Postural Movements and Developments of Nystagmus
in Standing Human on the Rotating Table

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抄 録

めまいを生じたとき直立姿勢をとっている人の身体動揺がどのようになるかを調べるため、回転する回転台上で直立している人の姿勢応答を測定した。(1) 回転台上で直立する人の重心は不規則な運動をしており、そのうちの一部の時間は右回りまたは左回りをしながら動揺している。被験者の約80%は回転台の回転方向が逆転すると重心の回転方向も逆転する。(2) 閉眼で回転台上に直立する人は回転台の回転方向が右回りでも左回りでも身体はわずかに前方に傾きながら前後左右の方向にほぼ同じように揺れる。(3) 開眼で回転台上に直立する人は回転台の回転方向が左回りの時は身体が右に、台が右回りの時は身体が左に傾きながら動揺を続ける。(4) 回転台の回転が停止するとき眼振が生じるが、回転台の回転角速度が大きいほど停止時の負の角加速度の絶対値も大きく回転中の被験者の眼振持続時間は長くなった。まためまい感の持続時間も長くなった。(5) 回転台上で直立する被験者が足を握って立つ時、閉じ立つ時、マンの姿勢をとるかによって身体動揺の様式が変わった。頭部と重心のパワースペクトルも異なる分布を示した。マンの姿勢は不安定でパワースペクトルは周波数の大きい成分が増大した。(6) 台の回転数を増すと頭部と重心のパワースペクトルの主成分は高い周波数の方へ移動した。

Abstract

Postural responses of subjects who feel dizzy on a rotating table were observed. The sways of the head and of the body center of gravity were recorded and analyzed by means of their frequency power spectra and their Lissajous' figures. When the rotating direction of the table is reversed, the rotating direction of the body center of gravity of a subject on the table is very likely to be also reversed. As the subject sways standing with eyes open, the center of sway shifts leftward (rightward) with the table rotated clockwise (counter-clockwise), although the center of sway of the subject standing with eyes closed indicates no shift. As the angular velocity of the rotating table is increased, durations of nystagmus and dizziness of the subject get longer. The analysis of power spectra and the Lissajous' figures for the various foot positions shows that power spectra for the Mann's posture, indicating greater instability, was composed much of higher frequency.

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1. Introduction
The postural movements in the state of human standing upright on a still table were investigated by Kapteyn(5) and Tokita et al.(10) The researches were also made of the stimulation on subject standing upright and its effect upon the postural movements. Since such responses as postural movements develop in existence of stimulation, it is convenient to figure out the mechanism of standing upright. Thus, postural responses to several types of stimulations such as horizontal swaying, inclining and seesawing movements of the table were observed.(3),(4),(5)

This article presents some investigations of postural responses induced by rotation of the table which have not been executed before.

2. Methods
Experimental arrangement is shown in Fig.1. Head movements of the antero-posterior (A.P.) directions and of the lateral (right and left: R.L.) directions were measured by the accelerometers attached to a subject's helmet. Sway of the body center of gravity of A.P. and of R.L. directions were measured by a statokinesimeter.

The sway of the head and the center of gravity of the body, E.O.G. (electro-oculography) and respiration were simultaneously recorded with a 6-channel data recorder. Angular velocity and centrifugal acceleration of rotating table were measured by the accelerometer. Characteristics of the rotating table are shown in Table 1.

Table 1 Characteristics of the rotating table

<table>
<thead>
<tr>
<th>Revolution per minute (rpm)</th>
<th>6.5</th>
<th>11.0</th>
<th>15.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular acceleration (starting) (deg/sec²)</td>
<td>5</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Angular acceleration (stopping) (deg/sec²)</td>
<td>-20</td>
<td>-30</td>
<td>-50</td>
</tr>
</tbody>
</table>

![Fig. 1 Experimental arrangement](image1)

A : Accelerometer (head movements)
B : E.O.G. (Electro-oculography)
C : Respiration
D : Accelerometer (centrifugal acceleration)
E : Statokinesimeter (center of gravity)
F : Rotating table

![Fig. 2 The sway of the head and center of gravity in upright standing posture with eyes closed on a counterclockwise rotating table. (15.5 rpm)](image2)
3. Results and consideration

3.1 The sway of the head and the body center of gravity on the rotating table

Fig. 2 indicates the time change of sway of the head and the center of gravity of a subject standing upright on the rotating table. Fig. 2 (a) indicates the time change of centrifugal acceleration at the edge point (50 cm apart from the center of rotation), Fig. 2 (b) the time change of antero-posterior movement of the head, Fig. 2 (c) the time change of its lateral movement, Fig. 2 (d) and (e) are the time change of antero-posterior and lateral movements of the body center of gravity. Fig. 3 indicates the Lissajous's figures of the sway path of the body center of gravity, corresponding to Fig. 2 (d) and (e). The sway paths in each short period of time were shown in Fig. 3 with the sequence of 10 sec before rotation, first single rotation, double rotations of 2nd and 3rd, double rotations of 4th and 5th, …, double rotations of 19th and 20th, final three-quarter rotation, first 10 sec, next 10 sec and another 10 sec with no rotation.

![Fig. 3](image)

Fig. 3 The sway paths of the body center of gravity. Arrows show the direction of sway.

As the rotation of the table starts, the body sway develops, and after some time of steady rotation, the rotating speed is reduced, and eventually stops, when considerable postural movements still remains.

3.1.1 Rotating direction of the table and that of the body center of gravity

The cross-spectra of antero-posterior and lateral movements of the subject standing upright on the rotating table was obtained, and the rotating direction of the body center of gravity was investigated against small frequency intervals explained below.

When phase difference \( \epsilon \) obtained from the Lissajous's figures synthesized with x- and y-axis of each frequency of its power spectra is less than \( \pi \) (0 < \( \epsilon \) < \( \pi \)), the rotating direction of the body center of gravity turns out to be counter-clockwise (CCW), and when phase angle \( \epsilon \) is in the range of 0 > \( \epsilon \) > -\( \pi \), the rotating direction becomes clockwise (CW).

The subjects examined consist of 17 twenty-year old persons in good health (14 males, and 3 females).

When the rotating direction of the table is reversed, and when the rotating direction of the center of gravity is also reversed, we assume the characteristic value takes on 1 for each frequency band, and otherwise 0. The entries in Table 2 is the sum of the characteristic values of each subject whose frequency falls in 0.1 Hz band ranging from 0.1 Hz to 1.0 Hz. The table shows the sum of the characteristic values for the subject with eyes open.

<table>
<thead>
<tr>
<th></th>
<th>Eyes open</th>
<th>7.86±1.99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes closed</td>
<td></td>
<td>8.20±1.08</td>
</tr>
<tr>
<td>Total mean</td>
<td></td>
<td>8.03±1.57</td>
</tr>
</tbody>
</table>

Table 2: The numbers of reversals of rotating direction of the body center of gravity in case of reversing the rotating direction of rotating table.
closed is greater than that of the subject with eyes open, which stands for the dominance of the number of subjects who experienced reversal after reversed rotation. In case of gross average 8.03 (with SD 1.57), more than 80% of subjects experienced reversal.

3.1.2 Rotating direction of the table and the shift of the center of sway

Fig. 4 indicates that as the subject standing with eyes open sways, the center of sway shifts leftward when the table rotates clockwise (CW), as shown in Fig. 4 (a) and rightward when rotates CCW as shown in Fig. 4 (b). On the other hand, Fig. 4 (c) shows that as the center of gravity of the subject standing with eyes closed sways, the center of sway shows no shift for rotations of table in either direction, i.e. CW or CCW.

The reason why the shift of the center of sway appears when the subject stands with eyes open, the room where the table is situated apparently rotates reversely relative to the subject, thus visual stimulation causes the deviation of sway while standing. Center of sway shifts by 1.03cm rightward in case of CCW, and 1.27cm leftward in case of CW. The subjects examined were 15 persons (12 males, 3 females).

![Fig. 4 Sway paths of the body center of gravity in the course of experiments by either clockwise (CW) or counterclockwise (CCW) rotation (15.5 rpm).](image-url)

3.2 Nystagmus and dizziness

Fig. 5 shows the time variations of (a) centrifugal acceleration of rotating table, (b) heart rate, (c) respiration, (d) (e) movements of body center of gravity and (f) nystagmus. As the rotation starts, the respiration rate increases. In the course of speeding up of rotation, pre-rotatory nystagmus

![Fig. 5 Dynamic behaviors of several characteristics during an experiment.](image-url)
occurs, although the nystagmus disappears during steady rotation. In the course of decrease of rotation, and just after end of rotation, postrotatory nystagmus and dizziness occur.

Fig. 6 shows the duration of nystagmus, Fig. 6 (A) and dizziness, Fig. 6 (B) of two subjects, respectively, against rpm.

3.3 Variation of the power spectra due to angular velocity of the table

Fig. 7 indicates that as the rpm is increased, the main frequency range of the power spectra of the movements of the body center of gravity progresses toward higher frequency.

Fig. 8 shows an example of power spectra of movement of the head and the center of gravity of the subject when rpm of the table is 2.5. The power spectrum of the head movement extends toward higher frequency, when compared with that of the center of gravity.

3.4 The power spectra and the Lissajous's

![Graphs](image-url)

Fig. 7 Power spectra of the antero-posterior postural movements of the body center of gravity.

![Graphs](image-url)

Fig. 8 Power spectra of postural movements of the head and the body center of gravity (2.5 rpm).

(anterior and posterior, A.P., and right and left, R.L.)
figures for the various foot positions.

Fig. 9 shows the Lissajous' figures for the various foot positions, i.e. (A) slightly open stance, (B) close stance and (C) the Mann’s posture. In case of foot position (A), antero-posterior movement prevails, and case (C) shows extreme instability, whose range of sway is the largest. Fig. 10 is the power spectra of the movement of the body center of gravity, corresponding to the foot positions (A), (B) and (C) under rotation of Fig. 9, respectively.

Fig. 11 is the power spectra of movements of the head and the center of gravity of subject standing in Mann’s posture, with the rpm of the table 6.5. The spectra show shifts toward higher frequency, when compared with Fig. 8.

Conclusions

While subjects balanced on the table which rotated 2~20rpm either clockwise (CW) or counter-clockwise (CCW), the sway of the head and of the body center of gravity were recorded and analyzed by means of their frequency power spectra and their Lissajous’ figures.

Results were obtained as follows:

1. When the rotating direction of the table was reversed, the rotating direction of the body center of gravity was also reversed with the probability of 0.80, approximately (for 17 normal subjects). (2) The body center of gravity with eyes closed on the rotating table sways in all directions alike with slight forward tilt, for rotations of the table in either directions. (3) The body center of gravity with eyes
open on the rotating table sways with leftward (rightward) tilt for CW (CCW) rotation of the table. (4) Post rotatory nystagmus recorded when the rotation of the table is ceased. The larger the angular velocity of the rotating table, the longer the duration of nystagmus of the subject on the table, due to the magnitude of the absolute value of negative angular acceleration in the termination of rotation. (5) The manner of postural responses of subjects varies according to the foot positions of (A) slightly open stance (20 cm), (B) close stance and (C) Mann’s posture. Respective power spectra of postural movements of the head and the body center of gravity were shown. Mann’s posture shows postural instability, and the high frequency range of the power spectra is proved to develop. (6) When the rotation of the table is increased, the main frequency range of the power spectra of the movements of head and the body center of gravity progresses toward higher frequency.

The result of these dynamic method induced by rotation differs from the static method without stimulation of rotation. It is suggested that application of this method for seasickness susceptibility may be possible.

The authors would like to express their appreciation to Prof. S. Sakai for his helpful advice and discussions.

References


質疑応答

神田 寛：1. この研究は船酔いにかかりやすい人と、かかり難い人の区別がどの程度できるかを検討するための基礎的 연구と考えて良いでしょうか。
2. 回転台上的座位と立位を比較すると、立位では重心の動揺を記録されていることだと思いますので、これにより平衡機能の検査には非常に限られているのではないかと思います。
3. 船酔いからみた船員適性検査では、座位と立位の比較は、どのようにみられますか。

今枝耕郎：1. 人が直立姿勢をとっている時、前庭、深部感覚、視覚の働きによって絶えず調節されながら身体は微小振動をしています。一方、動揺に対して前庭、視覚が敏感な人ほど船酔いにかかりやすいと考えられます。従って回転台でのめまいを生じている人の直立姿勢の基礎的研究を積み重ねて、船酔いにかかりやすい人とかり難い人の区別ができるかどうかなどを検討したいと思っています。
2. 御説のように回転台上的での身体動揺を調べると台が静止している時の平衡機能の検査は勿論、台が回転している時は動的平衡機能の検査が出来るので、すぐれた検査法であろうと思っております。
3. 昨年の深江丸の研究航海での経験から、眼振の検査は座位で安定した姿勢で行った方が良いと思いますが、視覚の影響などは座位の検査の方が感度が良いようです。大きなめまいを生じた時、立位では倒れてしまうので座位の検査が良いと思いますが、立位の検査では微小なめまいでも、それに対する応答が出やすいのが特徴で、それぞれ一長一短があると思います。