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THE INFLUENCE OF HYPO KINESIS AND FREQUENCY STRAIN OF A CAR RIDE ON MECHANICAL FUNCTIONS OF AXIAL SYSTEM CHANGES

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ABSTRACT

In our measurements, we used TVS method to detect mechanical changes of axial system. These mechanical changes can be base for discomfort feeling during monotonous driving in the car.
The TVS method is based on the use of consequent application of continuously changing harmonic stimuli, which periodically differ between 5 Hz and 160 Hz, to the vertebrae C7 and L5. This wave is carried through the axial system and its acceleration on the spinous processes between C7 and S1 is scanned with the help of accelerometric sensors. According to the measured data, it is possible to identify changes of the mechanical properties of the human spine before and after applying hypo kinesis and frequency loading by the car ride.

The research results proved the fact, that the TVS method is suitable for detection of the mechanical changes of axial system. It was also proved that changes caused by a monotonic and frequency loading influence the way of waves transfer through the axial system of the observed participants.

From our data results, that we can compare the subjects more intraindividual than interindividual. We found out that healthy and flexible spine oscillates like elastic bar. It is able to absorb more mechanical energy with higher elasticity and the spinal joints are more flexible. The resonant frequency of the healthy and flexible spine lies between 40 and 60 Hz or higher. In most of the cases we found higher damping and lower transmission of the vibrations after the loading. By some of the subjects we can find different reaction in thoracic and lumbar spine to the loading.

Keywords: Vibrations, hypo kinesis, frequency load, axial system, mechanical properties, vibrations transmission

INTRODUCTION

Monotonous static strain during the car ride together with vibrations from the roadside causes feelings of discomfort after a certain time. Ravnik (2008) found out, that feelings of discomfort when driving a car appeared in 77.8% in musculoskeletal system. Discomforts mostly manifested in the area of a spinal column (72.1%). According to him, the feeling of discomfort appears during the first hour of driving.

Thiffault (2003) made a study with 56 drivers, who drove for 40 minutes on a simulator under two different conditions. First time they drove with the repetitive and monotonous roadside stimuli and second time with visual stimuli disrupting the monotony. In his study they recognized signs of driver's fatigue during the first 20–25 minutes. To evaluate the impact of monotony of the roadside they used steering wheal analysis (SWA). During simulation tests, the location and speed of the vehicle are recorded. A potentiometer attached to the steering column allows detailed recordings of steering wheel movements (SWM).

According to Larue (2010), monotony of the roadside and roadside surroundings can lead to a decrease of a safe driving. According to Ravnik (2008), feeling of discomfort is a provable indicator of musculoskeletal problems, which are dependent on soft tissues strain and local chemical changes.

The work of Johnson (2001) brings us views on why discomfort and pain in the lower back occur due to the increased strain in lower back caused by a long term sitting in the car. His computations show, that even by low level of seat vibrations typical for the car ride (0.5 m/s^2 mean acceleration), the energy absorbed by lumbar spine is close to a power consumption of a small pocket torch. By his calculation is the work (displacement × force) performed by lumbar spine or absorbed energy 0.40 J/cycle = 1.8 J/s = 1.8 W. The effect can cumulate in the form of deforming energy and reach dangerous levels after years of using a car, even by low momentary levels. That is caused by normally slow energy dissipation by biologic materials, and location of the effect to the lower lumbar vertebrae.

Sandover (1983) also shows that failure due to fatigue can appear in lumbar spine. A failure of the intervertebral disc can also appear due to fatigue caused by a vibrational strain of driving a car. That similar fatigue is also found in metals due to their cyclic strain.

PURPOSE

In our pilot study we used TVS (transfer vibrations through spine) method to detect mechanical changes of axial system. These mechanical changes can be the reason for discomfort during a monotonous car drive. The TVS (transfer vibrations through spine) method was proved on a mechanical model of spine from wood and silicone, which has similar shape, dimensions, and Young's modulus as a human spine (Kloučková, 2011). The course of detected data was also solved as damping of harmonic oscillator by external force (Maršík, 2010).

METHODS

TVS method (transfer vibration through spine)

The TVS method is based on a continuous change of harmonic stimuli, which periodically differs between 20 Hz and 160 Hz follow. The frequency is changing continuously, so that the subject doesn't get used to the specific frequency, and the vibrations don't harm the body. Harmonic stimuli are applied on C7 and L5 vertebra. A vibrator carries out the excitation. The contact between vibrator and spinous processes of excited vertebra was provided by sufficient contact pressure of vibrator, which was measured and differs around 3.5 N.

The wave is carried through the axial system and its acceleration on each spinous processus between C7 and S1 is scanned with the help of the accelerometric sensors. It is expected that the wave transfer speed and its loss while detecting the responses of the human spine to the stimuli is dependent on the characteristics of a tissue, which the wave passes through. The mechanical tissue changes are retroactively characterized by a speed and other characteristics of the wave transmission.

Organization of experiment and subjects

The subjects lie on anti-decubitus mattress with muscles maximum relaxed during the experiment. This position is different from the driving position. On the other hand we could eliminate oscillations of other body parts, especially upper and lower extremities and head, which could devaluate measured signal. By this position, we also eliminate different body posture during measurement.

The whole experiment had different phases. During the first phase the physiotherapist made kinesiology tests with the subjects, tests of mental speed and examination of trigger points (in muscles of neck, back and pelvis). In the second phase the measurement by TVS method before the car ride was made. In the third phase the subjects was driving a car. After the car ride, the kinesiology tests, tests of attention, examination of trigger points and the measurement by TVS method was made for the second time. The details about subjects and length of the car ride are contained in Table 1.

Table 1. Detailed information about subjects and car ride

Subject	Age (years)	Occupation	Height (cm)	Weight (kg)	Length of car ride (hours)	Date of car ride	Sex
P	21	Student	175	62.5	5	21. 3. 2009	Male
L	22	Student	185	85	5	21. 3. 2009	Male
Š1	23	Student	170	74	2	19. 12. 2009	Male
LI1	20	Student	185	74	2	19. 12. 2009	Male
Š2	23	Student	170	74	5.5	20. 12. 2009	Male
LI2	20	Student	185	74	5.5	20. 12. 2009	Male

RESULTS

The model and results show, that it is possible to detect mechanical changes of axial system, especially spine.

In the following figures of graphs, the excitation frequency is on x axis and ratio of acceleration amplitudes, detected on two chosen vertebrae, on y-axis. As numerator are always data from vertebra more distant from the excited vertebra, and as denominator are always data from vertebra closer to excited vertebra. The ratio on y-axis in our graphs always means transmission of the vibrations between the two chosen vertebrae. If we would inverse the ratio on y-axis, we get damping between the two chosen vertebrae. The higher is the value of amplitude ratio on y-axis, the higher is the transmission of vibrations between the two chosen vertebrae and the lower is damping between the two vertebrae. With TVS method it is possible to observe transmission of vibrations in any section of the thoracic or lumbar spine.

In each graph, there is always transmission of the vibrations between two chosen vertebrae before and after the ride in the car by one subject.

To this chapter we chose some graphs to show, how it is possible to use TVS method for detecting changes in mechanical properties of subject's axial system after the car ride and what tendencies we saw by the subjects.

The transmission of vibrations by excitation from L5 vertebra is higher after the car ride, in the whole graph; the damping is lower (Fig. 1, left). After the car ride there is a different left-right reaction of the body – the resonant peaks are splited. The stiffness is higher after the car ride – all resonant frequencies are shifting to higher values. By excitation from the C7 vertebra in the same segment (Fig. 1, right), the resonant peaks decrease after the car ride, first resonant peak of 22 Hz before the car ride is half after the car ride. Second resonant peak of 33 Hz before the car ride, we don't find after the car ride.

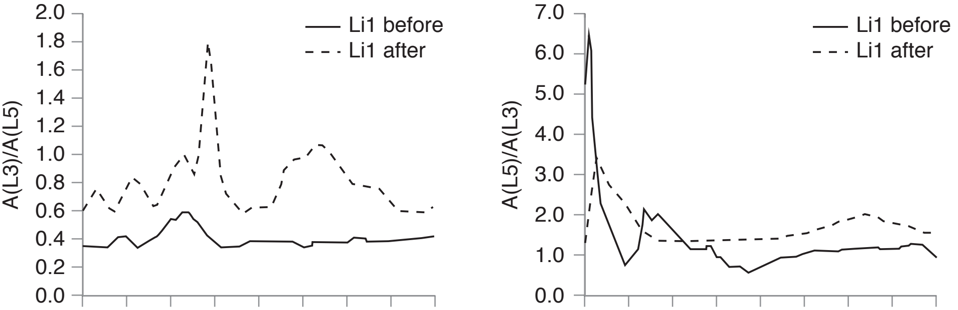

Figure 1. Transmission of the vibrations between L3 and L5 vertebrae before and after the car ride; subject Li1. Left: excitation from the L5 vertebra. Right: excitation from the C7 vertebra.

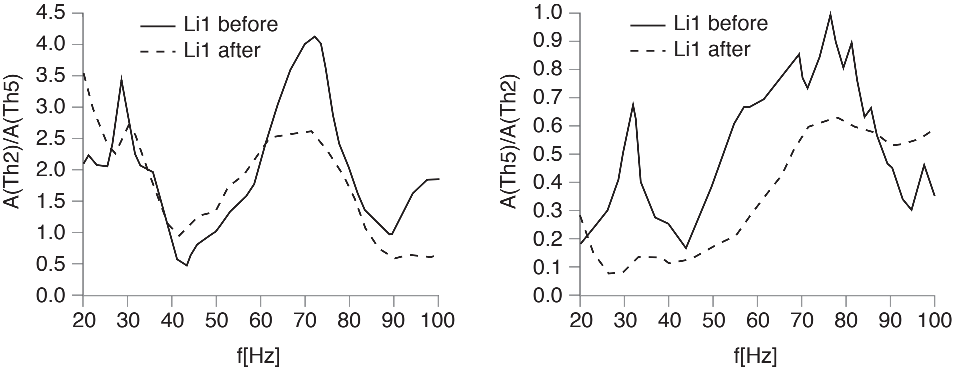

Figure 2. Transmission of the vibrations between Th2 and Th5 vertebrae, before and after the car rides; subject Li1. Left: excitation from the L5 vertebra. Right: excitation from C7 vertebra.

Excitation from L5

On figure 2 left, we can see transmission of the vibrations in thoracic segment, between vertebrae Th2 and Th5. Transmission is preserved in the whole area. Only in the small area of transmission peaks is the transmission after car ride decreased, and damping is increased. That means the opposite respond of thoracic spine to hypokinetic and frequency loading than in the lumbar area of the same subject (Fig. 1, left). First peak of 28 Hz, which occurs before the car ride, moves to 29 Hz after the car ride. Second peak of 70 Hz, which occurs before the car ride, moves to 64 Hz.

Excitation from C7

On the Figure 2 right, we can see almost in the whole graph lower transmission and higher damping after the car ride. That differs from lumbar area, where the transmission after car ride decreases only in the area of first two peaks (Fig. 1, right). The peak moves from 31 Hz before the ride to 32.5 Hz after the ride, it means that stiffness of the subject increases and the damping is higher after the car ride (Fig. 2, right).

By the excitation from L5, the transmission after the ride decreases and the damping increases in the whole frequency area by this subject (Fig. 3, left). We can see two resonant peaks. First moves from 20 Hz before the car ride to 22 Hz after the car ride. The second one moves more significantly from 36 Hz before the car ride to 30 Hz after the car ride. The damping after the car ride is three times higher, which happens to be the highest peak. The right-left symmetry of the body is slightly disrupted – the peaks are bifurcated after the car ride.

The transmission after the car ride was lower, while the damping was higher when excited from C7 (Fig. 3, right). We can see only one important resonant peak by the frequency of 61 Hz before the car ride and one of 62 Hz after the car ride. The resonant frequency moves to the higher frequency after car ride, the stiffness of connection to other vertebrae is higher and the damping is also increased. Damping in the main resonant peak is five times higher after the car ride.

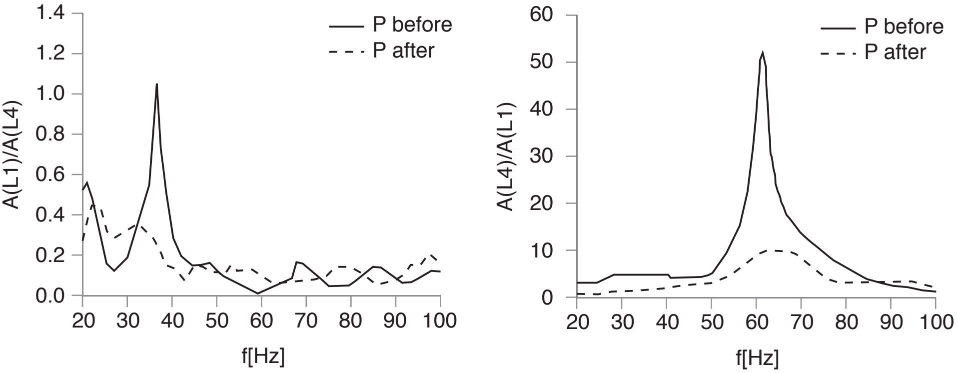

Figure 3. Transmission of the vibrations between L1 and L4 vertebrae before and after 5 hours of the car ride, subject P. Left: excitation from the L5 vertebra. Right: excitation from C7 vertebra.

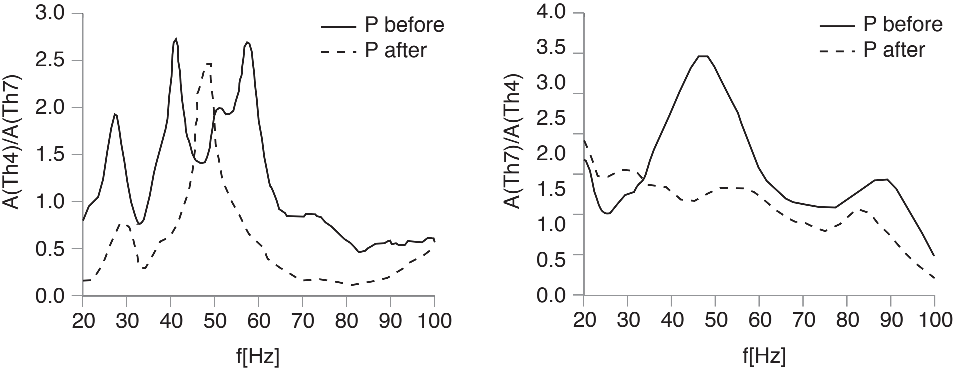

Figure 4. Transmission of the vibrations between Th4 and Th7 vertebrae before and after 5 hours of the car ride, subject P. Left: excitation from the L5 vertebra. Right: excitation from C7 vertebra.

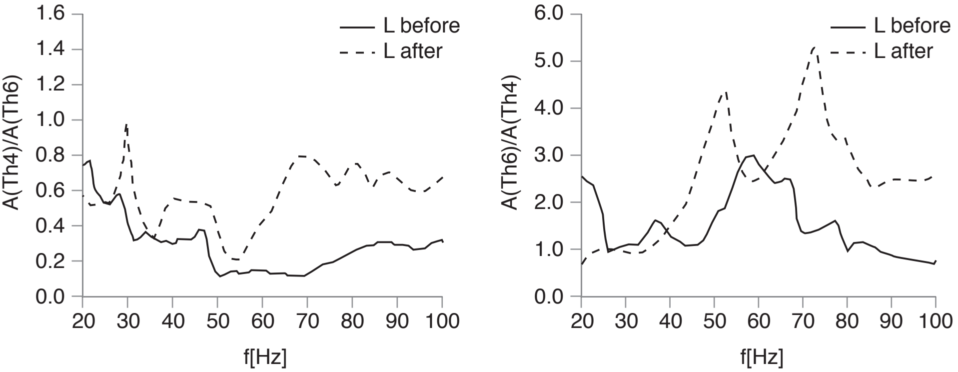

Figure 5. Transmission of the vibrations between Th4 and Th6 vertebrae before and after 5 hours of car ride, subject L. Left: excitation from the L5 vertebra. Right: excitation from C7 vertebra.

This subject shows higher damping and lower transmission between Th4 and Th7 vertebrae (Fig. 4, left and right) after exciting from both C7. At both graphs, the transmission is less than half after the car ride by the main resonant frequency, the resonant frequency moves from 45 Hz before car ride to 51 Hz after the car ride. Thoracic and lumbar segment react both the same by subject P, by excitation from C7 and also by excitation from L5 (Fig. 3 and 4). In all four cases the transmission is lower and the damping higher after the car ride.

By subject P, we can see lower damping and higher transmission in thoracic segment between Th4 and Th6 vertebra by the excitation from both sides – C7 and L5 vertebra. The course of the graph is similar before and after the car ride (Fig. 5, left and right). This differs from the previous subject P, by which the damping increases and the transmission decreases after the car ride in the similar thoracic segment between Th4 and Th7 vertebrae (Fig. 4). By the L subject (Fig. 5, right), the resonant peaks move from 36 Hz and 57 Hz before the car ride to 51 Hz and 72 Hz after the car ride, by the excitation from C7 vertebra.

DISCUSSION

Our model and measured data show, that it is possible to use the TVS method to detect changes in mechanical properties of the axial system before and after the strain. In this case, frequency strain when driving a car.

From our data results, that we can compare the subjects more intra individual than inter individual. The reaction of each subject to hypokinetic and frequency strain differs. It is clear, that different transmission of vibrations by each subject depends on body construction and rigidity of axial system, which may differ with muscle tension, hypermobility and water content by each subject. Our results confirm findings that were also made by Fairley in his study (1989).

By our measurements we found out, that healthy and flexible spine oscillates like elastic bar. It is able to absorb more mechanical energy with higher elasticity, and the spinal joints are more flexible. During our measurement with TVS method we found out, that the resonant frequency of the healthy and flexible spine lies between 40 and 60 Hz or higher. If the spine is less flexible, it tends to oscillate less and it reacts less to a vibratory excitation. Its joints are less relaxed and elastic (Panská, 2012). The resonant frequency is mostly determined by shear modulus of cartilage. The viscosity is responsible for damping of oscillations (muscles and ligaments). Transmission of the vibrations is, on the other hand, dependent mostly on elastic modulus (vertebrae and their joints) (Maršík, 2010). However, we didn't take into the account the lowest frequencies 0–20 Hz, for which we didn't have a vibrator.

In most of the cases we found higher damping and lower transmission of the vibrations after strain. However, with some of the subjects the monotony and frequency strain worked against our expectations positively and spine behaved like after physical exercises. We found bigger peaks with higher frequencies after the car ride with TVS method. The spine is oscillating better and it is more flexible after the car ride, the elasticity of the vertebrae joints increases (Fig. 1, left; Fig. 5, right).

By some of the subjects we can find different reaction in thoracic and lumbar spine to strain (e.g. subject Li1 by excitation from L5 in the area between L3 and L5 vertebrae and between Th2 and Th5 vertebrae – Fig. 1 and 2). It can be caused by different anatomy of thoracic and lumbar spine and also by the fact, that thoracic spine is connected to thorax and breathing, while there is abdominal cavity filled with abdominal organs in front of the lumbar spine.

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VLIV HYPOKINÉZY A FREKVENČNÍ ZÁTĚŽE NA ZMĚNU MECHANICKÝCH VLASTNOSTÍ AXIÁLNÍHO SYSTÉMU PŘI JÍZDĚ V AUTOMOBILU

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SOUHRN

V našem experimentu jsme použili metodu TVS k detekci mechanických změn axiálního systému. Tyto mechanické změny mohou být podkladem pro pocit diskomfortu během monotónního zatížení během jízdy v automobilu.

Metoda TVS je založena na aplikaci harmonického buzení plynule se měnícího od 5 Hz do 160 Hz na obratle C7 a L5. Toto vlnění se přenáší podél axiálního systému a akcelerometrickými snímači je snímáno zrychlení všech trnových výběžků obratlů, kterými se vlnění šíří mezi C7 až S1. Na základě naměřených dat lze vyhodnotit změnu mechanických vlastností páteře před a po hypokinéze a frekvenčním zatížení při jízdě v automobilu.

Náš výzkum prokázal, že metoda TVS je vhodná pro detekci změn mechanických vlastností axiálního systému. Dále bylo prokázáno, že změny způsobené monotónním a frekvenčním zatížením ovlivňují způsob přenosu vlnění axiálním systémem subjektů. Z našich naměřených dat vyplývá, že můžeme subjekty srovnávat spíše intraindividuálně než interindividuálně. Zjistili jsme, že zdravá a flexibilní páteř osciluje jako elastická tyč a je schopna absorbovat více mechanické energie a spojení na páteři jsou více flexibilní. Rezonanční frekvence zdravé a flexibilní páteře se při našich měřeních objevuje mezi 40 a 60 Hz nebo výše. Ve většině případů nacházíme po jízdě v automobilu vyšší tlumení a nižší přenos vibrací. U některých subjektů se objevuje odlišná reakce na zatížení v hrudní a bederní páteři.

Klíčová slova: vibrace, hypokinéza, frekvenční zatížení, axiální systém, mechanické vlastnosti, přenos vibrací

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