415

R^2 0.899, F 19.726, $d.f.$ 14, $p < 0.001$

(SCM sternocleidomastoid, CPS cervical paraspinal muscles, UT Upper trapezius, MT middle trapezius), self-rated fatigue, pain intensity VAS Visual Analogue Scale, NDI Neck Disability Index and TSK Tampa Scale of Kinesiophobia in prone position ($n = 46$)

^a Defines the importance of the predictors additively (product of the regression coefficient and zero-order correlation)

Table 4 Categorical regression analyzing the multivariate relationship between the supine NME test time (dependent variable) and mean bilateral MF EMG slope decline in muscles

Supine	Standardized coefficients		Importance ^a	d.f.	F	Significance
	Beta	SE				
SCM	1.41	0.52	0.68	3	7.27	0.001
CPS	−0.94	0.73	−0.27	4	1.67	0.186
UT	0.52	0.61	−0.05	3	0.73	0.546
MT	0.70	0.53	0.23	1	1.77	0.195
Fatigue	−1.01	0.56	0.75	2	3.25	0.055
VAS	−0.15	0.29	0.05	2	0.28	0.758
NDI	1.08	0.72	−0.41	3	2.28	0.103
TSK	0.02	0.22	0.00	1	0.01	0.914

R^2 0.861, F 8.441, $d.f.$ 19, $p < 0.001$

(SCM Sternocleidomastoid, CPS cervical paraspinal muscles, UT Upper trapezius, MT Middle trapezius), self-rated fatigue, pain intensity VAS Visual Analogue Scale, NDI Neck Disability Index and TSK Tampa Scale of Kinesiophobia in supine position ($n = 46$)

^a Defines the importance of the predictors additively (product of the regression coefficient and zero-order correlation)

Similar results have been shown with the NME test tested on patients with non-specific and postural-related neck pain [6, 17], and after anterior cervical decompression and fusion [18]. Psychological factors such as motivation and kinesiophobia have been suggested to influence physical performance [14, 19]. Lindstrom et al. [19] showed that multidirectional maximal voluntary force is inversely correlated with pain, fear of movement and aspects of disability in patients with chronic neck pain. A combination of the presence of pain, neck disability, kinesiophobia and possibly lower motivation levels in the CR group may explain the significantly higher rating of fatigue compared to the asymptomatic group during the both tests, except for the end of the prone test where asymptomatic subjects could push themselves to a greater fatigued state.

At multivariate associations, UT muscle EMG fatigue was shown to have the most important association with prone NME test time. This suggests that poorer physical performance is associated with increased UT fatigue in prone positions for patients with CR. Furthermore, this suggests that fatigue is of more importance than self-perceived pain, fatigue, disability and kinesiophobia.

SCM muscle EMG fatigue was shown to have a statistically significant individual association with supine NME test time. When observing the importance of independent variables in the model, self-rated fatigue was most important along with SCM muscle EMG fatigue. This suggests that poorer physical performance is associated with increased SCM fatigue and self-perceived levels of fatigue in supine positions. In, previous research compensation of the SCM muscles has been shown to be an indicator of poor deep cervical flexor muscles [20].

In previous research, the SCM and CPS have been shown to have greater EMG fatigability in patients with neck pain compared to asymptomatic cases [21]. Greater co-activation of SCM and CPS has also been observed in patients with neck pain compared to asymptomatic subjects with low-moderate significant correlation between fatigue in SCM and pain and disability [19].

Weakness of neck muscles has been proposed to contribute to persistent neck pain [22], but it remains unclear whether lack of strength is cause or a consequence of the neck pain. It is also unclear whether neck muscle fatigability and imbalance of bilateral muscle fatigability are causes or consequences of neck pain and radiculopathy. Imbalance of bilateral muscle activation in CPS muscle groups was more evident in the CR group compared to the asymptomatic group in prone and supine NME tests while imbalance in the UT muscles was seen more in the asymptomatic group. In this study, the subjects in the two groups were mostly right handed and the cervical radiculopathy patients had their pain more to the right ($n = 24$) than the left arm ($n = 17$) and often greater muscle fatigue

in the right side of the neck muscle groups. Falla et al. [23] also presented in their study, patients with unilateral neck pain demonstrated greater myoelectrical manifestations of muscle fatigue of the superficial cervical flexor muscles ipsilateral of the pain.

Therapeutic exercise has demonstrated efficacy in reducing pain and perceived disability in people with neck pain disorders [24]. Many factors influence the magnitude of neck pain. It is uncertain whether changes in muscle function are a cause or effect of pain, but a relationship has been shown between neck pain intensity and activity in the deep and superficial cervical flexor muscles [25].

Study limitations

The NME test used in this study has the deficit of no direct EMG measures of the deep neck muscles as only conventional surface EMG of the examined muscle groups was measured. The difference in the NME test time between the groups may have also been influenced by positioning as some patients were not comfortable due to their neck pain. For practical reason, it was not possible to randomize the position of the NME test. The order between positions was the same for all participants, which might be a reason for systematic biases. From a functional point of view, it would have been more functional to test NME in upright position. However, in the clinical setting, it is difficult to find a stable fixed upright position without expensive equipment [22]. However, further studies examining muscle endurance during upright might be interesting due to patient's problem in upright position. It would have even been good to analyze percentages of maximal voluntary contraction (MVC). This, however, was not used as we thought it would have been unethical to test MVC in patients with CR and neurological symptoms with risk of aggravating symptoms. The lack of how many underwent neurophysiological examination to confirm the cervical radiculopathy diagnosis should also be considered a possible source of bias.

Conclusion

The results showed altered neck muscle endurance in several of the muscles investigated with more negative MF slope, greater variability, side imbalance, lower endurance time and higher experience of fatigue among the patients compared with healthy subjects. The study confirms that myoelectric fatigability more than self-perceived levels of fatigue, pain, disability and kinesiophobia is the most important factor determining NME in CR patients. This suggests the possible utility of specific training of neck muscle endurance in the treatment of CR patients.

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Conflict of interest None.

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