THE TRAINING LOAD ON THE VESTIBULAR APPARATUS AFTER RAPID ROTATIONAL MOVEMENTS

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Using the "somersault simulator" we have studied the influence of rotational movements for the vestibular apparatus. These rotations are important for diving, trampoline and gymnastics. The control of balance were used for operationalisation the vestibular load. Different aspects were studied, the influence for balance control, the importance of the visual control, and the adaptation of the athletes in longer period of training in the somersault simulator. With the specially developed software we analysed the postural sway. We distinguished between a period of regulation and a period of stability. Differences between the data of these periods were demonstrated. After several experiments we transferred our experiences with rotational load and balance measurement in a test for age-group divers with positive response from the practitioners.

KEY WORDS: somersault rotation, control of balance, posturography, vestibular apparatus, dynamometric measurement, diving

INTRODUCTION: In sport, especially in diving, artistic gymnastics, and trampoline rapid rotations around the transverse axis are an important performance-limiting factor. The velocity of these rotations have grown up in the last years. The somersault velocity for example in diving is about 1300 deg/s (4½ forward somersault), and in gymnastics about 1200 deg/s (handspring and double salto forward on vault). Fast rotational movements induce load on the vestibular apparatus. The function of the vestibular apparatus is to record acceleration and to control balance. One criterion to perform exactly in diving or gymnastics is that athletes acquire a habit of fast rotational movements. To do an excellent entry into the water or an exact landing in gymnastics, athletes have to adapt to high speed rotations (Gundlach, 1985). Training, we assume, has positive effects on the adaptation of the vestibular apparatus by fast rotations. There is an invention called "somersault simulator" at the Institute for Applied Training Science in Leipzig, an apparatus to sit in and make rapid rotations (Figure 1). Especially young divers use this training apparatus, to get experience of high quantity rotations.

Figure 1 - Subject in the somersault simulator.

The following hypotheses should be examined:

1. The postural sway in the forward and backward direction (sagittal plane) is higher than the left and right direction (frontal plane) in the pre-test.
2. There will be an increase in postural sway after the rotations, in all components (from pre- to post-test).
3. But in the post-test, the increase in postural sway will be in forward and backward direction higher than in left and right direction.

METHODS: An investigation, with the three experiments, was carried out to study the vestibular load. The operationalisation of the balance of control was carried out as a function of force measurement. The especially designed arrangement includes the "somersault simulator", a diode lamp to test visual orientation in space (another part of the study with the somersault simulator), computer-based measurement system, incorporating a measuring instrument for angular velocity and a force plate (Kistler) for posturographic tests (Figure 2).

The force components F_x, F_y, F_z and the moment components M_x, M_y were recorded in this investigation. On the basis of these data the centre of pressure (CP) was calculated to operationalise the vestibular load with the parameter a_x and a_y. The equations (Rohrbach, 1967) are:

$$a_x = \frac{-M_y + F_x * a_z}{F_z} \qquad (1)$$

$$a_y = \frac{M_x + F_y * a_z}{F_z} \qquad (2)$$

where: a_z is the space between the measure plane and the platform plane.

In a differentiated analysis based on a pre-test versus post-test design, the vestibular adaptation to angular velocity of 400-700 deg/s was studied through posturographic methods. All experiments begin with a pre-test on the platform without any load. After a high quantity (10 or 15 rotations) of tucked passive somersaults in the "somersault simulator" the athlete had to go as quickly as possible to the platform for the post-test.

Subjects of different ages and different performance levels took part in a series of experiments (first experiment with youths: 13-15 years old female and male divers; second experiment with adults: female and male sport students; third experiment with children: 10-11 years old divers). Different rotational movements (2x 1 ½; 2x 2 ½; 2x 3 ½ somersault backwards) with an orientation task (to test visual perception) around the transverse axle should be performed. After the orientation task, subjects (Ss) had to perform 15 somersaults backwards. Then the athletes had to go to the platform and remain standing 10 seconds.

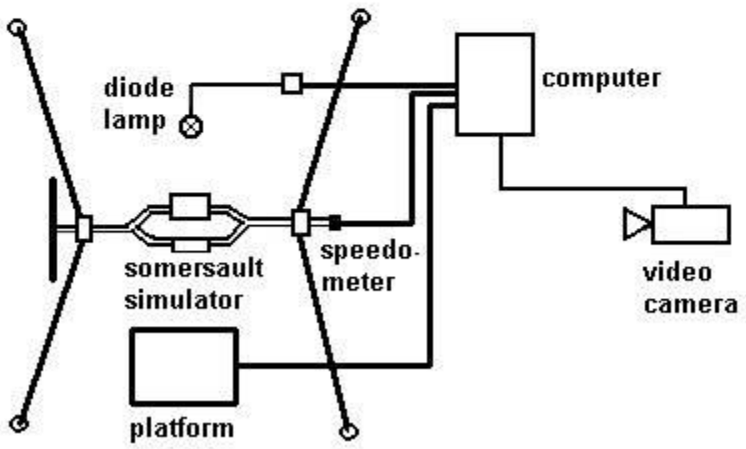

Figure 2 - Schematic of the somersault simulator.

In the second experiment 33 sport students had to perform only the second part of the experiment in the somersault simulator (no competition exercise and orientation tasks). They do only the rotational load of 10 backward or forward somersaults. The main interest of the experiment was to show the influence of visual control in balance. To test the influence of visual control on balance, Ss were instructed to remain standing 60 seconds on the platform with open eyes. After a time interval the students had to do the same rotational load and remain standing on the platform without visual control (closed eyes).

The third experiment was developed to test the adaptation to the rotation load. Over a period about three months Ss had to come twice weekly for training in the somersault simulator. The aim was to examine the adaptation of visual orientation and control of balance over a longer time period. The time of remain standing was 30 seconds in this experiment.

To analyse the data a special software had to be developed on the basis of object oriented programming using the software HP VEE 5.0. Based on the developed program the data listing was divided in three periods. A period of landing (only to get the time which athletes need from the somersault simulator to the platform), a period of regulation and the period of stability (Figure 3). To diagnose the period of landing, we use the force-curve of the component F_z. To divide the period of regulation and the period of stability we use the

alteration of the centre of pressure (calculated with a_x and a_y). If the alteration of the CP located on the same level than in the pre-test the athlete was in the period of stability.
For statistical analysis we used software package SPSS for Windows 8.0. T-test, the analysis of variance, and correlation analysis have been carried out.

RESULTS AND DISCUSSION: To prove the validity of the software the period of stability in pre- and post-test had to be compared. There was no statistical difference between the two data.
In the first experiment we have proved two of our three hypotheses. There was no significant difference between the components of force (F_x, F_y) in the pre-test of the first experiment (youth divers). The expectation that the oscillation increase significantly from pre-test to post-test was confirmed. The increase of the oscillation was in forward and backward (F_x, a_x) direction higher than in left and right direction (F_y, a_y). The average force-data were 6.1 N in sagittal plane (F_x) and 4.8 N in frontal plane (F_y).

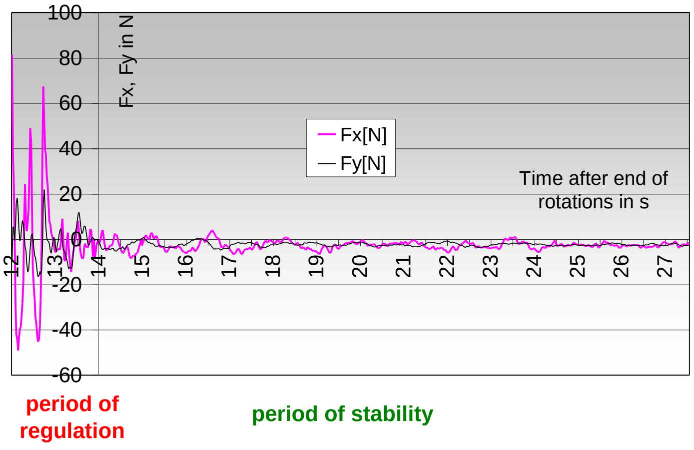

Figure 3 - Example of a force-time curve (F_x, F_y) after 10 rotations in the simulator.

In the second experiment, we used our own software to analyse the data. We compared the components in the period of regulation and the period of stability (table 1). The results were:
1. There are significant differences between the data a_x and a_y for the CP in both periods.
2. For the force data we had found only differences in the regulation period. These results were equal to the first experiment.

The hypotheses 2 and 3 were proved and hypothesis 1 is only proved for die alteration of CP and not for the forces (F_x, F_y).

Table 1 Average Data for Experiment with Sport Students, N=57, Sampling Rate 0.02 s

period	F_x [N]	F_y [N]	a_x [cm]	a_y [cm]
regulation	15.60	12.10	0.820	0.410
stability	2.35	2.49	0.064	0.023

For sport students the average time to reach the period of stability was 13,7 seconds after the end of the rotation load.
If we compare the results of the experiments on the platform with and without visual control (open and closed eyes) we found interesting results (Table 2):
1. In the period of regulation there was only a significant difference in duration of this period.
2. The data for the components a_x, a_y, F_x and F_y in the period of regulation showed that there was no difference between the postural sway with and without visual control.
3. Like other authors (Hufschmidt et al. 1980; Straube, 1996), we measured significant differences in the components a_x, a_y and F_x in the period of stability. Visual control had an important function for remain standing.

We assume that the balance control is strongly disturbed by the rotational load. The influence of visual control is less than the influence of the rotations in the period of regulation.

Table 2 T-test for Depended Measures (Student Experiment with/without Visual Control)

Period	Component	eyes open	eyes closed	T	Sig. (2-tail)	
Regulation	Time interval [s]	2.655	4.386	-2.213	0.036	*
	a_x [cm]	0.862	0.754	1.108	0.278	
	a_y [cm]	0.417	0.397	0.322	0.750	
	F_x [N]	15.436	15.242	0.135	0.893	
	F_y [N]	12.391	11.323	0.567	0.576	
Stability	a_x [cm]	0.047	0.083	-4.906	0.000	*
	a_y [cm]	0.018	0.027	-4.223	0.000	*
	F_x [N]	2.151	2.455	-2.362	0.026	*
	F_y [N]	2.539	2.368	1.168	0.254	

Note: Degrees of freedom = 25 * significant difference ($p < 0.05$)

CONCLUSION: Altogether we can report, the rotational load had a significant effect on the control of balance. This is to explain by the perceived exertion of the vestibular apparatus. A period of regulation of the balance was significantly to differ from a period of stability. But these effects were not measurable over a long period. The higher oscillation in sagittal plane is comparable to the rotation around transversal axis.

There was a first practical test for our system in a competition for the best age-group divers all over Germany. The test of visual orientation and the test of balance control after fast rotational movements were carried out. The results will help the national age-group coaches in their work with the young divers.

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