한국정밀공학회지 제 35 권 제 11 호 pp. 1107-1114
J. Korean Soc. Precis. Eng., Vol. 35, No. 11, pp. 1107-1114

https://doi.org/10.7736/KSPE.2018.35.11.1107
ISSN 1225-9071 (Print) / 2287-8769 (Online)

Check for updates

VR과 360°영상 시청이 척주세움근과 위등세모근의 근피로와 목굽힘-폄 각도에 미치는 영향

Effects of Watching Virtual Reality and 360° Videos on Erector Spinae and Upper Trapezius Muscle Fatigue and Cervical Flexion-Extension Angle

이대희[1], 한슬기[1,#]
Dae Hee Lee[1] and Seul Ki Han[1,#]

1 유원대학교 물리치료학과 (Department of Physical Therapy, U1 University)
Corresponding Author / E-mail: lovewisd@gmail.com, TEL: +82-43-740-1404
ORCID: 0000-0002-2868-1165

KEYWORDS: Fatigue (피부), Neck angle (목굽힘), Virtual reality (가상현실)

We investigated fatigue in the erector spinae, upper trapezius muscles and changes in the cervical flexion-extension angle when individuals watched 360° videos, general videos using virtual reality (VR), and smartphones. The subjects included 34 young, healthy, South Korean college students. The systems VR Gear3, the Galaxy S8, and "STAR WARS 360 VR" made by the manufacturer Cube CZ were utilized. The subject test conditions were: 1) watching 360° video with VR (V360), 2) watching 360° video on a smartphone (S360), 3) watching general video with VR (VG), 4) and watching general video on a smartphone (SG). The subjects watched a video for 10 min under each condition, where median frequencies of the erector spinae and upper trapezius muscles were measured using electromyography, while changes in the cervical flexion-extension angle were measured with an electrogoniometer. The results noted that the erector spinae and upper trapezius muscles were significantly fatigued over time in all conditions, with significant differences relating to time and conditional effect. Watching 360° videos was less fatiguing than watching general videos and neck muscles moved the most when watching V360, and least watching general videos. These results suggest that neck muscles are less fatigued when watching 360° videos.

Manuscript received: January 17, 2018 / Revised: June 26, 2018 / Accepted: July 17, 2018

NOMENCLATURE

VR = Virtual Reality
V360 = Watching 360° video with VR
S360 = Watching 360° video with smartphone
VG = Watching general video with VR
SG = Watching general video with smartphone

1. Introduction

Virtual Reality (VR) refers to "certain specific settings or situations that were made by artificial technology such as computers and are similar to reality, but not real, otherwise the technology itself."[1]

Recently, the Korean government announced plans to provide VR-AR (Augmented Reality) funds and start-up funds totaling 36 billion Won and will be actively promoting the VR-related industry in response to the fourth industrial revolution.[2] The bulk of the VR industry is accounted for by gaming, but entertainment, performance, and sports also utilize VR. In particular, music videos using VR have attracted many fans from the early stages of VR, which presents one of the negative aspects of VR. Specifically, watching videos for more than 3 - 5 min results in rapid fatigue and dizziness. Music videos tend to be watched repeatedly. They are expected to be developed and distributed by VR, which may result

in great ripple effects with respect to VR perception.[1]

With the rapid development of technology, users can appreciate high quality content anytime or anywhere, even without VR. The representative device for this is the smartphone. The smartphone dispersion rate of South Korea is 85%, and the worldwide smartphone dispersion rate is over 50%, and is expected to reach 75% in 2020.[3] In particular, 70% of smartphone owners use smartphones for watching videos, and more than 20% of smartphone owners watch videos on smartphones for more than 6 hours per week. Furthermore, in Korea, the duration of watching videos on a smartphone accounts for 20% of all types of video-watching, including TV, which is a two-fold increase from that in 2010.[4] In China, 2018 statistics reported that the Chinese people watch videos longer on a smartphone than on a TV.[5] Given these statistics, the increasing duration of watching videos on a smartphone appears to be a global trend.

Along with the distribution of smartphones and their increased use, users increasingly report pain.[6] This pain primarily seems to be caused by poor posture associated with smartphone use, mostly resulting from excessive bending of the neck.[7,8] Bending the head while using VR makes it hard to keep the eyes on the video. However, while watching a 360° video, the head should be moved frequently in different directions. Additionally, the degree of muscle fatigue may be different when watching 360° compared to traditional smartphone use, since smartphone users maintain a single posture with the head bent forward. VR devices are mounted on the head and may be unfavorable for the neck and shoulder muscles supporting it, since forward bending of the head during use may also be affected by gravity.

Kang et al.[9] reported that watching videos while wearing VR equipment requires movements of the head that increased feelings of fatigue more than watching videos that did not require movement of the head. Kim et al.[7] also reported that watching 3D videos using VR caused more fatigue than watching 2D videos. On the contrary, Kozulin et al.[10] found no difference in discomfort between viewing videos with VR and viewing videos in the conventional way, after 30 minutes of viewing. However, current studies of physical changes due to VR use are limited to expert opinions, surveys of users' subjective experiences, or their complaints of eye strain. There have been no quantitative studies on head movements and muscle fatigue.

This study investigated fatigue in the erector spinae and upper trapezius muscles while watching 360° videos and standard videos using VR and smartphones, as well as changes in cervical flexion-extension angle.

Table 1 Demographic characteristics of the subjects

Subject	Mean ± SD
Sex (M/F)	17 / 17
Age (yr)	20.29 ± 1.21
Height (cm)	165.77 ± 8.85
Weight (kg)	60.65 ± 15.59

2. Methods

2.1 Subjects

The number of subjects required to achieve significance was calculated using the G*power 3.1.5 program in reference to a report by So et al.[11] (α error probability = 0.05, power = 0.90), which found that 32 people (actual power = 0.90) were required. Thirty-four people (17 male and 17 female) were enrolled, in consideration of potential dropouts from the study. The present study received approval from the Institutional Review Board at U1 University. Individuals were included if they:

· Had no history of falls while performing daily activities due to ophthalmic disease or vestibular disease

· Had no musculoskeletal diseases or neurological disorders

· Voluntarily gave consent for this study

General characteristics of the subjects are listed in Table 1.

2.2 Measuring Equipment and Tools

2.2.1 VR

The VR Gear 3 (Samsung, South Korea, 2017) was utilized in this study. The VR device was 98.6 × 207.8 × 122.5 mm (length × width × thickness) in size and 345 g in weight. The Galaxy S8 was linked to the VR device, and a remote control was not used. Researchers operated the device to begin the video.

The VR gear was mounted to the subjects' heads by one of the researchers while they were in a seated position. During that time, the length and position of the head band was adjusted for the subject's comfort (Fig. 1).

2.2.2 Smartphone

The Galaxy S8 (Samsung, South Korea, 2017) was used as the smartphone device for this study. The device was 148.9 × 68.1 × 8.0 mm (length × width × thickness) in size and 155 g in weight. Smartphones were used in the horizontal mode with the user holding the ends of the smartphone with both hands. Devices were operated by the researchers (Fig. 2).

Fig. 1 Image of watching a video wearing a VR device

Fig. 2 Image of watching a video using a smartphone

2.2.3 Electromyography

To measure muscle fatigue in the erector spinae and the upper trapezius muscles, the BioNomadix 2-channel wireless EMG of MP150 (BIOPAC System Inc. Santa Barbara, CA, USA) was used, which has electrodes made of Ag-Ag/Cl (Biopac, 2 cm in diameter). Electromyography signals were collected at a sampling rate of 1,000 Hz and were processed by full-wave rectification. The signal data were processed using band pass filtering at 30 - 500 Hz using Acqknowledge 4.1 (Biopac System, USA) software, followed by notch filtering at 60 Hz to remove noise.

Electromyography electrodes were attached to the erector spinae on both sides of C4, while electrodes for the upper trapezius muscle were fixed to the point slightly outside the midpoint between C7 and the acromion.[12] A total of four measurements were taken from both the right and the left sides.

Median frequency was computed to examine muscle fatigue in relation to the duration of each condition. A lower median frequency indicates a more fatigued muscle.[13,14]

2.2.4 Electrogoniometer

To measure the degree of changes in the cervical range of motion, the BN-GON-150-XDCR (BIOPAC Systems, Inc., USA) was utilized.

2.2.5 Video contents

The STAR WARS 360 VR (running time 10 min 35 sec), made by Cube CZ, was used as the experimental video in the present study.

For viewing the 360° video, video images were set to move according to the position of the device. Video images used in the general videos were fixed, although the same video contents were used for all conditions.

2.3 Measurements

A total of four measurement conditions were applied as follows:

1) Watching 360° video with VR (V360)
2) Watching 360° video with smartphone (S360)
3) Watching general video with VR (VG)
3) Watching general video with smartphone (SG)

Subjects were seated on a chair that had armrests and a back support in all conditions, which allowed for free head and arm movement. For safety, chairs without wheels were used.

To eliminate learning effects, the order of the measurement conditions was randomized for each subject. While measurements were taken for 10 min in each condition, the experiment was stopped if subjects complained of dizziness or fatigue during the experiment.

Table 2 Median frequency changes in the erector spinae muscle

min	Mean ± SD (unit: Hz)				Time	Time*group
	V360	S360	VG	SG	F(p)	F(p) post-hoc
1	41.616 ± 11.521	41.704 ± 11.513	43.320 ± 11.639	41.922 ± 11.251	12.737 (< 0.001)	3.839 (< 0.001) V360, S360 > SG, VG
2	41.147 ± 13.956	43.730 ± 14.151	28.798 ± 14.246	37.759 ± 14.136		
3	36.445 ± 14.998	41.569 ± 14.285	24.953 ± 14.803	33.272 ± 13.924		
4	42.212 ± 14.095	39.925 ± 14.352	23.025 ± 14.394	31.466 ± 14.445		
5	41.779 ± 12.922	41.090 ± 13.472	23.757 ± 13.624	28.754 ± 13.501		
6	38.988 ± 16.115	39.925 ± 15.878	23.470 ± 16.352	33.760 ± 16.097		
7	40.340 ± 12.112	44.780 ± 12.902	20.721 ± 12.819	25.591 ± 13.382		
8	42.183 ± 13.352	41.463 ± 13.367	20.325 ± 13.504	30.775 ± 13.366		
9	41.090 ± 15.217	39.530 ± 15.142	20.793 ± 14.735	23.935 ± 15.119		
10	37.764 ± 14.678	34.012 ± 14.423	19.009 ± 14.831	27.381 ± 14.075		

Table 3 Median frequency changes in the upper trapezius muscle

min	Mean ± SD (unit: Hz)				Time	Time*group
	V360	S360	VG	SG	F(p)	F(p) post-hoc
1	37.724 ± 15.336	37.347 ± 15.300	40.094 ± 15.171	37.714 ± 14.969	12.104 (< 0.001)	5.747 (< 0.001) V360, S360 > SG, VG
2	36.633 ± 13.591	35.804 ± 13.164	32.687 ± 13.168	25.328 ± 13.084		
3	29.137 ± 13.243	41.747 ± 13.118	29.790 ± 13.227	26.468 ± 12.867		
4	34.924 ± 14.757	39.379 ± 14.569	27.745 ± 14.596	23.882 ± 14.713		
5	37.108 ± 15.238	37.405 ± 14.922	27.312 ± 15.123	28.496 ± 15.149		
6	32.853 ± 15.193	36.010 ± 14.244	28.076 ± 15.100	24.104 ± 14.238		
7	38.943 ± 15.435	33.020 ± 15.214	25.167 ± 15.294	24.059 ± 15.224		
8	32.397 ± 14.801	29.891 ± 14.707	24.016 ± 14.712	23.379 ± 14.729		
9	33.204 ± 13.547	34.028 ± 13.412	22.180 ± 13.737	23.953 ± 13.582		
10	32.418 ± 15.591	34.398 ± 14.463	19.906 ± 15.528	21.379 ± 14.742		

*V360 = Watching 360° video with VR; S360 = Watching 360° video with smartphone; VG = Watching general video with VR; SG = Watching general video with smartphone

2.4. Statistical Analyses

SPSS 18.0 was used for the statistical analyses, and the significance level was set as 0.05.

In all conditions, the mean values of median frequency and cervical flexion-extension angle were measured every 1 min after a video was started to play. The value of the cervical flexion-extension angle measured in the first 1 min was used as the reference angle, and the motions of the neck muscles at every minute were added after all 10 measurements were obtained to find the total motion.

The changes in the median frequency and cervical flexion-extension angle depended on the condition and time lapse. Repeated measures of analysis of variance (ANOVA) were performed, and the Bonferroni correction was applied for the post-hoc analysis.

3. Results

3.1. Changes in Median Frequency of the Erector Spinae

The erector spinae showed significant differences in the median frequency with time ($p < 0.05$) and conditional effects ($p < 0.05$). In a post-hoc analysis, V360 and S360 formed a high group (less muscle fatigue), while VG and SG formed a low group (more muscle fatigue) (Table 2).

3.2. Changes in Median Frequency of the Upper Trapezius Muscle

The upper trapezius muscle showed significant differences in median frequency with time ($p < 0.05$) and conditional effects ($p < 0.05$). In a post-hoc analysis, V360, S360, and VG formed a high

Table 4 Changes in the cervical flexion-extension angle

min	Mean ± SD (unit: degree)				Time	Time*group
	V360	S360	VG	SG	F(p)	F(p) post-hoc
2	0.106 ± 2.343	0.308 ± 2.175	0.810 ± 2.173	0.738 ± 2.175	5.248 (< 0.001)	3.753 (< 0.001) SG, S360, VG, V360
3	0.88 ± 3 .418	1.384 ± 3.326	0.967 ± 3.382	0.523 ± 2.935		
4	2.001 ± 3.02	1.546 ± 2.857	1.235 ± 2.982	1.212 ± 2.464		
5	0.049 ± 4.476	1.217 ± 4.335	1.669 ± 4.477	2.056 ± 3.565		
6	-0.986 ± 4.735	1.627 ± 4.755	1.61 ± 4.738	2.528 ± 3.871		
7	-0.143 ± 6.060	2.326 ± 6.065	1.687 ± 6.071	2.996 ± 5.249		
8	0.727 ± 3.698	1.958 ± 3.588	1.468 ± 3.670	2.849 ± 3.272		
9	1.275 ± 4.668	2.434 ± 4.592	1.442 ± 4.712	3.096 ± 4.100		
10	0.520 ± 5.158	2.629 ± 5.071	1.520 ± 5.165	3.385 ± 4.383		

*V360 = Watching 360° video with VR; S360 = Watching 360° video with smartphone; VG = Watching general video with VR; SG = Watching general video with smartphone

Table 5 Changes in the cumulative cervical flexion-extension angle

min	Mean ± SD (unit: degree)				Time	Time*group
	V360	S360	VG	SG	F(p)	F(p) post-hoc
2	1.789 ± 1.485	1.107 ± 1.362	0.909 ± 1.366	1.399 ± 1.361	50.745 (< 0.001)	3.774 (< 0.001) V360 > S360, SG > VG
3	4.116 ± 2.433	3.024 ± 2.467	1.518 ± 2.429	2.419 ± 2.371		
4	6.013 ± 2.802	4.359 ± 2.960	2.170 ± 2.881	3.397 ± 2.923		
5	8.500 ± 3.991	5.513 ± 4.162	3.082 ± 4.046	4.918 ± 3.896		
6	10.153 ± 4.703	6.992 ± 4.722	4.314 ± 4.814	6.223 ± 4.446		
7	12.143 ± 5.646	8.293 ± 5.646	5.044 ± 5.784	7.722 ± 5.511		
8	15.640 ± 7.975	9.482 ± 8.132	5.851 ± 8.162	9.017 ± 7.827		
9	18.136 ± 8.873	11.239 ± 8.913	7.248 ± 8.992	10.780 ± 8.672		
10	19.730 ± 9.456	12.800 ± 9.419	8.308 ± 9.541	11.782 ± 9.150		

*V360 = Watching 360° video with VR; S360 = Watching 360° video with smartphone; VG = Watching general video with VR; SG = Watching general video with smartphone

median frequency group. S360, VG, and SG formed a low median frequency group (Table 3).

3.3. Changes in the Cervical Flexion-Extension Angle

Cumulative changes in the cervical flexion-extension angle showed significant differences depending on time ($p < 0.05$) and also based on both the time and conditional effects ($p < 0.05$). In a post-hoc analysis, the amount of changes decreased following the order of SG, S360, VG, and V360, but there was no significant difference ($p > 0.05$) (Table 4).

3.4. Cumulative Changes in the Cervical Flexion-Extension Angle

Cumulative changes in the cervical flexion-extension angle showed significant differences depending on time ($p < 0.05$) and based on both time and conditional effects ($p < 0.05$). In a post-hoc analysis, V360 formed group with the highest cervical flexion-extension angle, S360 and SG made a middle group, and VG formed the lowest group (Table 5).

4. Discussion

The present study aimed to investigate changes in fatigue of the erector spinae and the upper trapezius muscles while watching 360° video compared to traditional video using VR and smartphones. It also aimed to identify changes in the cervical flexion-extension angle.

In the present study, the length of time for using the smartphone was set at 10 min, which was primarily for ethical protection of the subjects. Koreans tend to spend 12.5 min each time they used a smartphone,[6] and prolonged use of a smartphone can cause muscle fatigue and pain.[15-19] In the present study, researchers operated the smartphone or VR for the subjects to minimize potential stress that subjects may experience by being unfamiliar with the operation of the devices. Furthermore, the subjects sat on a chair with a backrest and armrest but without wheels. This was not only to ensure safety of the subjects but also to minimize stress resulting from the anxiety that the chairs may roll unintentionally. As shown here, this study attempted to minimize the stress factors other than effects on muscle fatigue of watching general and 360° videos on VR and smartphone.

Video watching was selected as the setting for use of VR and smartphones in the present study because the primary uses of smartphones by Koreans are for messenger (99.8%), playing games (89.5%), and watching videos (45.5%).[16] Although VR can be used for messenger, the targets and contents of messenger might have affected the results of the present study. There is currently no game that can be controlled by both VR and smartphone. As such, neither messenger nor games could be chosen. Since videos can be viewed in VR, videos were chosen in the present study. Unlike the results of our study, Kang et al.[9] reported that watching 360° videos using VR caused more fatigue than watching standard videos. Since Kang et al.[9] reported the sense of fatigue, not muscle fatigue, their results cannot be compared directly to those of the present study. In addition, Kang et al.[9] used different videos for the traditional and 360° videos; so, the effects of the difference in video contents were effectively compared. In the present study, we used the same video for both 360° and traditional videos to minimize variation in the function of the 360° rotation, which may also lead to the difference between the results of the two studies.

We chose to use “STAR WARS 360 VR” made by Cube CZ as the experimental video. To find this video, YouTubeKR was searched using “VR” as the keyword, and filters for videos with over 4 K in pixel size, 360° videos, over 2 million views, and over 10 min of continuous running time were selected. Ultimately, this video was chosen because it had neither sexuality nor violence.

Muscle fatigue is a neuromuscular condition where muscles fail to generate the required force. In the present study, extracted EMG data were analyzed to investigate muscle fatigue. With respect to this, Karthick et al. (2015) reported that more diverse range of frequencies are observed when the muscles are not fatigued, as compared to when they are fatigued,[14] while Kupa et al. (1995) reported that different frequencies are observed according to the types of muscle fibers.[13] Lower frequencies are observed with type 1 muscle fibers with strong endurance, whereas higher frequencies are observed with type 2 muscle fibers with weak endurance. In other words, when muscles are not fatigued, diverse frequencies are observed as both type 1 and type 2 muscle fibers are used, whereas when muscles are fatigued, higher frequencies are not readily observed as the activities of type 2 muscle fibers with weak endurance decrease while lower frequencies are still observed as the activities of type 1 muscle fibers with relatively strong endurance are maintained or decreased to a lesser degree than the type 2 muscle fibers. Consequently, as muscles become more fatigued, the median value of all frequencies become lower. The present study was able to identify muscle fatigue by analyzing the frequencies that are observed according to muscle types.

Park et al.[16] reported that the use of a video display terminal had a close relationship with an increase in fatigue of muscles in the neck, the upper extremities, and the general musculoskeletal system. Many researchers also reported that prolonged use led to increased complaints of pain and fatigue.[21-23] In the present study, fatigue in the erector spinae and the upper trapezius muscles increased with time when using either smartphone or VR. We found that prolonged use of VR could cause muscle fatigue, although VR induced less muscle fatigue than smartphone, depending on the condition.

The head weight accounts for about 1/7th of the whole body weight. Pressure to the bones of the neck increases, and negative changes in the connections between the head and the neck are induced as the center of gravity moves forward.[24] Kim and Sung[25] reported that about 10% of people who were wearing glasses complained of discomfort with their glasses. Although the weight of the VR apparatus has become lighter due to technological advancements, the total weight of the latest VR, and the smartphone mounted to VR in the present study was about 0.5 kg. It was speculated that such weights would enhance fatigue in the neck and the upper back muscles in order to bend the neck or prevent the head from bending forward. For the median frequency of the erector spinae and the upper trapezius muscles, however, V360 and S360 formed a high group and VG and SG made a low group depending on time and the conditional effect. In other words, the 360° video and a general video seemed to have a larger impact on muscle fatigue than VR and smartphone. In addition, the present study investigated cumulative changes in the cervical flexion-extension angle, resulting in a larger change watching a 360° video than watching a general video. Specifically, V360 showed a statistically significant difference compared to the other conditions. It was postulated that since subjects were able to view a wider scene as they moved their head while watching a 360° video, they moved their heads continuously. Continuous movements

seemed to have prevented them from taking an undesirable posture. According to researchers, bending the neck forward while using VR or smartphones is a poor posture which increases fatigue in the erector spinae and the upper trapezius muscle.

So and Yoo[11] reported that bending the neck while using a smartphone caused pains, while there was little neck pain when using a smartphone at eye level. However, only 18% of users use smartphones at eye level in a sitting position.[22] The small screen of smartphones is one of the factors that causes smartphone users to bend their necks.[19,26,27] On the contrary, VR has a much wider screen compared to the smartphone. In addition, it is impossible to control the position of the video if the neck is bent while using VR, unlike when using a smartphone, because it would end up focusing on the lower part of video. Therefore, it was thought that the subjects did not bend their neck in order to watch video from the appropriate angle. It also seemed that such movements caused VG to have the least cumulative change in the cervical flexion-extension angle. However, it was postulated that subjects were not accustomed to watching video while maintaining a posture without bending their necks. That may be the reason why VG formed a group with a low change of median frequency of the erector spinae and the upper trapezius muscle depending on time and conditional effect.

There were two main limitations to this study. First, the present study was conducted using only healthy subjects in a specific region. Second, the fatigue of all the muscles that could be affected by use of VR and smartphone, and the rotation of the neck muscles with various lateroflexion movements were not examined in this study. Further study will be needed with respect to evaluating more muscles and movements.

5. Conclusion

The present study was performed to investigate fatigue of the erector spinae and the upper trapezius muscles and the changes in the cervical flexion-extension angle when watching 360° videos and traditional videos using VR and smartphone. As a result, the erector spinae and the upper trapezius muscles showed significant fatigue in all conditions with time, and also had significant difference depending on time and conditional effect. In general, watching 360° videos caused less fatigue than watching traditional videos. In addition, the neck muscles showed the largest movement when watching 360° videos with VR and the least movement when watching general videos with VR. These results suggested that movement of the neck while watching 360° videos leads to less fatigue in the erector spinae and the upper trapezius muscles.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT & Future Planning) (No. NRF-2017R1C1B5014991).

REFERENCES

1. Kang, C. H., “Flow of Next Generation Broadcast Video, Present and Future of VR Contents,” The Korea Contents Association., Vol.14, No.2, pp.14-18, 2016.
2. Ministry of Science, “ICT and Future Planning,” https://www.msit.go.kr/web/msipContents/contentsView.do?cateId=mssw315&artId=1329779 (Accessed 22 OCT 2018)
3. GSMA, “Global System Mobile Communications,” https://www.gsma.com (Accessed 22 OCT 2018)
4. KCA, “Korea Communication Agency,” https://www.kca.kr/open_content/ko/index.jsp (Accessed 22 OCT 2018)
5. Aju Economics, “Cina’s Smartphone Usage Surpasses TV Viewing This Year for the First Time in History,” https://www.ajunews.com/view/20180420170552115 (Accessed 22 OCT 2018)
6. Statistics Korea. http://kostat.go.kr/portal/korea/index.action (Accessed 22 OCT 2018)
7. Kim, M.-S., “Influence of Neck Pain on Cervical Movement in the Sagittal Plane During Smartphone Use,” Journal of Physical Therapy Science, Vol. 27, No. 1, pp. 15-17, 2015.
8. Lee, Y. S., “A Study on the Effect of Mobile Phone Use Addiction on Teenage Health: Focused on Neck Pain,” M. Sc. Thesis, Gwangwoon University, 2013.
9. Kang, H., Yoo, I. W., Lee, J. H., and Hong, H., “Effect of Application Type on Fatigue and Visual Function in Viewing Virtual Reality (VR) Device of Google Cardboard Type,” Journal of Korean Ophthalmic Optics Society, Vol. 22, No. 3, pp. 221-228, 2017.
10. Kozulin, P., Ames, S. L., and McBrien, N. A., “Effects of a Head-Mounted Display on the Oculomotor System of Children,” Optometry and Vision Science, Vol. 86, No. 7, pp. 845-856, 2009.
11. So, Y. J. and Woo, Y. K., “Effects of Smartphone Use on Muscle Fatigue and Pain and, Cervical Range of Motion Among Subjects with and Without Neck Muscle Pain,” Physical Therapy Korea, Vol. 21, No. 3, pp. 28-37, 2014.
12. Chriswell E., “Cram’s Intrduction to Surface Electromyography,” Jones & Bartlett Publishers, pp. 1-40, 1998.
13. Kupa, E., Roy, S., Kandarian, S., and De Luca, C., “Effects of Muscle Fiber Type and Size on EMG Median Frequency and

Conduction Velocity," Journal of Applied Physiology, Vol. 79, No. 1, pp. 23-32, 1995.

14. Karthick, P., Venugopal, G., and Ramakrishnan, S., "Differentiating Muscle Fatigue and Nonfatigue Conditions Using Surface EMG Signals and Zhao-Atlas-Marks Based Time-Frequency Distribution," Biomedical Sciences Instrumentation, Vol. 15, No. 51, pp. 115-121, 2015.

15. Ko, K., Kim, H. -S., and Woo, J. -H., "The Study of Muscle Fatigue and Risks of Musculoskeletal System Disorders from Text Inputting on a Smartphone," Journal of the Ergonomics Society of Korea, Vol. 32, No. 3, pp. 273-278, 2013.

16. Park, J. -H., Kang, S. -Y., and Jeon, H. -S., "The Effect of Using Smart-Phones on Neck and Shoulder Muscle Activities and Fatigue," Physical Therapy Korea, Vol. 20, No. 3, pp. 19-26, 2013.

17. Berolo, S., Wells, R. P., and Amick III, B. C., "Musculoskeletal Symptoms Among Mobile Hand-Held Device Users and Their Relationship to Device Use: A Preliminary Study in a Canadian University Population," Applied Ergonomics, Vol. 42, No. 2, pp. 371-378, 2011.

18. Chang, C. H., Amick III, B. C., Menendez, C. C., Katz, J. N., Johnson, P. W., et al., "Daily Computer Usage Correlated with Undergraduate Students' Musculoskeletal Symptoms," American Journal of Industrial Medicine, Vol. 50, No. 6, pp. 481-488, 2007.

19. Straker, L., Coleman, J., Skoss, R., Maslen, B., Burgess-Limerick, R., et al., "A Comparison of Posture and Muscle Activity During Tablet Computer, Desktop Computer and Paper Use by Young Children," Ergonomics, Vol. 51, No. 4, pp. 540-555, 2008.

20. Statistics Korea, http://kostat.go.kr/portal/korea/index.action (Accessed 22 OCT 2018)

21. Kang, S. -J., Kim, K. -H., and Kim, C. -H., "Effects on Sight, Quickness, Balance, Pain of Normal Human Body with Using Portable Mobile Phone," The Journal of Korean Academy of Orthopedic Manual Physical Therapy, Vol. 18, No. 2 , pp. 95-102, 2012.

22. Hwang, K. -H., Yoo, Y. -S., and Cho, O. -H., "Smartphone Overuse and Upper Extremity Pain, Anxiety, Depression, and Interpersonal Relationships Among College Students," The Journal of the Korea Contents Association, Vol. 12, No. 10, pp. 365-375, 2012.

23. Greig, A. M., Straker, L. M., and Briggs, A. M., "Cervical Erector Spinae and Upper Trapezius Muscle Activity in Children Using Different Information Technologies," Physiotherapy, Vol. 91, No. 2, pp. 119-126, 2005.

24. Sauter, S. L., Schleifer, L. M., and Knutson, S. J., "Work Posture, Workstation Design, and Musculoskeletal Discomfort in a VDT Data Entry Task," Human Factors, Vol. 33, No. 2, pp. 151-167, 1991.

25. Kim, S. -K. and Sung, A., "The Clinical Study on Spectacle Wearers of Highschool Students," Journal of Korean Ophthalmic Optics Society, Vol. 9, No. 1, pp.19-27 2004.

26. Yoo, S., "Effects of Posture, Break Type and Work-Break Schedule on Fatigue During Smartphone Use," M. Sc. Thesis, Hanyang University, 2012.

27. Szeto, G. P. and Lee, R., "An Ergonomic Evaluation Comparing Desktop, Notebook, and Subnotebook Computers," Archives of Physical Medicine and Rehabilitation, Vol. 83, No. 4, pp. 527-532, 2002.

Dae-Hee Lee
Professor Department of Physical Therapy, U1 University. His research interest is Neurological physiotherapy.
E-mail: dhlee@u1.ac.kr

Seul-Ki Han
Professor Department of Physical Therapy, U1 University. His research interest is Underwater therapy, Gait analysis.
E-mail: lovewisd@gmail.com