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The Effectiveness Of Virtual Reality-Based Treatment On Sensorimotor And Functional Outcomes In College Students With Chronic Neck Pain

Jaewon Lee[1], Jaeho Yu*[2]
[1]Dept. of Physical Therapy, Sunmoon Univ, 70, Sunmoon-ro 221beon-gil Tangjeong-myeon Asan-si Chungcheongnam-do Republic of Korea, 31460
[2]Professor
***Corresponding author:**
Jae-Ho Yu
Email ID: naresa@sunmoon.ac.kr

ABSTRACT

Objective: *The aim of this study was to investigate the effectiveness of virtual reality (VR)-based treatment, motor exercise therapy (MEG), and a control group (CG) without treatment over a 6-session period on the observed sensorimotor changes in individuals with chronic neck pain.*

Methods: *Total of 36 participants between the ages of 18-45, who were university students and had a Neck Disability Index (NDI) score of 10 or higher, as well as a complaint of neck pain lasting for more than 3 months, were included in this study. The participants were evaluated twice, both before and after the treatment.*

Results: *The results of the post hoc Bonferroni test following a 6-session treatment period lasting a total of 120 minutes revealed significant differences between the MEG and the CG in terms of joint position sense errors (JPSE) in flexion, extension, left lateral flexion, and right rotation directions. Additionally, statistically significant findings were observed in the extension range of motion (ARoM), NDI scores, and pain intensity during movement. The post hoc test comparing the VRG and the CG yielded statistically significant p-values for JPSE in extension and right rotation, as well as for extension ARoM, NDI scores, and pain intensity under two conditions.*

Conclusion: *Based on the results of this study, it is believed that the concurrent use of VRG and MEG may enhance the effectiveness of the treatment process, as it appears that both treatments-initiated changes in some parameters earlier.*

Keywords: *Chronic neck pain, gait speed, static balance, joint position sense error, muscle stiffness*

1. INTRODUCTION

Chronic neck pain can be defined as the presence of unpleasant sensory and emotional experiences persisting for more than three months between the external occipital protuberance and the first vertebra of the thoracic (Climent, Bagó & García-López, 2014). The prevalence of neck pain in the general population in different parts of the world ranges from 30% to 80% (Haldeman, Carroll & Cassidy, 2010; Fejer, Kyvik & Hartvigsen, 2006). It is more common in people aged 45-55, in women than in men, and in office workers (Staudte, & Dühr, 1994; Ye et al., 2017).

Neck pain has been identified as a source of cervical disability (Sarig Bahat et al., 2014). Research has demonstrated an association between the severity of pain and the degree of cervical active range of motion (ARoM), as well as the fear of movement (Beltran-Alacreu et al., 2018; Lin et al., 2010). Prolonged avoidance of movement among individuals experiencing neck pain can potentially lead to alterations in the kinetic properties of the muscles in the cervical region. The diminished activation of deep cervical muscle groups leads to fatigue and the emergence of stiffness in superficial muscle groups (Falla & Farina, 2007). A study comparing Sternocleidomastoid (SCM) stiffness in individuals with chronic neck pain has reported greater SCM activation and stiffness in women as opposed to men (Wolff et al., 2022). On the other hand, the muscle spindle density per gram in the suboccipital muscles is approximately 30 times greater than in the gluteal muscles (Kang et al., 2021). Postural control is facilitated by transmitting stimuli from these afferent receptors in the cervical region to the central nervous system (Treleaven, 2008). In patients with chronic neck pain, involvement of cervical mechanoreceptors has been shown to increase joint position sense error (JPSE), and negatively impact both static and dynamic balance (de Vries et al., 2015; Yuceasli et al., 2022). In this context, alterations in spatial and temporal gait parameters have been reported in individuals with cervical neck pain (Poole, Treleaven & Jull, 2008).

Due to the significant negative impacts of chronic neck pain, various treatment methods are employed in its management. These include motor exercise, sensorimotor exercise, manual therapy, electrotherapy, and laser therapy. However, no study has conclusively established the superiority of one treatment modality over others. Therefore, multimodal care is recommended for individuals with chronic neck pain, as it integrates different treatment approaches to optimize outcomes (Im et al.,2015).

The progress of technology has resulted in the integration of virtual reality-based (VR) therapy in the therapeutic interventions for chronic neck pain (Cetin, Kose, & Oge, 2022). VR provides the individual with multiple sensory inputs, including visual, auditory, and proprioceptive stimuli, by creating an artificial world, thus directing the person's attention towards the task, and resulting in a reduction in the perception of pain (Nusser et al., 2021; Li et al., 2011).

A comparative study evaluating the effectiveness of VR therapy versus motor exercise demonstrated a statistically significant difference in JPSE as well as pain pressure threshold values (Cetin, Kose & Oge, 2022). However, there was no study investigating the effectiveness of VR therapy on walking speed in people with chronic neck pain compared to motor exercise.

In addition, in a study investigating changes in balance in individuals with chronic neck pain, proprioceptive training was given to the control group (CG), and it was determined that the VR technique significantly improved balance compared to the CG (I et al., 2019).

However, there is limited research examining the effectiveness of VR treatment for chronic neck pain. Exploring the effectiveness of VR therapy in comparison to motor exercise on walking speed, balance, and JPSE among individuals with chronic neck pain could assist in developing an improved treatment. Therefore, this study aimed to evaluate the efficacy of VR therapy versus motor exercise in improving gait speed, balance, JPSE, neck disabilities, pain severity, ARoM, and muscle stiffness in individuals with chronic neck pain.

2. METHODS:

This study was a randomized controlled trial with a three-group pre-posttest design, including the VR treatment group (VRG), the motor exercise group (MEG), and the CG. This study adhered to the principles outlined in the Declaration of Helsinki and received approval from the Institutional Review Board of Sunmoon University (SM-202311-035-2).

2.1. General Characteristics:

Participants for the study were recruited from SM University in Asan, South Korea. The inclusion criteria were as follows: (1) a Neck Disability Index (NDI) score greater than 10; (2) ongoing neck pain for more than three months; (3) age between 18 and 45. Exclusion criteria were: (1) positive neurological signs; (2) history of cervical surgeries; (3) ankylosing spondylitis; (4) lower extremity issues such as leg length discrepancies; (5) history of traumatic fractures; (6) presence of systemic diseases.

2.2. Procedures:

Participants were randomized into groups in a 1:1:1 ratio. The VR and the MEG each underwent a total of six sessions over a two-week period, with three sessions per week. Each session consisted of two 10-minute segments. Thus, participants in both the VRG and the MEG engaged in the study for a total of 120 minutes. Participants in the CG were only involved in the pre- and post-assessment processes.

2.2.1. Interventions for VRG

VR therapy was administered using Oculus Quest 2 VR glasses and remotes. The weight of these glasses is 503 grams and the resolution for each eye is 1832x1920 pixels. The treatment included a 10-minute session of using the "Ocean Rift". Ocean Rift is a VR application that offers an immersive experience of observing and interacting with various sea creatures, which can be selected and controlled using the remote. The treatment protocol has incorporated the "Nature Treks" game into the remaining half. "Nature Treks" offers an immersive experience under various nature-themed headings such as Green Meadows, Blue Ocean, Red Savanna, Black Beginning, White Winter, Green Bamboo, and Blue Ocean, providing the opportunity to observe natural phenomena in a short period of time. The content used for each session was different. The participants' posture during VR is depicted in Figure 1.

2.2.2. Interventions for MEG

The first 10 minutes of each of the 6 sessions remained consistent, focusing on range of motion, stretching, and strengthening exercises. However, the remaining 10 minutes were altered every other session, resulting in the application of three different treatments. In the remaining 10 minutes, the focus was on further enhancing coordination between deep and superficial muscles. In the first and second sessions, craniocervical flexion and extension exercises were performed. In the third and fourth sessions, co-contraction exercises for the cervical muscles were included. Eccentric exercises were incorporated on the fifth and sixth days. The exercises performed during the first 10 minutes for the MEG, while those performed during the last 10 minutes. The participants' posture during motor exercise is depicted in Figure 2.

2.3. Measurement and instrumentation

2.3.1. Gait speed

The gait speed was evaluated using a 10-meter walk test, and the time taken by participants to walk this distance was recorded under five conditions, including (1) preferred walking speed (PWS), (2) maximal walking speed (MWS), (3) tandem walking speed (TWS), (4) motor dual-task walking speed (MDTWS), and (5) cognitive dual-task walking speed (CDTWS). Motor dual-task walking involves performing a head rotation while walking, while cognitive dual-task walking involves counting backwards from 300 in decrements of 3 while walking.

2.3.2. Static Balance

Static balance was assessed using the Tetrax system (Tetra-ataxiometric posturography, Israel). Balance was assessed under four different conditions: eyes open on a firm surface, eyes closed on a firm surface, eyes open on a foam cushion, and eyes closed on a foam cushion. The stability index, which reflects the degree of participant sway during the test, was taken into consideration in the evaluation of static balance.

2.3.3. JPSE and ARoM

The JPSE and ARoM of the cervical spine was measured in six different positions using a universal goniometer. These positions included flexion, extension, lateral flexion, and rotation movements. It has been reported that the Intraclass Correlation Coefficient (ICC) for cervical range of motion measurements using the Goniometer (Baseline® 180 degrees) falls between 0.83 and 0.98 (Faroog et al., 2016).

2.3.4. Muscle Stiffness

The Myoton Pro is a device developed by Myoton AS in Tallinn, Estonia, for the non-invasive measurement of muscle tone. This device is known for its high reliability, with an ICC of 0.90 or higher (Aird et al., 2012). Muscle stiffness is quantified in "Newtons per meter," representing the resistance to muscle contraction. For the SCM muscle measurement procedure, participants were instructed to assume a supine position. The measurement was taken by identifying the midpoint along the muscle extending between the manubrium and mastoid process, and the measurement was performed after marking the midpoint. The measurement for the upper trapezius was taken about 10 cm away from the C7 vertebra along a straight line extending from C7 to the acromion.

2.4. Statistical Analysis

Statistical analyses were conducted using the Statistical Package for Social Sciences (IBM SPSS) Statistic version 26.0 (SPSS Inc, Chicago, IL, USA), and the data were presented in the format of mean ± standard deviation. A paired-samples t test was employed to statistically analyze the changes over time within and between groups. The one-way ANOVA test was employed to assess whether the mean difference between groups is statistically significant in the comparison among groups. Post-hoc multiple comparisons were conducted using the Bonferroni test, and the significance level for the test was established at ($p < 0.05$).

3. RESULTS

3.1. General characteristics of participants

The general characteristics of the participants, including age, height, weight, gender, CVA, NDI scores, and duration of pain are presented in Table 1. The average values for the VRG, MEG, and CG, respectively, were as follows: age (22.91±2.15, 21.75±1.96, 23.17±2.33 years), weight (70.08±18.32, 59±14.24, 55.83±8.64 kg), height (167.5±7.63, 163.00±6.65, 162.25±6.90 cm), NDI score (14.25±2.63, 13.17±2.12, 12.75±1.71), and CVA (54.33±1.91, 53.29±3.06, 54.09±2.35 degree).

3.2. Outcomes

In this study, none of the parameters considered showed a statistically significant difference between the VRG and the MEG in post-hoc tests. However, significant differences were found in post-hoc tests between the MEG and the CG for FJPSE, EJPSE, LLFJPSE, RRJPSE, EROM, NDI, and VAS at movement. Statistically significant differences were also observed in post-hoc tests between the VRG and the CG for EJPSE, RRJPSE, EROM, RRROM, NDI, VAS at rest, and VAS at movement parameters. The p^b-value from the Bonferroni test for the EROM value between the MEG and the CG was less than 0.01. For the MDTWS parameter, the p^a-value of the within-group paired t-test was <0.01 for both the VRG and the MEG. In the VRG, the p-values were 0.01 for both SB (PC) and VAS at rest parameters. However, these parameters had p-values greater than 0.05 in the MEG. The results of Paired samples t-tests (p^a) and one-way ANOVA with Bonferroni post hoc tests (p^b) for all parameters are presented in Table 2.

4. DISCUSSION

The aim of this conducted study was to investigate the effectiveness of two treatment modalities for students with chronic neck pain complaints. After six sessions, each lasting 20 minutes, the study aimed to assess the impact of these treatments on walking speed under five conditions, balance, and the accuracy of joint positioning sensation. The study also intended to compare the results between these two groups and conduct a separate comparison with the CG. The effectiveness of the treatment modalities mentioned in this study on the secondary outcomes, which include neck disability, pain severity, muscle stiffness, and ARoM parameters, was intended to be investigated by assessing the changes in these parameters before and after the treatment interventions.

The p^a-value used to investigate whether the time-dependent change in PWS within the groups is statistically significant revealed significance only in the MEG. Furthermore, the paired sample t-test did not yield statistical significance for the time factor in three groups regarding MWS, TWS, and CDTWS. The p-value for the MDTWS condition was found to be less than 0.01 for both the VRG and the MEG over time, while the p^b-value between groups was not significant. However, although not statistically significant, the pb value for MDTWS was the smallest compared to other walking speeds. According to motor programming theory, repetitive movements like walking can occur with less conscious effort. However, in cases of chronic neck pain leading to disturbances in dynamic balance, it results in individuals needing to walk with greater concentration, which, in turn, reduces walking speed (Petryń´ski,2007). Disturbances in balance have an impact on walking speed, whereas balance is influenced by visual, auditory, and somatosensory inputs. One of the factors contributing to an increase in walking speed can be interpreted as improvements in the processing of sensory inputs for dynamic balance and, in addition to these improvements, better coordination among muscles. This, in turn, suggests that the integrated functioning of both the central and peripheral nervous systems is more effective (Shumway-Cook & Woollacott, 2000). As a result, it appears that neck mobility has a positive impact on dynamic balance in the MEG. However, the lack of this effect in the VRG might be attributed to the possibility of not achieving a sufficient amount of neck mobility. This is suggested by the finding that in the VRG, there was significance only in rotational movements in the ARoM. In support of this, the MDTWS, which involves neck rotation in each step, was found to be significant in the VRG. However, the lack of significance in the Bonferroni test for multiple comparisons of the mean change value for MDTWS may be attributed to the limited number of sessions in our study (only a total of 6 sessions). This lack of significance in the analysis could be associated with the short duration of the sessions and may become significant in studies with longer sessions.

We analyzed the selected primary outcome, balance, in four different ways, and the only posture that exhibited a time-dependent change was the "pillow eyes closed" posture in the VRG. However, in the post-hoc test, no significant difference was observed among these groups. In Rezai's study involving participants with chronic neck pain, the intervention consisted of 8 sessions, and an improvement in balance was reported. However, no significant difference was observed between the VRG and the conventional

treatment group (I et al., 2019). The mobility in the cervical region contributes to the enhancement of proprioceptive acuity in the neck area, thereby assisting in the development of postural control. In pillow eye closed posture, the evaluation of balance solely relies on the proprioceptive sense, excluding the influences of visual and auditory inputs, which are known to play a role in maintaining balance. One of the reasons for the lack of statistical significance in the other three postures may be attributed to participants experiencing relatively less disturbance in balance due to neck pain or the possibility that this is linked to the visual input in the eye-open posture. Given that an elevation in NDI could be more strongly associated with anatomical and biomechanical alterations in the neck region, we inferred that the administered treatment might lead to more substantial outcomes.
Another primary outcome parameter for our study was the JPSE value. In the context of JPSE, time-dependent changes in flexion, extension, left lateral flexion, right lateral flexion, and left rotation directions yielded statistically significant p-values only in the MEG. However, in the VRG, statistical significance was not achieved. For JPSE in the rotation direction, a statistically significant change was observed in the right direction in the VRG between pre-treatment and post-treatment. However, for left rotation, statistical significance was observed only in the MEG. According to the p^b-values, a significant difference was found between the ME and the CG in the directions of flexion, extension, right lateral flexion, left lateral flexion, and left rotation. In contrast, in the comparison between the VRG and the CG, significance was observed only in the directions of extension and right rotation. No significance was found in any direction of the JPSE values in the multiple comparison test between the MEG and the VRG. The lack of significance in left rotation direction for the JPSE parameter in the VRG, despite significance in the right rotation direction, may be associated with the location of participants' pain. The basis for interpreting this lies in our observation that, when assessing the parameter of stiffness of the upper trapezius muscle, there was statistically significant improvement in the right upper trapezius, whereas this significance was not observed in the left upper trapezius. When examining the literature, Çetin's study reported that, based on JPSE values in all directions, the VRG was more effective compared to the MEG (Cetin, Kose & Oge, 2020).
The analysis of secondary outcomes, specifically ARoM, revealed that over time, there was a significant change in extension, right rotation, and left rotation degrees in the VRG. On the other hand, in the MEG, significance was observed in all directions except for rotation. Similar to our study, Tejera's study reported that the VRG did not exhibit statistical significance for all movement directions. However, in Cetin's study, ARoM was significant in the VRG in all directions (Tejera et al., 2020; Cetin, Kose & Oge, 2022). In both studies, they reported no statistical significance between the two groups for any ARoM in the post hoc test. However, in the Sahat study, during the VR-based kinematic training process, they reported that the VRG showed greater effectiveness for flexion, while for the right rotation movement, kinematic training was reported to be more effective (Sarig Bahat et al., 2014). This led to interpreting the reason for this difference between studies as potentially variable depending on the specific VR game used or the level of neck disability among participants. When interpreting changes in the range of active motion, it is essential to consider that individual variations may exist based on factors such as age and ethnicity. Consequently, when evaluating the magnitude of changes in the participants, it is imperative to take these factors into account.
The stiffness values of the muscles in their relaxed position were recorded; the paired sample t-test showed statistical significance for the LUT muscle in the MEG and for the RUT muscle in the VRG, but the p-value of the Bonferroni test for multiple comparisons did not indicate significance for muscle stiffness. A review of the existing literature reveals a lack of studies that directly compare the efficacy of VRG with MEG for this parameter. We believe that this result may be associated with the localization of pain in the neck region. The reduction in sympathetic nervous system activation accompanied by a decrease in pain is further characterized by the reduction of negative effects on Type 1 muscle fibers. This reduction is concomitant with the restoration of synergy between deep and superficial muscles, resulting in the diminished utilization of superficial muscles. The increase in blood flow associated with movement may have an impact on reducing factors that can contribute to muscle stiffness (Alagingi, 2022).

The Bonferroni test revealed statistically significant p-values for both NDI and VAS during movement parameters in both the VRG-CG and MEG-CG. However, for VAS at rest, the Bonferroni test indicated significance only between the VRG and CG. In the VRG, the significant reduction in pain severity over time is attributed to the immersive effect, indicating that when deeply engaged in a captivating experience, the mind finds it challenging to perceive stimuli outside the attentional focus. In a study, they reported that the use of VR in individuals with pain was associated with a reduction in pain-related brain activation in the anterior cingulate cortex, primary and secondary somatosensory cortex, insula, and thalamus regions (Gold, Belmont & Thomas, 2007). Despite the paired samples t-test for vas at rest showing significance only in the VR, the lack of significance in the Bonferroni test between the VRG and the MEG was interpreted as indicative of a reduction in pain severity in the MEG. In Çetin's study, it was reported that pain intensity decreased by 3.69 in the VRG and by 2.44 in the motor exercise group. In other words, the amount of decrease in the MEG was less than the VR group. However, they noted that this decrease was statistically significant within each group; However, when they compared the two groups, they did not find a statistically significant difference (Cetin, Kose & Oge, 2020).
This study has several limitations. Firstly, the localization of pain in the neck region was not recorded, which complicates the interpretation of the results. Secondly, the short duration of the treatment limits the ability to assess the long-term effects of the treatment modalities.

5. CONCLUSION

The results of this study, encompassing six sessions, indicated no superiority of the VR-based treatment method over the motor exercise method in terms of gait speed, static balance, and JPSE values. In the analyses conducted for the time factor, the motor exercise method demonstrated effectiveness, especially in ARoM and JPSE values. In contrast, the VR-based method indicated potential superiority in resting pain intensity. The emergence of this difference may be attributed to the motor exercise method's greater emphasis on promoting mobility in the neck region and focusing on the accuracy and quantity of movement. Furthermore, the reduction in pain-related brain activation associated with VR usage may explain the significant impact on resting pain intensity. The findings suggest that combining these two treatment modalities may enhance effectiveness in the therapeutic process. Based on these results, we believe that longer-duration treatments may be required to achieve greater statistical significance.

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Table 1. The table showing participant's general characteristics

Variables	VRG (n=12)	MEG (n=12)	CG (n=12)	F	p
Age (years)	22.91±2.15	21.75±1.96	23.17±2.33	1.481	0,24
Weight (kg)	70.08±18.32	59±14.24	55.83±8.64	3.256	0,51
Height (cm)	167.5±7.63	163.00±6.65	162.25±6.90	3.742	0,16
CVA (degree)	54.33±1.91	53.29±3.06	54.09±2.35	0.569	0,57
NDI	14.25±2.63	13.17±2.12	12.75±1.71	1.115	0,24

P^b: one-way Anova between groups ($p<0.05$) CVA: craniovertebral angle, NDI: neck disability index, VRG: virtual reality group, MEG: motor exercise group, CG: control group

Table 2. Comparison of pain severity during movement within and between groups

Variables	VRG	MEG	CG	F	P^b
Baseline	5.25 ±0.75	4.83 ±0.84	4.36 ±1.12	2.726	0.08
Post-intervention	4.42 ±0.90	3.92 ±0.99	4.54 ±1.21	1.195	0.32
Mean changes	-0.83 ±0.94	-0.92 ±1.31	0.18 ±0.75	4.202	$0.02^{B*, C*}$
t	-3.079	-2.421	0.803		
P^a	0.01*	0.03*	0.44		

*p <0.05, ** p <0.01. p^a: Paired samples t test, p^b: one-way anova with bonferroni post hoc test.
A: Comparison between virtual reality group (VRG) and motor exercise group (MEG)

B: Comparison between virtual reality group (VRG) and control group (CG)
C: Comparison between motor exercise group (MEG) and control group (CG)

Figure 2. Implementation of VR-Based Treatment in the Therapeutic Process

Figure 1. Implementation of motor exercise types in the Therapeutic Process