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Neuromuscular Responses to Acute Whole Body Vibration in Healthy Young Men

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Abstract The purpose of this study was to investigate the acute effects of whole body vibration stimulus on neuromuscular performances in healthy male students. Twenty healthy students (mean age 19.7 ± 0.5 years) were recruited for this study. They were randomly divided into two groups of 10 subjects: whole body vibration (WBV) group and control group. The intervention consisted of standing on a vibrating (for the WBV group) or non-vibrating (for the control group) platform in a semi-squat posture for 3 minutes. Vibration was produced at a frequency of 20 Hz, peak amplitude of 3 mm and frequency-weighted acceleration of 21.3 m/s^2 rms. Statistical analysis with two-way repeated measures ANOVA revealed that the reaction time decreased significantly in both groups ($P < 0.05$) and the absolute angular error value at 30 degree knee flexion decreased significantly only in the WBV group ($P < 0.05$). The findings indicate that the acute WBV stimulus used in this study is not adequate to induce any significant improvement in neuromuscular responses among young healthy men. To reveal the training effects of WBV, future research works should be conducted among both young and elderly subjects with long-term or chronic exposure to WBV within a safe exposure limit.

Key words: whole-body vibration, neuromuscular response, cardiovascular response, acute effect, healthy young men

Introduction

Generally, vibration stimulus has been suggested to induce various effects on human body. Local mechanical vibration has been used by physiotherapists as treatment options for relief of pain, to relax tense muscles and to increase blood flow. The treatment or training intervention using whole body vibration (WBV) device has recently become increasingly popular.

Numerous previous studies with application of WBV training have shown positive health effects; for example, improvements in walking ability or postural balance after WBV intervention in elderly people,[1,2] increase in vertical jump height and counter movement jump height in young female subjects,[3,4] and improvements in proprioception and postural stability of patients with anterior cruciate ligament reconstruction.[5] Rehn et al.[6] demonstrated that long-term WBV exercise can have positive effects on the leg muscular performance among untrained people and elderly women.

In the literature, both short-term and long-term of effects WBV training on human health have been reported. Several previous studies suggested that regular long-term exposure to WBV may represent a health risk and can cause low back pain, sciatic pain, and degenerative changes in the spinal system including lumbar intervertebral disc disorders.[7-9] According to the International standard ISO 2631-1,[10] subjects should not be exposed to high levels of vibration during experiments involving human exposure to vibration and shock. To control harmful WBV exposure in the industry, the EU Directive 2002/44/EU[11] mandates that people regularly exposed to whole-body vibration, an A(8) value of 1.15 m/s^2 rms should not be exceeded. A(8) is calculated as: $A(8)= a \times \sqrt{(t/8)}$ m/s^2 rms, where a is the frequency-weighted acceleration and t is the exposure duration in hours. However, this issue has not been mentioned by the previous researchers investigating health effects from WBV exercise. Furthermore, though previous studies demonstrated beneficial effects of WBV training on human health, there is a lack of clear evidence for the effects of acute WBV exercise on neuromuscular performances in healthy young men.

Therefore, the purpose of the current study was to investigate the acute effects of exposure to WBV on neuromuscular performances in young healthy adult male subjects, taking into consideration the recommendations of the international standard. Additionally, cardiovascular responses were also measured to investigate the physiological stability of the subjects from such exposure.

Methods

Subjects

A matched case-control intervention study was designed. Twenty young healthy male students (mean age ± SD, 19.7 ± 0.5 years; mean height ± SD, 172.7 ± 4.3 cm; mean weight ± SD, 65.0 ± 5.8 kg) from a school of physical therapy and occupational therapy were recruited for this study and assigned to 2 groups of 10 subjects each (WBV group and control group). They did not have any musculoskeletal or neurological disorders, cardiovascular disease, kidney stones or diabetes mellitus.

After explanation of the study procedures, the participants provided written informed consent to participate in this study. Also, before enrollment in the study, the subjects answered to a questionnaire about their dominant leg (side of kicking a ball) and health status. The baseline data for both groups are shown in Table 1 with statistical comparisons between the groups.

All experimental procedures used in this study were approved by the ethics committee of the Kyushu Rosai Hospital.

Measurement procedure and condition

Participants were exposed to intervention on 3 different sessions each separated by an equal period of 1 week. The 3 sessions were attended by the WBV group and control group on different days. An interval of 1 week between interventions was used to minimize any effects of previous exposure on the intervention or the measurement.

The measurements and/or tests were performed before (pre-intervention) and after intervention (post-intervention) in all participants. Blood pressure, heart rate and reaction time were measured on the 1st session. On the 2nd session, knee joint reposition test was performed. And on the 3rd session, rectus femoris muscle activity was measured by surface EMG during maximum isometric knee extension; also maximum isometric knee extensor torque was measured during the same session. The measurements/tests were performed on different sessions to remove any potential effects of previous measurements/tests on the subsequent measurements/tests (Fig. 1).

All experiments were performed in a temperature-controlled experiment room with an ambient temperature of 21 ± 2 ℃.

Measurement of blood pressure and heart rate

Systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate (HR) were measured with a sphygmomanometer BP-8800 (COLIN co., JAPAN). The manchette of sphygmomanometer was wrapped around the left upper arm of a participant. Before and after intervention, the measurements were performed automatically in standing posture of the participant.

Measurement of static postural balance

The static postural balance was measured

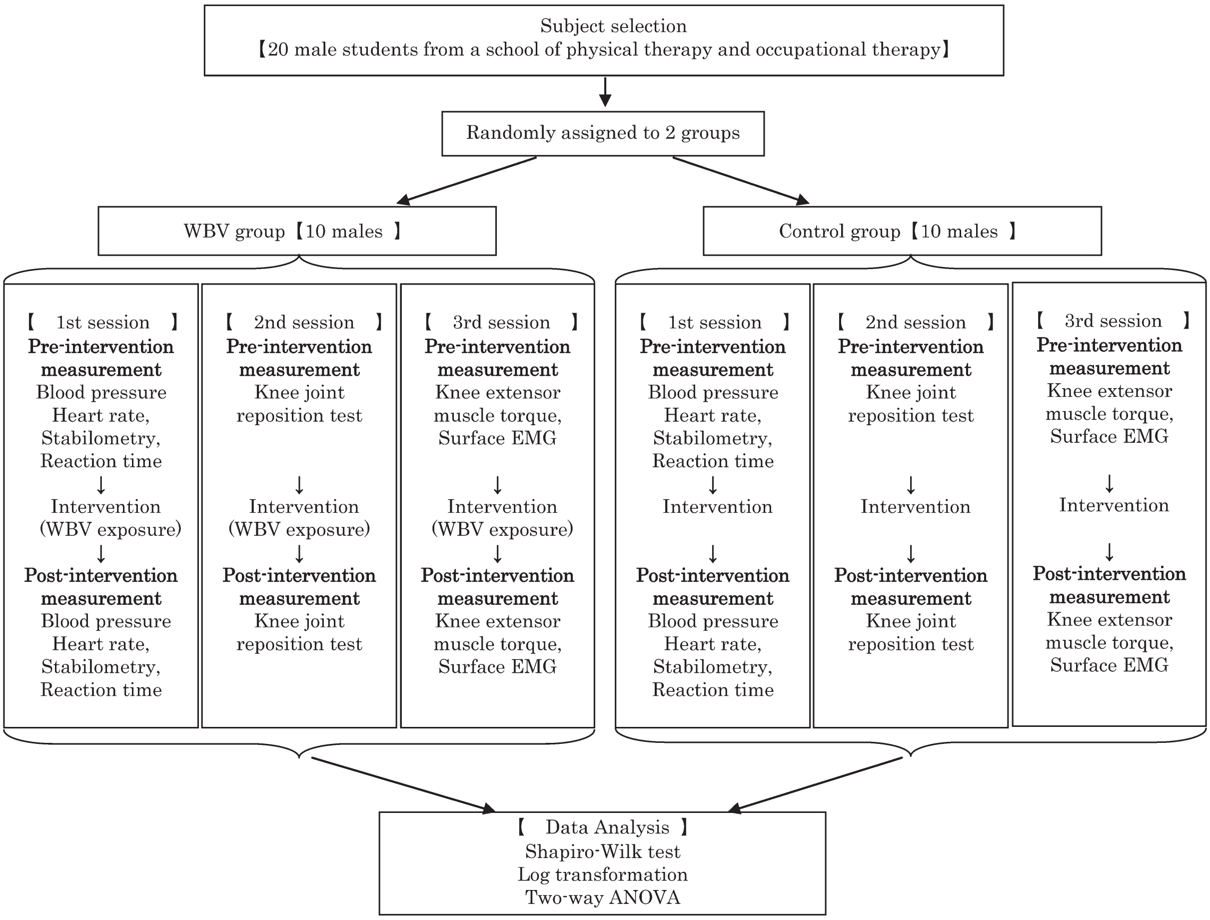

Fig. 1 Flow diagram of the study.

by the stabilometer UM-BAR2 (UMC co., Ltd., JAPAN). The standardized procedure for stabilometry test recommended by the Japan Society for Equilibrium Research[12] was followed.

The subjects stood on a triangular strain gauge platform, with their shoes off and upper limbs hanging loosely by the side. Then they looked forward pointing at a marker positioned at eye level at a distance of 2 m. Under this condition, the subjects were asked to keep a static posture for 60 sec with their eyes open, and subsequently, next 60 sec with their eyes closed. The sampling frequency for recording was 20 Hz. Two parameters were calculated in this study: locus length (L) and periphery area (A) of center of foot pressure.

Measurement of reaction time

The measurement of reaction time as an agility test was performed using flash light equipment and the connected pressure sensing mat T.K.K.5408 (TAKEI co., Ltd., JAPAN).

The subject stood on the mat with their knees slightly bent without shoes and was asked to jump upright as quickly as possible in response to the flash of a light set at a distance of 2 m in front of the subject. The lapse of time between the flash signal and the withdrawal of foot pressure from the sensor mat was recorded. After practices twice, continuous 5 measurements were taken. Then, the average for 5 measurements was calculated for each subject. Pre and post-intervention measurements of reaction time were recorded after the above-mentioned measurements performed on the same session.

The knee joint reposition test

The knee joint reposition test was performed by Biodex 3 Isokinetic Dynamometer (Biodex Corp, NY, USA), according to the method mentioned by Moezy et al.[5] The electrogoniometer of this dynamometer is sensitive to 1 degree increments. By this test, the ability of a seated subject to reproduce actively an angle at which the joint was placed before is evaluated.

In this experiment, the subject sat on the seat with the popliteal fossa positioned outside of the Biodex chair. The subjects were blindfolded. An air splint was kept around the dominant leg of the subject to minimize any cutaneous sensory input during the measurement. Alignment of the axis of the knee of test leg with the axis of the dynamometer was performed; the tibial pad was secured to the shank 3 cm superior to the lateral malleolus.

Then the subject actively moved the knee from the starting angle of 90 degree flexion to the target angle of 60 degree flexion. After reaching the target angle, the leg position was held for 10 sec and then returned to the starting position of 90 degree knee flexion. After an interval of 5 sec, the subject was asked to move the leg and reproduce the target angle actively and press the hand-held stop button after achieving the target angle. Test for the target angle of 30 degree of knee flexion was conducted using the same procedure. Each target angle was measured 3 times at the dominant leg. The average absolute angular error in the test knee of each subject at 60 degree (60AE) and 30 degree flexion (30AE) was calculated.

Measurement of isometric torque and surface EMG

The maximum isometric knee extensor torque of dominant leg was measured on the Biodex system 3 Isokinetic Dynamometer (Biodex Medical, Inc., Shirley, NY, USA).

The subject sat on the seat upright with the axis of the knee aligned with the axis of the dynamometer. To prevent any additional body movement, subject's trunk and thigh were fixed to the chair with seat belts; and the tibial pad was secured to the shank 3 cm superior to the lateral malleolus. Then the subject was asked to perform the maximum isometric voluntary knee extension at 60 degree knee flexion angle held for 15 sec. For normalization, the maximum isometric voluntary knee extension torque value was divided by the body weight of the subject and the resulting value was used in statistical analysis. To obtain subject's maximum effort, the same encouraging recorded voice instructions were played for all subjects.

The EMG activity of the rectus femoris muscle was recorded during the measurement of the knee extensor muscles torque, for 15 sec, by the MyoSystem 1200 and analyzed by the MyoResearch Software (Noraxon U.S.A. Inc., USA). In accordance with the European recommendations for non-invasive assessment of muscle activity by surface EMG (SENIAM project),13 surface Ag-AgCl disposable electrodes of 20 mm diameter were placed in a bipolar lead, at the mid-point of the line between the anterior superior iliac spine and the superior part of the patella. To improve the electrode-skin contact, the contact area of the skin with electrodes was shaved and rubbed with sandpaper carefully.

Electrodes were fixed parallel to muscle-fiber direction, with an inter-electrode (center-to-center) distance of 25 mm. The reference electrode was attached to the right patella. The EMG cables were fastened to prevent movement artifact from swinging cables. A sampling frequency of 1000 Hz was used for the analysis of EMG data.

Vibration intervention

The participants stood on the vibration platform wearing socks, and placed their feet with the 2nd toe and the heel located over line 3 on either side of the platform (distance between feet, 325 mm). They were instructed to maintain a static half squat posture with knee angles at approximately 135 degrees of flexion and with hands holding the handlebar of the equipment.

The vibration frequency was set to 20 Hz with a peak-to-peak displacement of 6 mm. The root mean squared acceleration and frequency-weighted root mean squared acceleration in our study, calculated according to ISO 2631-110 were 33.5 m/s^2 rms and 21.3 m/s^2 rms, respectively. The WBV group subjects were exposed to vibration for a period of 3 min. Hence, A(8) in our study was 1.68 m/s^2 rms. The control group followed the same experimental procedure except that they were not exposed to vibration (0 Hz).

Statistical analysis

All analyses were carried out using IBM SPSS statistics version 19 (IBM, Japan). The Shapiro-Wilk test was used to check for Normal distribution of data. If any variables did not follow the normal distribution, these were used after natural logarithmic transformation of data. Mean and standard deviation (SD) were calculated for all measurement variables. A two-way repeated measures ANOVA was used using time (pre and post intervention) and group (WBV and control) as the independent variables. The level of significance was set at P < 0.05.

Results

The subject characteristics are shown in Table 1. There were no significant differences between the two groups with respect to height or weight.

The post-intervention values of SBP and DBP or HR did not differ significantly from the corresponding pre-intervention values in both WBV and control groups except that DBP decreased significantly in WBV group (Table 2). Also, those values for WBV group were not significantly different from the corresponding control values.

Similarly, static postural balance parameters did not show any difference between pre- and post-intervention measurements of two groups, or between the two groups at pre-intervention or post-intervention (Table 3). In both groups, the post-intervention reaction time was significantly shorter than the corresponding pre-intervention reaction time (P < 0.05); but pre or post-intervention values did not differ significantly between WBV and control groups (Table 3).

The results of knee joint reposition test are shown in Table 4. The absolute angular error at 60 degree flexion was not significant dif-

Table 1 Characteristics of the study participants

	WBV group (N=10) Mean (SD)	Control group (N=10) Mean (SD)	WBV vs Control P value
Body height (cm)	172.6 (3.75)	172.7 (4.99)	0.960
Body weight (kg)	64.0 (5.23)	65.9 (6.40)	0.477

Values represent mean ±SD.

Table 2 Comparison of cardiovascular parameters between WBV and control groups

		WBV (N=10) Mean (SD)	Control (N=10) Mean (SD)
SBP (mmHg)			
	Pre	126.3 (6.5)	125.3 (7.3)
	Post	129.7 (7.7)	128.1 (10.2)
DBP (mmHg)			
	Pre	78.1 (6.0)	73.7 (6.1)
	Post	74.1 (8.5)*	71.9 (5.1)
HR (beats/min)			
	Pre	89.6 (18.6)	92.3 (15.7)
	Post	94.0 (13.0)	95.4 (17.1)

Values represent mean ± SD.
SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate
Pre: measurements before intervention; Post: measurements after intervention
*Significant difference between pre- and post-intervention measurements (P < 0.05).
For statistical analysis, natural logarithmic transformation of data was performed.

Table 3 Comparison of postural balance and reaction time between WBV and control groups

			WBV (N=10) Mean (SD)	Control (N=10) Mean (SD)
Locus length (mm)				
	eye open	Pre	498.5 (75.4)	444.2 (123.9)
		Post	530.2 (120.4)	456.9 (103.8)
	eye close	Pre	757.4 (156.9)	742.5 (287.8)
		Post	709.5 (153.9)	666.9 (188.6)
Periphery area (mm^2)				
	eye open	Pre	188.0 (44.7)	155.5 (92.5)
		Post	173.2 (74.8)	144.1 (59.3)
	eye close	Pre	243.1 (86.3)	267.2 (153.5)
		Post	249.3 (179.4)	222.1 (106.1)
Reaction time (sec)				
		Pre	0.34 (0.05)	0.37 (0.03)
		Post	0.32 (0.04)*	0.36 (0.03)*

Values represent mean ± SD.
Pre: measurements before intervention; Post: measurements after intervention
*Significant difference between pre- and post-intervention measurements ($P < 0.05$).

Table 4 Comparison of absolute angular error, muscle activity and muscle torque between WBV and control groups

		WBV (N=10) Mean (SD)	Control (N=10) Mean (SD)
60AE (°)			
	Pre	3.03 (1.75)	2.80 (1.44)
	Post	4.73 (2.74)	3.77 (3.46)
30AE (°)			
	Pre	5.53 (2.31)	3.80 (1.31)
	Post	3.83 (2.99)*	3.30 (1.31)
EMG amplitude (μV)			
	Pre	270.8 (169.1)	265.3 (150.3)
	Post	263.0 (141.0)	284.0 (162.0)
Torque/Body weight (Nm/kg)			
	Pre	1.70 (0.34)	1.82 (0.46)
	Post	1.65 (0.33)	1.89 (0.44)

Values represent mean ± SD.
Pre: measurements before intervention; Post: measurements after intervention
Values represent mean ± standard deviation (SD).
60AE: average of absolute angular error at a target angle of 60 degrees in the dominant side knee; 30AE: average of absolute angular error at a target angle of 30 degrees in the dominant side knee. EMG amplitude: average of rectus femoris muscle activity during the maximum isometric contraction for 15 second. Torque / Body weight: average torque per body weight of maximum isometric knee extension for 15 seconds.
*Significant difference between pre- and post-intervention measurements ($P < 0.05$). For statistical analysis, natural logarithmic transformation of data was performed for all the variables except muscle torque.

ferent in any of the groups between pre- and post-intervention measurements or between the groups (at pre- or post-intervention). However, the absolute angular error value at 30 degree flexion for the WBV group at post-intervention decreased significantly from its pre-intervention value; in contrast, the control group did not show such a difference in absolute angular error at 30 degree flexion.

In general, the post-intervention values of surface EMG and isometric torque showed a decreasing pattern in the WBV group and an increasing pattern in the control group. However, the post-intervention values of surface EMG and isometric torque did not differ significantly from the corresponding pre-intervention values in both WBV and control groups. Also, at pre- or post-intervention, the values for WBV group did not differ significantly from the corresponding control values (Table 4).

Discussion

To our knowledge, no previous research work involving human exposure to whole body vibration exercise followed the recommendations of the international standard or the European standard for such exposure. Experimental subjects in some previous studies were exposed to a higher level of WBV than the A(8) value of 1.15 m/s^2 rms recommended in the standards.[14-16] For example, the calculated A(8) values in the study of Rittweger et al.[14] was 6.43 m/s^2 rms, and of de Ruiter et al.[15] or Pollock et al.[16] was 6.52 m/s^2 rms. A(8) in our study was 1.68 m/s^2 rms, which slightly exceeds the suggested value of 1.15 m/s^2 rms. However, the A(8) value used in our study seems to be within a safe exposure limit as our study involved exposure of human subjects on an occasional, rather than a long-term daily basis (ISO 13090-1).[17] Overall, the vibration level used in this study was well tolerable by the participants except that 2 participants in the WBV group reported an itching sensation in the leg immediately after WBV stimulation.

As the blood pressure and HR did not change significantly before and after intervention, it indicated the physiological stability of the subjects with the current level of WBV stimulation. Rittweger et al.[14] also demonstrated that, even if performed to exhaustion (peak acceleration of 147 m/s^2), cardiovascular effects of whole-body vibration exercise are mild.

Various balance tests are used to test for postural control during standing such as Timed Up & Go test, test with Tinetti Balance Scale, or test with Berg Balance Scale, etc. However, the test systems using force platform or strain gauge are particularly useful because of their ability to test balance control more accurately.[18] For Japanese males 20-25 years of age, the average values of L and A were shown to be 710.2 mm (length, open eye) and 970.6 mm (length, closed eye), and 286 mm^2 (area, open eye) and 364 mm^2 (area, closed eye), respectively.[19] The values of L and A obtained in this study are comparable with the standard values, indicating the subjects had comparably stable posture balance.

Torvinen et al.[20] and Mahieu et al.[21] reported no effects on postural balance from WBV training in healthy young people. On the other hand, some studies demonstrated improved postural stability after WBV training among patients with knee ligament injuries[5] or chronic stroke[22] etc. Like the former studies with healthy subjects, in this study also, no significant effect of WBV on static postural balance of young healthy subjects could be revealed.

The reaction time test is an agility test by which a subject's ability to jump quickly in response to a flashing light is evaluated. It depends on several factors including the accuracy of its operation, the processing time of the central nervous system and the threshold of sensory stimulation, nerve conduction velocity, muscle contraction speed etc. The reaction time of the current study participants ranged between 0.338 sec and 0.374 sec which corresponds to average level (0.323～0.377 sec) of the reference standard for Japanese males 20-24 years of age (Japan Industrial Safety & Health Association, 1996).[23] Enhancement in neuromuscular performance should result in a decrease in reaction time. However, Cochrane et al.[24] did not observe any significant difference for agility between WBV and control groups. In this study, a significant decrease in reaction time in both groups indicates that it may have been caused by the improvement in neuromuscular performance or by learning effects from repeated measurements of participants.

In the literature, only a few studies verified the acute effects of WBV stimulation on joint position sense in healthy young people. However, the results of those studies demonstrate that in young healthy subjects, WBV did not affect joint position sense.[16,25] In the current study, joint position sense was evaluated using the absolute angular error value at 30 degree or 60 degree knee flexion; WBV intervention caused a significant decrease in the absolute angular error value at 30 degree knee flexion, but it was not sufficient to induce any change at the target angle of 60 degree. WBV treatment probably influenced proprioceptive feedback mechanisms and led to an improvement in the joint position sense.[26]

Muscle activity induced by the application of WBV was monitored by recording the EMG signal from the muscles. Although our study did not show any significant change in muscle activity or peak isometric torque after exposure to WBV, a decreasing pattern in those values was revealed.

Cardinale and Lim[27] found an increase in EMG activity of vastus lateralis muscle during exposure of subjects to WBV transmitted through a vibrating platform. Krol et al.[28] also reported an increase in vastus lateralis and vastus medialis muscle activities during exposure of subjects to WBV stimulation. In those studies, the researchers measured EMG activity during exposure to WBV, whereas we measured it after exposure to WBV. But, our study results are consistent with the findings of Jordan et al.[29] The authors reported a decrease in voluntary muscle activation of knee extensors and peak isometric torque following WBV. They explained this as a compensatory effect of vibration in a fatigued state. In contrast, enhanced muscle activation and increase in peak isometric observed in some studies may be due the training effect of long-term exposure to WBV. de Ruiter et al.[15] also mentioned that in the short-term, WBV training does not improve muscle activation during maximal isometric knee extensor force production and maximal rate of force rise in healthy untrained students.

Conclusions

In this study, the neuromuscular responses to acute WBV were examined using a vibration acceleration value considered to be within a safe exposure limit. The findings indicate that the exposure to acute WBV within the recommended dose limits by international standards appears to be not adequate to induce any significant improvement in neuromuscular responses among healthy young men. These data may have implications for the researchers in selecting the WBV dose that has potential in enhancing neuromuscular performances in human subjects. Based on the current findings, it seems necessary to investigate the health and safety aspects of a higher dose of WBV than that recommended by the international standards. To investigate the effects of WBV on human health, future research works should be conducted among both young and elderly subjects with long-term or chronic exposure to WBV within a safe exposure limit.

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Conflict of Interest

The authors state no conflict of interest.

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