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Immediate physiological responses to magnetic particle-containing tape: A quasi-experimental study on autonomic function, cervical mobility, and deep neck flexor endurance

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ABSTRACT

Background: The interaction between cervical structures and autonomic nervous system activity has gained increasing attention in musculoskeletal research in recent years. Magnetic particle-containing tape (MPCT) has been proposed as a non-invasive cutaneous intervention potentially capable of modulating neurophysiological responses, although its mechanisms and effects remain poorly understood. This study examined the immediate physiological responses associated with MPCT application on autonomic function, cervical mobility, and deep neck flexor endurance in asymptomatic participants.

Methods: A quasi-experimental single-group pre-post study was conducted with 36 healthy participants. The outcomes included pupillary diameter assessed using automated pupillometry, cervical flexion-rotation test, and neuromuscular performance measured using the deep neck flexor endurance test. Following baseline assessment and a 20-minute rest period, MPCT was applied to the cervicothoracic region (C5-T4). Outcomes were assessed at two time points: baseline and immediately after tape application. Associations between baseline and post-intervention values were analyzed using generalized additive models to account for potential non-linear relationships.

Results: Increases were observed across most outcome measures following MPCT application, particularly in cervical mobility and pupillary diameter. However, the clinical relevance of these changes remains uncertain. Nonlinear analyses revealed that the changes were not uniform across participants but appeared to depend on the baseline values, with more pronounced responses in individuals with lower initial measurements. These findings suggest threshold-dependent response patterns and potential ceiling effects in the study.

Conclusions: MPCT application was temporally associated with immediate changes in autonomic function and cervical mobility, with variable effects on neuromuscular endurance. The observed responses were dependent on the baseline physiological status. Further studies are required to determine the clinical relevance and underlying mechanisms.

Keywords: magnetic particle-containing tape, autonomic nervous system, pupillometry, cervical mobility, deep neck flexor endurance, cutaneous neuromodulation, nonlinear analysis, generalized additive models

INTRODUCTION

Neck pain is a highly prevalent musculoskeletal condition, affecting approximately 2.4-2.7% of the global population at any given time, with up to 70% of individuals experiencing at least one episode during their lifetime [1-4]. Among the various anatomical contributors, the upper cervical spine has been consistently implicated in the development of neck pain and related conditions such as cervicogenic headache [5]. However, the underlying mechanisms responsible for upper cervical dysfunction remain only partially understood, with multiple structures, including joint capsules, spinal nerves, and musculature likely contributing to symptom generation.

Altered movement patterns in the upper cervical region have been identified as potential factors contributing to

cervical dysfunction [6]. Notably, afferent input from the upper cervical spinal nerves converges within the trigeminocervical nucleus [7, 8], providing a neuroanatomical basis for the referral of nociceptive signals to the craniofacial regions, a hallmark feature in individuals with neck pain and headaches.

Additional anatomical considerations further support the complexity of these areas. Myodural connections between suboccipital muscles—including the rectus capitis posterior minor and major, as well as the obliquus capitis inferior—and the dura mater have been demonstrated [9, 10], along with collagenous continuities between the nuchal ligament and the dura [11]. These structural relationships suggest that alterations in cervical biomechanics may be related to changes in dural tension, although their clinical relevance is unclear.

From a functional perspective, upper cervical stability is largely dependent on neuromuscular control, particularly involving the deep neck flexor musculature [12]. Restrictions in atlas mobility have been correlated with both cervical dysfunction and headache symptomatology [13-15]. Furthermore, impairments in these muscles are associated with reduced postural control and neck pain [16].

Beyond biomechanical and neuromuscular factors, increasing attention has been directed toward the role of the autonomic nervous system (ANS) in pain modulation and in physiological responses. Sympathetic pathways originating in the upper thoracic region ascend through the cervical sympathetic chain and synapse in the superior, middle, and inferior cervical ganglia, with the superior ganglion located near the C2-C3 level [17-19]. In parallel, the anatomical connections between the upper cervical spinal nerves and vagus nerve suggest potential interactions with parasympathetic pathways [20]. These interconnections have been proposed as a theoretical framework for bidirectional communication between cervical structures and autonomic regulation.

The interaction between the somatic and ANS is well recognized at both peripheral and central levels [21-25]. Changes in muscle tone, particularly in the suboccipital region, may influence autonomic output, highlighting the importance of integrated neurophysiological mechanisms in musculoskeletal disorders. Several methodologies have been developed to assess ANS activity [26, 27], among which pupillometry is a noninvasive and reliable approach [28-31]. Pupil diameter reflects the dynamic balance between sympathetic (dilator) and parasympathetic (constrictor) activities, providing a real-time surrogate measure of autonomic function [26, 32, 33]. Automated pupillometry has demonstrated strong reliability in capturing these responses [34-36].

In addition to central autonomic measures, emerging evidence supports a broader view of neurophysiological regulation involving peripheral tissues. The skin, hypodermis, and superficial fascia are richly innervated by sensory and autonomic fibers [37]. The epidermis, derived from the ectoderm, is similar to the central nervous system [38] and contains keratinocytes that interact closely with Aδ and C-fibers [39]. These cells express transient receptor potential (TRP) channels that respond to mechanical, chemical, and electromagnetic stimuli [40]. Upon activation, keratinocytes release signaling molecules such as ATP, which influence nearby sensory neurons and contribute to systemic modulation [40, 41]. This bidirectional communication is a part of the neuroimmunocutaneous system.

In this context, magnetic particle-containing tape (MPCT) has been proposed as a cutaneous intervention capable of interacting with superficial sensory and autonomic structures [42, 43]. Although preliminary evidence suggests that such applications may influence physiological responses, including pain and blood flow [42, 43], the underlying mechanisms remain unclear and are still being debated. In particular, the extent to which low-intensity electromagnetic fields generated by such materials can induce meaningful neurophysiological changes remains unknown.

Given these uncertainties, it is plausible that any observed effects of MPCT may be mediated not only by electromagnetic interactions but also by non-specific factors such as cutaneous stimulation, sensory input modulation, or contextual influences. Therefore, a cautious and exploratory approach is warranted when investigating its potential physiological effects on the body.

To date, no study has specifically examined the immediate physiological responses associated with MPCT application on autonomic function, cervical mobility, and neuromuscular performance in asymptomatic individuals. Therefore, this study aimed to explore whether a single application of MPCT to the cervicothoracic region (C5-T4) is associated with short-term changes in

(1) pupillary diameter as a surrogate marker of ANS activity,

(2) upper cervical rotational range of motion (ROM) assessed using the cervical flexion-rotation test (CFRT), and

(3) deep neck flexor endurance (DNFE) measured using the deep neck flexor endurance test (DNFET).

MATERIALS AND METHODS

Study Design

This study followed a quasi-experimental, single-group, pre-post design to explore short-term physiological responses associated with the application of MPCT. Given the exploratory nature of the investigation and the absence of a control group, this study was not intended to establish causal relationships but rather to generate preliminary evidence regarding the potential associations between the intervention and selected outcome measures.

The design and reporting of this study were conducted in accordance with the transparent reporting of evaluations with nonrandomized designs statement [44], ensuring methodological transparency in participant selection, intervention procedures, and outcome assessment. The use of a within-subject pre-post design was intended to partially control for inter-individual variability, although it did not replace the need for a control group in the study.

Participants

Healthy volunteers aged 18-50 years were recruited using a convenience sampling strategy from the student population of Marieb College of Health and Human Services at the Florida Gulf Coast University (FGCU). Recruitment was conducted through institutional email communication and verbal announcements over three months. Ethical approval was obtained from the Institutional Review Board of FGCU (IRB#

2024-30, approved April 8, 2024), and all participants provided written informed consent prior to their inclusion in the study.

An a priori sample size calculation was performed using G*Power (version 3.1), assuming a medium effect size (d = 0.50), an alpha level of 0.05, and a statistical power of 0.80 for a two-tailed paired comparison. The required sample size was estimated to be 34. A total of 36 individuals were recruited to account for potential dropouts or incomplete data. The eligibility criteria were designed to ensure a homogenous and asymptomatic sample and to minimize potential confounding factors. The inclusion criteria required participants to be free of current or previous cervical pathologies. The exclusion criteria were pregnancy, presence of a pacemaker, cardiovascular or neurological conditions, central nervous system disorders, retinal disease, acute or chronic pain, current musculoskeletal injury, known allergies to adhesive tape or magnetic materials, autoimmune disease, epilepsy or seizure history, psychiatric conditions, and known upper cervical instability. No adverse events related to the MPCT were anticipated.

All the participants were healthy and asymptomatic at baseline. For terminological clarity, “symptomatic” does not describe the present cohort and is used only when referring to potential future clinical populations. Any transient discomfort during MPCT application would constitute an application-related symptom in an otherwise asymptomatic individual rather than a symptomatic clinical status; symptom provocation was not used to define or classify the participants in this study.

Experimental Procedure

All assessments were conducted in a controlled laboratory environment at FGCU under standardized conditions, including constant ambient light and temperature, to minimize external influences on the ANS activity. Each participant completed the protocol in a single session. Data collection was performed by a single trained examiner using a standardized sequence of measurements to reduce inter-examiner variability and enhance the reliability of the measurements. Upon arrival, the participants received verbal and written instructions and were positioned at the edge of a treatment table for all assessments.

Baseline measurements included pupillometry, CFRT, and DNFET. Following completion of the baseline assessments, participants underwent a 20-minute rest period. MPCT (Magnetic Tape SL, Valencia, Spain) was then applied to the posterior cervicothoracic region (C5-T4) without tension. Immediate post-application measurements were subsequently obtained using the same assessment procedures. Only two measurement time points were included: baseline and immediately after MPCT application.

Outcome Measures

Pupillometry

ANS activity was assessed using automated pupillometry (Vorteq®; Micromedical Technologies, Inc., Chatham, IL, USA), a device incorporating high-sensitivity infrared cameras. This method has demonstrated strong reliability and clinical utility in previous studies [34].

Participants were positioned supine, and measurements were obtained in complete darkness following a two-minute adaptation period, as previously described [34, 42]. The bilateral pupil diameter was continuously recorded over a 60-second interval. The absence of light stimulation minimized parasympathetic interference, allowing for a more stable assessment of autonomic balance. The software-derived pupillometry measurements were expressed in pixels.

Cervical flexion-rotation test

Upper cervical rotational mobility was assessed using the CFRT, a validated method for isolating movements in the C1-C2 segment [45, 46]. The participants remained in the supine position while the examiner passively flexed the cervical spine to the end range and rotated the head bilaterally until firm resistance was observed. The ROM was measured using a universal goniometer. This procedure has demonstrated high intra-rater reliability, with intraclass correlation coefficients (ICCs) ranging from 0.95 to 0.97 [46].

Deep neck flexor endurance test

Deep neck flexor performance was assessed using the DNFET, a standardized measure of neuromuscular endurance [47]. The participants were positioned in a supine hook-lying position, with their arms resting on the abdomen. They were instructed to perform a chin tuck and elevate their heads by approximately 2.5 cm while maintaining cervical flexion.

The examiner manually monitored the occipital position of the participants. The test was terminated when the participant lost the chin tuck position or when the occiput contacted the examiner’s hand for one second or longer. The time to fatigue was recorded in seconds. The DNFET has demonstrated acceptable reliability, with ICCs of 0.92 in women and 0.93 in men, and a standard error of measurement ranging from 8 to 11 seconds [47].

Intervention

MPCT was applied directly to the skin over the posterior cervicothoracic region (C5-T4) without mechanical stretch or tension. The application procedure was standardized for all the participants. The tape contains magnetic particles designed to generate low-intensity electromagnetic fields. These particles do not produce attraction or repulsion forces, and their proposed effects are considered to be limited to superficial tissues [43].

Data Analysis

All statistical analyses were performed using R software (version 4.1.3; R Foundation for Statistical Computing, Vienna). The level of statistical significance was set at $p < 0.05$. Descriptive statistics were used to summarize participant characteristics and outcome variables. Continuous variables are expressed as mean ± standard deviation, and categorical variables are presented as frequencies and percentages.

The normality of the data distribution was assessed using the Shapiro-Wilk test. A directed acyclic graph (DAG) was constructed to identify the minimal sufficient adjustment set for estimating associations between pre- and post-intervention outcomes, considering age and sex as potential confounders [48-50] (**Figure 1**). Regression analyses were performed to examine the associations between baseline and post-intervention measures for pupillometry, CFRT, and DNFET. Generalized additive models (GAMs) were fitted using penalized smooth terms and a double-penalty approach for automatic variable selection. Effective degrees of freedom (EDF) were subsequently examined to characterize the functional form of each estimated smooth term. Values close

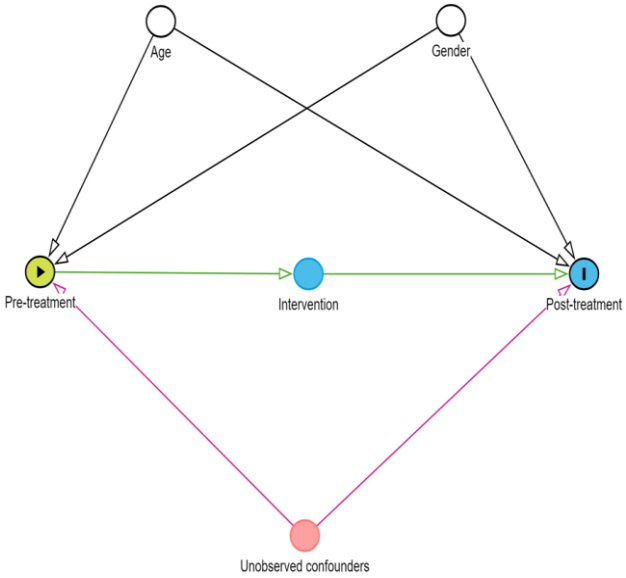

Figure 1. DAG illustrating the assumed relationships among age, sex, pre-intervention values, the intervention, post-intervention outcomes, and unobserved confounders (the authors' own work)

to 1 indicated approximately linear relationships, whereas larger values suggested increasing nonlinearity. EDF was not used as a threshold for determining whether GAMs should be fitted. Pre-treatment left pupillometry values were log-transformed for model fitting. For graphical presentation in **Figure 2**, these values were back-transformed and are displayed on the original pixel scale.

Model adequacy was evaluated using multiple diagnostic procedures. Concurvity was assessed, with values greater than 0.8 considered potentially problematic. The adequacy of the smoothing basis was evaluated using the k-index. Residual diagnostics included the Shapiro-Wilk test for normality, the Breusch-Pagan test for heteroskedasticity, and the Durbin-Watson test for autocorrelation. Model fit was compared using the Akaike information criterion (AIC), with lower values indicating better model performance.

RESULTS

A total of 36 participants were included in the analysis, the majority of whom were women (61.1%) with a mean age of 25.19 ± 4.57 years. The full set of clinical and demographic characteristics, including the pre- and post-intervention values for all outcome measures, are presented in **Table 1**.

All 36 participants analyzed belonged to the predefined healthy, asymptomatic cohort; no participant was categorized as a symptomatic patient for the present analysis. The descriptive results showed a general increase in post-treatment values for cervical ROM and right pupillometry, whereas changes in left pupillometry and DNFE were comparatively smaller. Despite these increases, the magnitude of change was relatively small across most variables, and their clinical relevance remains unclear. The effect sizes were small across most outcomes, further supporting the exploratory nature of these findings.

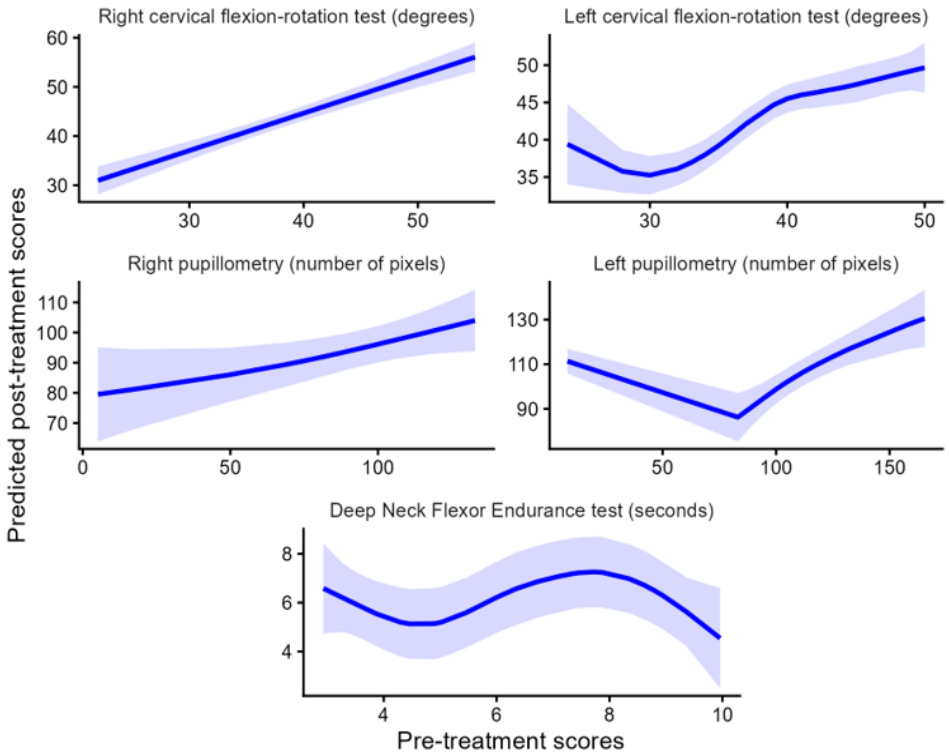

Figure 2. Smoothed associations between pre-treatment measurements and predicted post-treatment outcomes derived from generalized additive models. Solid blue lines represent the estimated smooth functions, and shaded areas represent the corresponding confidence intervals. Outcomes include cervical flexion-rotation (degrees), pupillometry (number of pixels), and deep neck flexor endurance (seconds). Pre-treatment left pupillometry was log-transformed for model fitting and is displayed on the original pixel scale after back-transformation for graphical interpretation (the authors' own work)

Table 1. Clinical and demographic characteristics of the participants (n = 36)

Demographic characteristics		Value
Age		25.19 ± 4.57
Gender: n(%)	Female	22 (61.1)
	Male	14 (38.9)
Autonomic nervous system response (pixels)	Right pupillometry pre-treatment	89.81 ± 26.57
	Right pupillometry post-treatment	91.80 ± 14.53
	Left pupillometry pre-treatment	106.13 ± 26.21
	Left pupillometry post-treatment	106.64 ± 15.65
Muscle endurance (seconds)	DNFET pre-treatment	5.96 ± 1.99
	DNFET post-treatment	6.09 ± 2.02
ROM (degrees)	Right CFRT pre-treatment	37.92 ± 7.66
	Right CFRT post-treatment	41.89 ± 6.92
	Left CFRT pre-treatment	38.83 ± 6.41
	Left CFRT post-treatment	42.22 ± 5.49

Note. Data are expressed as M ± SD or absolute and relative frequencies (%)

Table 2. Final outcome models derived from GAMs

	EDF	[a]p-value
Pre-treatment: DNFET (seconds)	2.702 (df_{ref} = 8)	F = 1.151, p = **0.021**
Pre-treatment: Right CFRT (degrees)	0.991 (df_{ref} = 4)	F = 26.28, p < **0.001**
Pre-treatment: Left CFRT (degrees)	4.220 (df_{ref} = 9)	F = 10.904, p < **0.001**
Pre-treatment: Right pupillometry (number of pixels)	1.101 (df_{ref} = 9)	F = 0.748, p = **0.010**
Pre-treatment: Left pupillometry (number of pixels)	1.450 (df_{ref} = 8)	F = 3.314, p < **0.001**

Note. EDF: Effective degrees of freedom; df_{ref}: Reference degrees of freedom. [a]Significant if p < 0.05 (shown in **bold**).

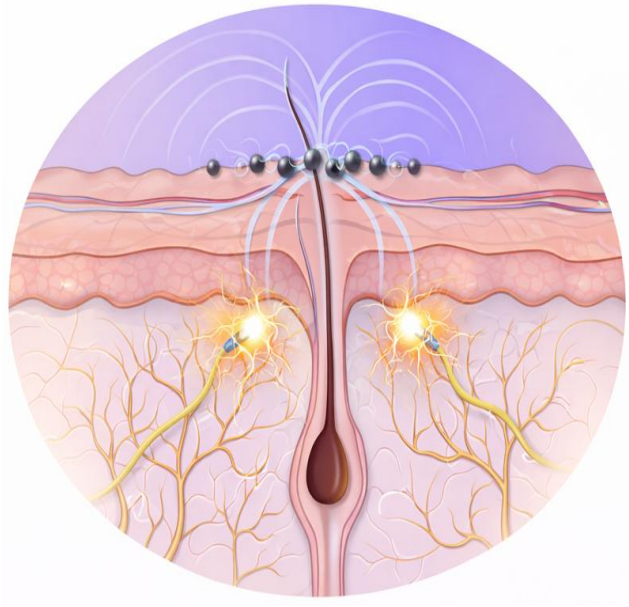

Figure 3. Facilitation of keratinocytes and free nerve endings by magnetic particles (Conceptual representation of the interaction between magnetic particle-containing tape and cutaneous sensory structures, including keratinocytes and free nerve endings, illustrating a hypothetical pathway for potential neuromodulatory effects that was not directly tested in this study) (the authors' own work)

Baseline values significantly predicted post-treatment values for all outcomes in the final GAMs (**Table 2**). The fitted smooths showed outcome-specific patterns. For left cervical flexion-rotation and left pupillometry, higher predicted post-treatment values relative to baseline were mainly apparent below approximately 35° and 90 pixels, respectively, whereas for DNFET no increase was apparent above approximately 7 seconds (**Figure 2**).

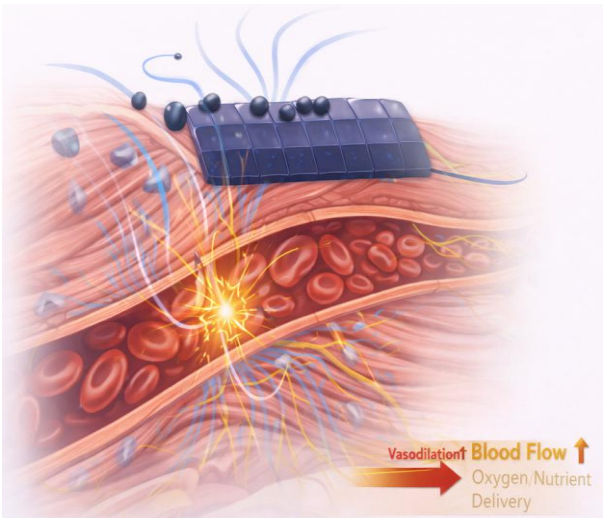

Figure 4. Vasodilatation effect of MPCT impacting blood flow (Schematic illustration of the proposed influence of MPCT on vascular dynamics, potentially affecting tissue perfusion and neuromuscular function through autonomic modulation) (the authors' own work)

Supplementary Table S1 summarizes the EDF values for the explanatory variables. Model diagnostics showed concurvity values below 0.8, no evidence of inadequate basis dimension based on the k-index, and no evidence of relevant heteroskedasticity or autocorrelation. GAMs showed lower AIC values than the corresponding linear models (**Supplementary Table S2**).

Conceptual illustration created with the assistance of ChatGPT (OpenAI), based on author-provided scientific concepts and reviewed and approved by the authors (**Figure 3**, **Figure 4**, and **Figure 5**).

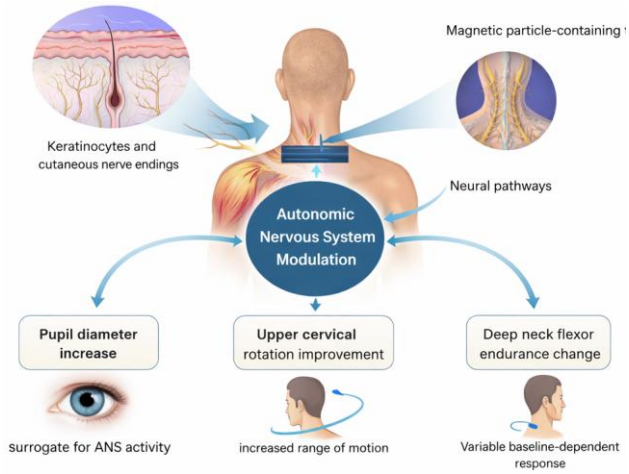

Figure 5. Integrated conceptual model summarizing the potential combined effects of MPCT on autonomic regulation, vascular responses and neuromuscular performance (the authors' own work)

DISCUSSION

This study explored the immediate effects of MPCT applied to the cervicothoracic region (C5-T4) on ANS activity, upper cervical rotational mobility, and DNFE in asymptomatic participants. The main findings indicate that MPCT application was temporally associated with short-term changes in physiological and functional outcomes, including increased pupillary diameter, improved cervical flexion-rotation range of motion, and variable responses in DNFE. Importantly, these effects were not uniform across participants but appeared to depend on baseline values, suggesting a nonlinear and threshold-dependent response pattern.

To our knowledge, this is the first study to apply GAMs to investigate the immediate physiological responses associated with MPCT, allowing for the identification of nonlinear relationships that would not be captured using conventional linear approaches.

Autonomic Nervous System Modulation

The observed increase in pupillary diameter following MPCT application may reflect a shift in autonomic balance, potentially indicating increased sympathetic activity or altered sympathovagal interaction. Pupillometry is widely recognized as a sensitive and reliable non-invasive measure of ANS function, capturing real-time changes in autonomic tone through modulation of the iris musculature [35, 36, 51].

However, nonlinear analyses revealed that these changes were predominantly present in participants with lower baseline pupil diameters, suggesting a ceiling effect. This finding reinforces the idea that physiological responses to neuromodulatory interventions may be more pronounced in individuals with suboptimal baseline function than in those with optimal physiological functions.

These results are consistent with previous studies reporting autonomic modulation after MPCT. The researchers in [42] described sympathetic activation in response to similar interventions, whereas the researchers in [43] demonstrated both autonomic and clinical effects associated with the use of magnetic tape. Furthermore, prior research has shown that cervical and thoracic interventions can influence stress-related physiological systems, including both ANS and hypothalamic-pituitary-adrenal axis responses [52].

From a mechanistic perspective, these effects may be interpreted within the framework of the neuroimmune system. Keratinocytes, which act as active sensory transducers, can interact with peripheral nerve endings and influence central processing [39, 53]. Upon stimulation, these cells release ATP and other mediators that modulate afferent-signaling pathways [54].

Additionally, the anatomical proximity of the cervicothoracic region (C5-T4) to the sympathetic chain provides a plausible structural substrate for these responses [17-19]. Nevertheless, it should be emphasized that the precise mechanisms underlying these effects remain speculative. The contribution of low-intensity electromagnetic fields generated by MPCT is still debated, and alternative explanations, such as cutaneous stimulation and sensory input modulation, cannot be excluded.

Upper Cervical Mobility

The improvements observed in CFRT performance suggest that superficial cutaneous interventions may influence deeper neuromuscular and biomechanical function. These findings are consistent with those of previous studies reporting that taping interventions can improve cervical mobility and reduce symptoms [55].

Several mechanisms may explain these findings. First, increased sympathetic activity may influence the sensitivity of the muscle spindles. Sympathetic innervation of intrafusal fibers has been shown to modulate spindle responsiveness, potentially allowing greater muscle elongation and increased joint ROM [56, 57].

Second, autonomic-mediated changes in vascular tone may contribute to improved tissue compliance. Increased perfusion can enhance the mechanical properties of the musculotendinous unit, facilitating movement. This hypothesis is supported by evidence indicating that MPCT may influence blood flow [43].

Third, modulation of cutaneous afferent input may alter sensorimotor integration. The upper cervical spine, particularly the C1-C2 segment, relies heavily on proprioceptive input for precise movement control. Changes in afferent signaling from the skin and fascia may reduce neuromuscular inhibition and improve motor output. Structural connections, such as myodural bridges, further support the interaction between superficial tissues and deeper neuromechanical systems [11].

Importantly, as observed in the autonomic outcomes, improvements in CFRT were more pronounced in individuals with lower baseline mobility. This finding supports a threshold-dependent response and suggests potential clinical relevance for populations with impaired cervical function.

Deep Neck Flexor Endurance

The effects of MPCT on DNFE were less consistent than those on other outcomes in this study. While some participants demonstrated improvements, others showed minimal or no change. The GAM analysis clarified that improvements were primarily observed in individuals with baseline values below approximately 7 seconds, indicating a potential ceiling effect.

This variability may reflect the interactions between the competing physiological mechanisms. Enhanced sensory input

may facilitate motor unit recruitment through improved sensorimotor integration. Sympathetic activity may modulate muscle spindle sensitivity and neuromuscular function [56-58]. These findings are consistent with evidence demonstrating that autonomic activation influences fatigue-related processes and motor performance [59].

The ANS plays a key role in regulating vascular responses. Increased blood flow to the skeletal muscles may enhance oxygen and nutrient delivery, potentially supporting muscle performance [60]. However, the magnitude of this effect in the context of short-term interventions remains uncertain.

It is also important to consider the limitations of the DNFET. Although the test demonstrates acceptable reliability [47, 61], its sensitivity in detecting immediate neuromodulatory changes may be limited. Furthermore, the requirement for continuous proprioceptive control may introduce variability, particularly in the presence of autonomic modulation.

Nonlinear Response and Methodological Implications

A key contribution of this study is the identification of nonlinear, threshold-dependent relationships for each outcome measure. Traditional linear models assume uniform responses across individuals, potentially masking clinically relevant patterns. In contrast, the use of GAMs allowed for a more flexible and data-driven analysis, revealing that the effects of MPCT were contingent on baseline physiological status.

From a methodological perspective, these findings highlight the importance of selecting appropriate statistical approaches to investigate complex biological systems. The integration of DAG-informed modeling and GAM analysis represents a robust framework for exploring nonlinearity and minimizing bias in observational studies.

Clinical Implications

The findings of this study suggest that MPCT may represent a noninvasive stimulus capable of eliciting short-term physiological responses, the mechanisms of which remain unclear, but may influence autonomic function, cervical mobility, and neuromuscular performance. The immediate nature of the observed changes supports the potential role of adjunctive rehabilitation strategies.

However, the presence of threshold-dependent responses indicates that its effects may be more relevant in individuals with impaired baseline function than in asymptomatic individuals. Therefore, caution is warranted when extrapolating these findings to clinical practice, particularly in the absence of controlled trials on this topic.

The intended clinical positioning of MPCT is as a potential adjunct to rehabilitation, rather than as a replacement for established care. The most direct extension of the present findings is to symptomatic musculoskeletal populations in whom cervical mobility or neuromuscular performance is impaired. In sports medicine settings, these physiological findings provide a rationale for future studies examining whether MPCT can support the recovery of cervical mobility or neuromuscular performance after musculoskeletal injury; enhancement of athletic performance was not evaluated in the present study. The possible therapeutic role of chronic neurological conditions, including pediatric cerebral palsy, remains exploratory and would require condition-specific mechanistic and clinical evaluations before such use could be inferred. Because the present study is not disease-specific, the relevant standard of care in a subsequent trial should be the condition-specific usual rehabilitation for the selected clinical population, applied identically across the study groups.

Limitations

This study had several limitations. First, the quasi-experimental design without a control group precludes causal inference and limits the ability to distinguish specific intervention effects from non-specific factors. Second, the use of asymptomatic samples reduced the generalizability of the findings to clinical populations. Third, although pupillometry provides a valid surrogate for ANS activity, it reflects the global autonomic balance rather than localized responses. Additionally, although a priori sample size calculation was performed, the study may still be underpowered to detect small-effect sizes. Finally, the potential placebo effect or influence of cutaneous stimulation cannot be ruled out. Given the absence of a control group, the observed changes cannot be specifically attributed to this intervention. Alternative explanations, such as regression to the mean, measurement variability, cutaneous stimulation, or contextual and expectancy-related effects must be considered. Therefore, the present findings should be interpreted strictly as exploratory and hypothesis-generating rather than confirmatory.

CONCLUSION

A single application of MPCT to the cervicothoracic region (C5-T4) was temporally associated with immediate changes in autonomic function and upper cervical mobility, with variable effects on muscle endurance. These responses were nonlinear and dependent on the baseline physiological status, suggesting a potential neuromodulatory involvement rather than purely mechanical effects, although this interpretation remains speculative and requires confirmation in controlled studies. Future randomized controlled trials in symptomatic populations are required to confirm these findings and clarify the clinical relevance and underlying mechanisms of MPCT intervention. Specifically, future randomized controlled trials should evaluate MPCT as an adjunct to condition-specific usual rehabilitation against a visually and mechanically comparable non-magnetic sham tape receiving the same usual care, with conventional kinesiology tape included as an active comparator when comparative effectiveness against established taping is the clinical question.

Author contributions: **FS-S:** conceptualization, investigation, methodology, supervision, visualization, writing – original draft, writing – review & editing; **RIS:** data curation, formal analysis, project administration; **MED:** conceptualization, investigation, methodology, visualization, writing – original draft, writing – review & editing; **SF-C:** conceptualization, supervision, visualization, writing – original draft; **JNCZ:** data curation, formal analysis, supervision, writing – review & editing; **EAS-R:** formal analysis, supervision, writing – review & editing; **RS:** conceptualization, data curation, formal analysis, investigation, methodology, resources, supervision, writing – original draft, writing – review & editing. All authors have agreed with the results and conclusions.

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Ethical statement: This study was approved by the Institutional Review Board at Florida Gulf Coast University on 8 April 2024 with approval number IRB# 2024-30. This study was conducted in

accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their inclusion in the study.

AI statement: ChatGPT (OpenAI) was used to generate conceptual scientific illustrations included in this manuscript. These illustrations were created to visualize hypothetical mechanisms and do not represent experimental observations or research data. The authors reviewed and approved the final illustrations and assumed full responsibility for their scientific content and accuracy. Generative AI was not used to generate or modify research data or to perform statistical analyses.

Declaration of interest: FS-S was involved in the development of the magnetic tape evaluated in this study and holds a European patent related to the adhesive fascial tape (no. 3479804). This represents a potential conflict of interest. The other authors declare no conflict of interest. To minimize potential bias, data collection, statistical analysis, and interpretation were conducted independently.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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SUPPLEMENTARY MATERIAL

Supplementary Table S1. Effective degrees of freedom for explanatory variables in the final GAMs

Quantitative explanatory variable	Term	EDF
Deep Neck Flexor Endurance test (seconds)	Pre-treatment	**2.702**
	Age	**5.561**
Right cervical flexion-rotation test (degrees)	Pre-treatment	0.991
	Age	0.969
Left cervical flexion-rotation test (degrees)	Pre-treatment	**4.220**
	Age	0.847
Right pupillometry (number of pixels)	Pre-treatment	**1.101**
	Age	< 0.001
Left pupillometry (number of pixels)	Pre-treatment	**1.450**
	Age	< 0.001

Note. EDF: Effective degrees of freedom. Pre-treatment EDF values correspond to the final outcome models reported in **Table 2**. Values higher than 1 are shown in **bold**.

Supplementary Table S2. Model assumptions

		Global concurvity[a]	Pre-treatment	Age	K index ([b]p-value)	Shapiro-Wilk test ([b]p-value)	Breusch-Pagan test ([b]p-value)	Durbin-Watson test ([b]p-value)	LM AIC vs. GAM AIC
Left cervical flexion-rotation test (degrees)	Pre-treatment	0.728		0.704	1.292, p = 0.927	0.337	0.672	0.232	193.753-184.092
	Age	0.731	0.704		1.359, p = 0.968				193.753-184.092
Right cervical flexion-rotation test (degrees)	Pre-treatment	0.691		0.59	1.21, p = 0.838	0.665	0.363	0.836	195.371-192.419
	Age	0.662	0.59		1.296, p = 0.955				195.371-192.419
Deep neck flexor endurance test (seconds)	Pre-treatment	0.656		0.569	0.971, p = 0.378	0.818	0.194	0.498	148.795-137.82
	Age	0.669	0.569		1.179, p = 0.8				148.795-137.82
Left pupillometry (number of pixels)	Pre-treatment	0.756		0.711	1.024, p = 0.492	0.099	0.917	0.94	305.478-285.052
	Age	0.731	0.711		1.163, p = 0.78				305.478-285.052
Right pupillometry (number of pixels)	Pre-treatment	0.58		0.543	1.341, p = 0.985	0.071	0.72	0.518	294.174-291.942
	Age	0.586	0.543		1.2, p = 0.853				294.174-291.942

Note. In pairwise concurvity, the values of 1 corresponding to the concurvity of a variable with itself have been deleted to increase clarity; LM: Linear model; GAM: Generalized additive model; AIC: Akaike information criterion; [a]Values higher than 0.8 (shown in red); & [b]Significant if $p < 0.05$ (shown in **bold**)