LIFE: International Journal of Health and Life-Sciences
ISSN 2454-5872

Yu-Jin Cha, 2020

Volume 6 Issue 1, pp. 17-29

Date of Publication: 06th April 2020

DOI- https://dx.doi.org/10.20319/lijhls.2020.61.1729

This paper can be cited as: Cha, Y., (2020). Analysis of a Difference in the Biomechanical Characteristics According to the Habituation by Heights of Shoes: High-Heel and Low-Heel Shoes. LIFE: International Journal of Health and Life-Sciences, 6(1), 17-29.

ANALYSIS OF A DIFFERENCE IN THE BIOMECHANICAL CHARACTERISTICS ACCORDING TO THE HABITUATION BY HEIGHTS OF SHOES: HIGH-HEEL AND LOW-HEEL SHOES

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Abstract

This study was performed to comprehensively investigate whether there is a difference in the biomechanical characteristics according to the habituation by heights of shoes of those who habituate to high heeled shoes and low heeled shoes. The women with low heeled habituation show significantly higher values of peak pressures in the lateral forefoot and midfoot areas, and wider contact areas in toes and midfoot than the women with high heeled habituation for the contact area. From the EMG comparison, the women with high heeled habituation show significantly higher maximum peak EMG in GM, and from the percentage of maximum voluntary isometric contraction (%MVIC), the women with high heeled habituation show significantly higher values of the plantarflexion in GM the low heeled shoe user. For the static balance, the women with high heeled habituation show significantly greater values with eyes open. The study was able to verify that there is a significant difference in biomechanical fitness such as foot pressure, %MVIC, etc. Based on the result, this study can be utilized as base data to develop a customized insole that disperses pressure and softens shock absorption of the high heeled shoes.

Keywords

Biomechanics, EMG, Foot Pressure, Habituation, High Heels, Muscle Activation, Static Balance

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This paper is extracted from a part of the result of a research project (No. NRF-2018RICIB5083000) supported by National Research Foundation of Korea

1. Introduction

The high heeled shoes have evolved into various forms as recognized by a part of the fashion, and many types of research on the impact on ambulation have been conducted (Kim & Lim, 2016). Recently as major news media in U.S. intensively reported diseases and/or problems caused by shoes, the media severely warned with expressions such as 'High heels killing you?', 'The curse of high heels', etc. (Associated Newspapers Ltd, 2017; Korea Consumer Agency, 1998).

In U.S., around 40% of adults have foot-related diseases, and it has been reported that it requires USD 1.5 trillion of direct expenses for an operation and post-operative care to treat hallux valgus, bunion, hammer toe, corm, low back pain, etc., and USD 15 trillion of indirect expenses are spent among the majority of adults with the foot-related diseases. However, despite invisible pains due to the high cost, inconvenience, and malformation, women prefer high heeled shoes and spend most of the time with wearing high heeled shoes (Coughlin & Thompson, 1995). In Korea, according to statistical data from Health Insurance Review & Assessment Service (HIRA), the plantar fasciitis is a disease which frequently occurs in women due to the shoes which have difficulties to absorb an impact such as high heeled shoes, and the number of patients who were treated for the plantar fasciitis was increased by 1.26 times from 180,062 in 2014 to 227,418 in 2016. The expenses were also increased by 1.33 times from KRW 11.67 billion to KRW 15.51 billion (Korea National Statistical Office, 2016).

The high heeled shoes increase the plantar flexion of feet and instability of ankle joints is increased as supporting areas are reduced. Also, as momentum of outer sides of feet is increased, ankle sprains and falls might be caused, and in case of wearing the high heeled shoes for long time, it may reduce efficiency by increasing energy consumption during walking. In addition, by accelerating muscular fatigue, it stresses out feet (Song & Park, 2001). As the center of gravity of the body changes, it not only changes alignment of the body but also gives a harmful influence to walking and functions of low extremities (Moon & Kim, 2011).

There is a significant difference between the women with high heeled habituation and women with low heeled habituation, and a prolonged use of the high heeled shoes bring differences in a malfunction of a sensory function change to a center line of the balance of ankles and knee joints, etc. (Lee et al., 2010), while the women with low heeled habituation show differences such as reduced muscle activation, activation of the biceps femoris, etc. (Park et al., 1999), but there are insufficient aspects as only a single aspect which is a kinetic aspect was reviewed.

There are many results of researches on the high heeled shoes for this study, but not much researches on the impact derived from habituation of the high heeled hoses. Therefore, this study was performed to comprehensively investigate whether there is a difference in the biomechanical characteristics according to the habituation by heights of shoes of those who habituate to high heeled shoes ("women with high heeled habituation", more than 6cm) and low heeled shoes (women with low heeled habituation" lower than 3cm). This study intends to provide basic data for developing customized insoles that have aesthetic factors, convenience, and biocompatibility as well as the capability to disperse pressure and absorb and release shocks caused by various types of high-heeled shoes, differentiated according to habituation by heel height.

2. Methods

The comparison analysis was comprehensively performed to check if there is a difference in a level of the biomechanical characteristics through surface EMG, foot pressure analysis, static dynamic balance measurement in order to compare functional variables related between women with high heeled habituation and women with low heeled habituation

2.1 Research Subject and Period

The research subjects consist of total 37 healthy women in 20s, 19 women with high heeled habituation who habituate to living with wearing high heeled shoes, higher than 6 cm and 18 women with low heeled habituation, lower than 3 cm for more than recent 1 year, 3 days a week and 4 hours a day (Kim et al., 2015; Snow & Williams, 1994).

2.2 Research Tools

Followings are the analytical equipment and variables used for this study (Table 1).

Table 1: *Equipments*

Equipment	Model	Company	Variables
Plug-in shoe type foot pressure mearing equipment	Pedar® system	Novel GMBH, Germany	peak pressure (PP) (kPa) contact area (CA) (cm^2)
Surface EMG	Noraxon EMG	Noraxon, USA	RMS EMG (uV) %MVIC
Balance measuring equipment	Gaitview	alFOOTs, Korea	Displacement of a center of pressure (COP)

* Measure a dominant leg

2.3 Research Procedure

The subjects of this study is categorized by the women with high heeled habituation (Group A) and women with low heeled habituation (Group B). In order to examine the muscle activation, perform a measurement for 20 seconds standing on a measuring plate, Gaitview system, with both feet by attaching EMG electrods to 7 points and wearing experimental shoes, 7cm, with a remote sensor attached to Pedar® system in an inner sole which is a foot pressure mearing equipment. Measure 3 times, 20 seconds for each, and take a 10 seconds break between the tests, and then calculate average values (Lee et al., 2010). All measurements were performed with a dominant leg, and a leg used to kick a ball was considered as a dominant leg.

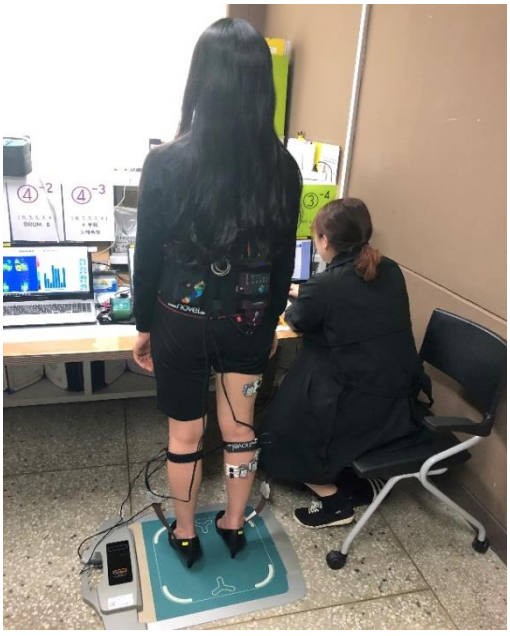


Figure 1: *Scene of the Test*

2.4 Analytical Method

Data treatment of this study was analyzed by SPSS (version 22,0-Chicago, IL, USA). General characteristics of the subjects are i) calculating average and standard deviation, ii) performing a homogeneity analysis and iii) t-test with an independent sample was performed to analyze differences in foot pressure, surface EMG and balance between the women with high heeled habituation and women with low heeled habituation. A statistical significant level is α=.05.

3. Results

The age is 20.11 ± 1.59 years, weight is 53.29 ± 4.07 kg, height is 169.56 ± 3.71 cm and shoe size is 240 ± 3.22 mm of the group A, and for the group B, the age is 19.66 ± 1.14 years, weight is 54.11 ± 5.09 kg, height is 165.78 ± 3.87 cm and shoe size is 246.23 ± 2.56 mm. Since there was no significant difference in the age, weight, height and shoe size as a result of the homogeneity analysis of the two groups, the two groups can be a homogeneous group.

Table 2: *Participant Demographics* (N= 37)

Variables	Group A[a] (N=19)	Group B[b] (N=18)	t	p
Age (years)	20.11 ± 1.59	19.66 ± 1.14	0.958	0.090
Weight (kg)	53.29 ± 4.07	54.11 ± 5.09	-0.544	0.171
Height (cm)	167.45 ± 3.13	165.78 ± 3.87	1.450	0.237
Shoes size (mm)	240 ± 3.22	246.23 ± 2.56	0.414	0.376

Values are means ± SE

[a]Over 12 months, 4 times a week, and over 6cm heeled shoes group

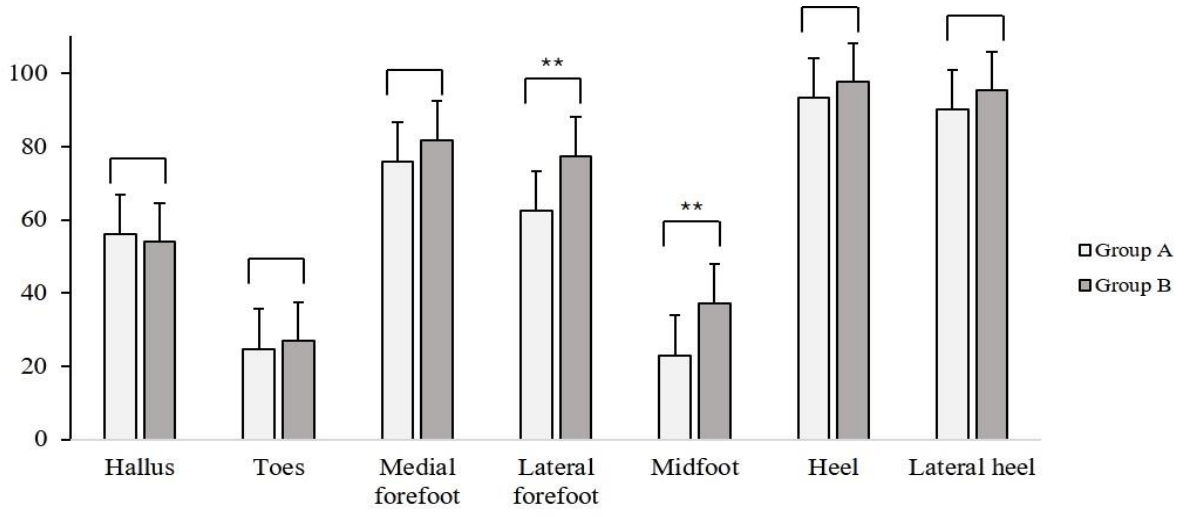
[b]Over 12 months, 4 times a week, and below 3cm heeled shoes group

From the foot pressure analysis between group A and B, the group B show significantly higher values of peak pressures (PP) in lateral forefoot and midfoot areas than the group A. For the contact area, the women with low heeled habituation show significantly higher values in toes and midfoot than the group A ($p<.05$) ($p<.001$) (Figure 2) (Table 3).

Table 3: *Average Pressure by Each Area of the Women with High Heeled Habituation and Women with Low Heeled Habituation*

Variables		Group A[a]	Group B[b]	t	p
Hallus	PP (kPa)	56.04 ±13.13	54.04±19.58	.368	.715
	CA (cm^2)	8.39 ±1.52	8.00±1.77	.653	.518
Toes	PP (kPa)	24.78 ±7.93	26.94±7.10	-.869	.391
	CA (cm^2)	5.71±1.93	7.16±2.09	-2.210	.034*
Medial forefoot	PP (kPa)	75.77 ±20.30	81.75±15.96	-.993	.328
	CA (cm^2)	17.79±1.73	17.82±2.27	.090	.929
Lateral forefoot	PP (kPa)	62.35 ±13.12	77.39±15.14	15.003	.000**
	CA (cm^2)	16.01±1.90	16.69±1.92	-1.062	.296
Midfoot	PP (kPa)	23.03 ±9.36	37.22±14.00	-3.606	.001**
	CA (cm^2)	5.60±3.57	8.70±3.62	-2.669	.012*
Heel	PP (kPa)	93.24 ±18.11	97.69±17.94	-.750	.458
	CA (cm^2)	27.43±1.52	28.26±2.58	-1.086	.285
Lateral heel	PP (kPa)	90.16 ±19.15	95.34±18.31	-.840	.406
	CA (cm^2)	19.17±4.95	18.37±1.00	.723	.478

*p<.05, **p<.001
Values are means ± SE
CA, contact area; PP, peak pressure



Peak Pressure (PP)

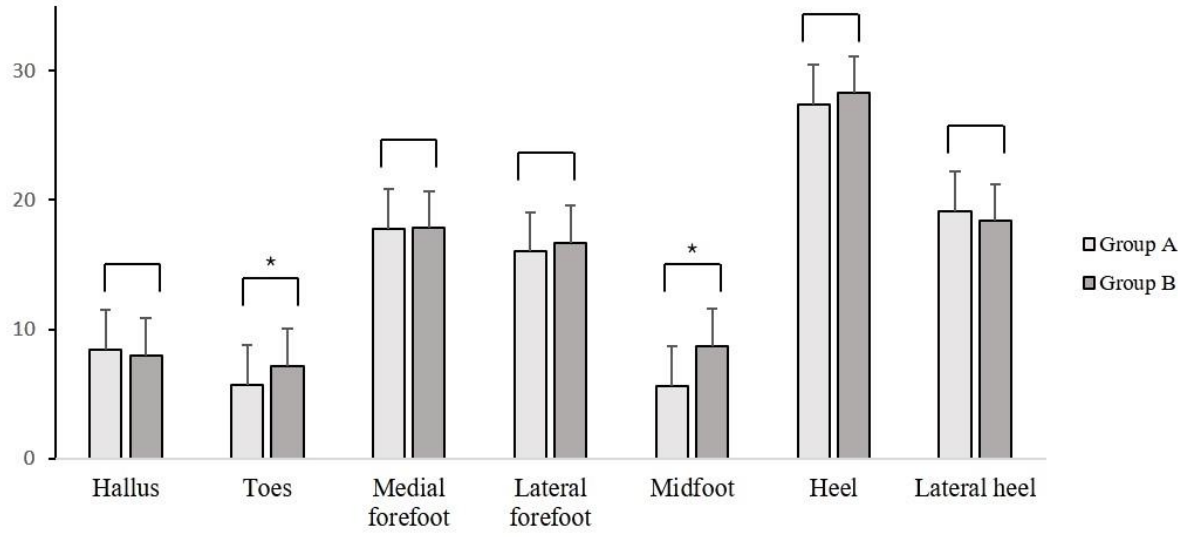


Figure 2: *Peak Pressure (PP) and Contact Area (CA). Error Bars Represent One Standard Deviation*

In the maximum peak EMG comparison, it shows a significant difference in Medical Gastrocnemius (GM), and the group A show higher values than the group B ($p<.05$) ($p<.001$) (Table 4).

Table 4: *Muscle Activation Comparison between the Women with High Heeled Habituation and the Women with Low Heeled Habituation*

Variables		**Group A[a]**	**Group B[b]**	**t**	**p**
TA	RMS EMG (uV)	6.07±3.22	7.04±3.23	-.906	.371
	Maximum Peak EMG (uV)	329.84±146.42	339.76±169.95	-.188	.852
RF	RMS EMG (uV)	8.10±7.02	6.87±5.65	.573	.571
	Maximum Peak EMG (uV)	260.80±182.39	274.99±189.85	-.229	.821
GM	RMS EMG (uV)	9.96±3.21	7.19±4.99	1.998	.054
	Maximum Peak EMG (uV)	487.79±194.26	324.94±130.18	2.918	.006**
GL	RMS EMG (uV)	5.66±3.97	6.38±2.82	-.620	.540
	Maximum Peak EMG (uV)	286.89±207.10	327.06±141.82	-.671	.507
BF	RMS EMG (uV)	2.69±1.74	3.70±2.24	-1.519	.138
	Maximum Peak EMG (uV)	148.56±88.33	202.81±100.61	-1.723	.094
ES	RMS EMG (uV)	2.98±0.73	3.54±2.00	-1.145	.260
	Maximum Peak EMG (uV)	156.26±38.95	193.01±92.77	-1.580	.123

*p<.05, **p<.001
Values are means ± SE
TA, tibialis anterior; RF, Rectus femoris; GM, medial gastrocnemius; GL, lateral gastrocnemius; BF, Biceps Femoris; ES, Thoracic Erector Spinae

From the percentage of maximum voluntary isometric contraction (%MVIC), the group A show significantly higher values of the plantarflexion in GM than the group B (p<.05) (Table 5).

Table 5: *Muscle Activation Comparison (%MVIC) between the Women with High Heeled Habituation and the Women with Low Heeled Habituation*

Variables		Group A[a]	Group B[b]	t	p
TA (%MVIC)	Plantarflexion	2.98±1.27	4.39±2.93	-1.837	.080
	Dorsiflexion	0.56±0.48	0.96±5.20	-1.590	.121
GM (%MVIC)	Plantarflexion	12.57±10.49	6.92±4.80	2.080	.047*
	Dorsiflexion	2.90±2.11	4.06±0.99	-1.323	.195
GL (%MVIC)	Plantarflexion	2.86±1.18	4.27±3.09	-1.177	.255
	Dorsiflexion	6.52±4.63	7.16±4.90	-.402	.690

*p<.05, **p<.001
Values are means ± SE

The static balance shows a significant difference in case of eyes open (EO). As the shorter COP implies a better balance ability, the group A show significantly higher COP than the group B.

Table 6: *Balance Ability Comparison between the Women with High Heeled Habituation and the Women with Low Heeled Habituation*

Variables		Group A[a]	Group B[b]	t	p
Static balance (COP)	EO	110.51±23.78	177.48±136.96	-1.450	0.016*
	EC	141.74±44.07	120.23±41.69	-0.759	0.152

*p<.05
Values are means ± SE
EO, eye opening; EC, eye close; COP, center of pressure

4. Discussion

In modern society, the high heeled shoes that women prefer has emphasized a feature pursuing an individuality and aesthetic beauty than a functional feature of shoes to protect

feet and support walking. Although it has been already reported that the high heeled shoes cause various functional problems and damages to the musculoskeletal system, this study comprehensively compares and analyzes differences in a level of the biomechanical characteristics between the two groups of the women with high heeled habituation (higher than 6cm) and women with low heeled habituation (lower than 3cm) in order to examine biomechanical changes caused by wearing high heeled shoes for long time.

The results of this study say that form the PP comparison between the women with high heeled habituation and women with low heeled habituation, the low heeled shoe user show significantly higher values of PPs in lateral forefoot and midfoot areas, and wider contact areas in toes and midfoot than the women with high heeled habituation for the contact area. From the maximum peak EMG the women with high heeled habituation show significantly higher values in GM than the women with low heeled habituation. In the comparison of %MVIC between the two groups, the women with high heeled habituation show significantly higher values of the plantar flexion in GM the low heeled shoe user. For the static balance, the women with high heeled habituation show significantly greater values than the women with low heeled habituation with eyes open. In other words, the high heeled users show higher values in the maximum peak EMG, plantar flexion of GM and have a better static balance ability. The women with low heeled habituation show higher values in the Lateral forefoot and midfoot areas from the PP comparison, and wider contact areas in the toes and midfoot areas.

It has been reported that increase of the PP promotes degeneration of ankle joints, and it is a direct cause which induces arthritis and pains. Small contact areas increase instability and momentum, and cause ankle sprains and falls (Putti et al., 2007; Jung et al., 2012). Especially, it is said that compensatory actions occur in knee joints and/or hip joints in order to compensate for reduced stability in ankles while walking with waring high heeled shoes (Lee et al., 2010). Therefore, if the women with low heeled habituation wear high heeled shoes that they don't usually habituate to wear, they are much more exposed to such negative problems, and in particular, it was shown that a phenomenon where a weight is born on a front side of a foot including toes noticeably comes up.

The existing analysis research results of the muscle activation show the same results as the research (Gefen et al., 2000) by indicating imbalance of medial gastrocnemius (GM) activities in the EMG measurement of the women with high heeled habituation, and activities of ankles, soleus muscle and rectus femoris (RF) are increased according to the height of heels. This is because a side incline tendency focused on a pressure of the women with high

heeled habituation causes imbalanced activities by increasing fatigues in GL and GM (Moon & Kim, 2011).

Also, it accords with the research of Lee et al. which says that prolonged wearing time of high heeled shoes increases the muscle activation of GM and GL which are flexor muscles of the sole. As a result, it causes imbalance of muscles, disk, degenerative arthritis, swollen and benumbed feet, body shape change, etc. (Lee et al., 2010). It also accords with the research which says that the study conducted with men who habituate to low heeled shoes shows there is no change to the percentage of maximum muscle activation of anterior tibialis (AT) as a result of a measurement measuring electromyogram sings of AT and gastrocnemius while walking with wearing high heeled shoes, but the percentage of maximum muscle activation of gastrocnemius is reduced (Shin et al., 2012).

The women with high heeled habituation show a higher static balance ability, and it is accords with results of the research conducted by Lee and others which says that women who habituate to waring high heeled shoes feel less instability while wearing high heeled shoes and the research of Snow and Williams which shows that as the center of gravity moves forward, it gives a positive influence to the balance adjustment and causes the kinetic adaptation phenomenon (Lee et al., 1990; Snow & Williams, 1994).

This study can verify significant differences in the biomechanical adaptation such as the center of gravity, muscle activation, balance, etc. between the women with high heeled habituation and women with low heeled habituation. As there is a challenge to generalize results of this study because the subjects of the study consist of women in early 20s, it is necessary to conduct a further study expanded to various age groups, type of heels and group of men who habituate to wearing high heeled shoes. As there is a challenge to generalize results of this study because the subjects of the study consist of women in early 20s, it is necessary to conduct a further study expanded to various age groups, type of heels and group of men who habituate to wearing high heeled shoes.

5. Conclusions

In order to examine biomechanical changes caused by wearing high heeled shoes for long time, this study comprehensively performed the comparison analysis to check if there is a difference in a level of the biomechanical characteristics through surface EMG, foot pressure analysis, static dynamic balance measurement to compare functional variables between the women with high heeled habituation (higher than 6cm) and women with low heeled habituation (lower than 3cm). The results of this study say that form the PP comparison between the women with high heeled habituation and women with low heeled

habituation, the low heeled shoe user show significantly higher values of PPs in lateral forefoot and midfoot areas, and wider contact areas in toes and midfoot than the women with high heeled habituation for the contact area. From the maximum peak EMG the women with high heeled habituation show significantly higher values in GM than the women with low heeled habituation. In the comparison of MVIC between the two groups, the women with high heeled habituation show significantly higher values of the plantarflexion in GM the low heeled shoe user. For the static balance, the women with high heeled habituation show significantly greater values than the women with low heeled habituation with eyes open. In conclusion, this study can verify significant differences in the biomechanical adaptation such as the center of gravity, muscle activation, balance, etc. between the women with high heeled habituation and women with low heeled habituation. It is necessary to conduct a further study expanded to various age groups, type of heels and group of men who habituate to wearing high heeled shoes.

6. Abbreviations

HH, high heels; %MVIC, percentage of maximum voluntary isometric contraction; EMG, electromyography; COP, center of pressure; EO, eye opening; EC, eye close; COP, center of pressure; TA, tibialis anterior; RF, Rectus femoris; GM, medial gastrocnemius; GL, lateral gastrocnemius; BF, Biceps Femoris; ES, Thoracic Erector Spinae; CA, contact area; PP, peak pressure; SE, standard error

7. Conflicting Interests

The author declares that he has no competing interests.

8. Consent for Publication

No applicable.

9. Ethics Approval and Consent to Participate

I obtained an exemption from the Institutional Review Board at the Semyung University (SMU-2018-09-004).

10. Funding

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2018RICIB5083000). ※ MSIT: Ministry of Science and ICT.

11. Availability of Data and Materials

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

12. Author's Contributions

YJC has solely carried out the data analysis, wrote and approved the manuscript.

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