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Abstract

Driving on irregular terrain will expose the driver to sideways mechanical shocks or perturbations that may cause musculoskeletal problems. How a cognitive task, imposed on the driver, affects seated postural reactions during perturbations is unknown. The aim of the present study was to investigate seated postural reactions in the neck and trunk among healthy adults exposed to sideways perturbations with or without a cognitive task. Twenty-three healthy male subjects aged 19-36 years, were seated on a chair mounted on a motion system and randomly exposed to 20 sideways perturbations (at two peak accelerations 5.1 or 13.2 m/s²) in two conditions: counting backwards or not. Kinematics were recorded for upper body segments using inertial measurement units attached to the body and electromyography (EMG) was recorded for four muscles bilaterally in the neck and trunk. Angular displacements (head, neck, trunk and pelvis) in the frontal plane, and EMG amplitude (normalised to maximum voluntary contractions, MVC) were analysed. The cognitive task provoked significantly larger angular displacements of the head, neck and trunk and significantly increased EMG mean amplitudes in the upper neck during deceleration, although 10% of MVC was never exceeded. A cognitive task seems to affect musculoskeletal reactions when exposed to sideways perturbations in a seated position.

Introduction

Driving on irregular terrain, e.g. within forestry, mining or agriculture, will expose the seated driver to substantial mechanical shocks or perturbations. Exposure to mechanical shocks could, due to known health risks for the lower lumbar spine, be evaluated using the international standard ISO 2631-5 (2004). The standard does not, however, include muscle activities which may be overactive during unexpected shocks, thus creating excessive load on spinal joints (Bazrgari et al., 2008). Lately, studies have reported musculoskeletal problems in the neck region among drivers of various vehicles (Hagberg et al., 2006; Smith and Williams, 2014). Whether this is associated with the exposure to mechanical shocks and postural reactions in the driver remains unclear.

The biodynamic reaction after a mechanical shock or perturbation in a seated position results in - due to inertia in the trunk - a delay in subsequent head movement (Allum et al., 1997; Kumar et al., 2005; Vibert et al., 2001). For an unpredictable perturbation, passive mechanics (inertia, stiffness, and viscosity) constitute the first stabilizing mechanism. Secondly, skeletal muscle reflexes are added (Tarkka, 1986). Thirdly, voluntary reactions contribute to the stabilisation process (Mazzini and Schieppati, 1992).

Postural reactions in the neck or trunk due to perturbations in seated positions depend on several factors attributed to the perturbation characteristics, such as the amplitude and direction (Masani et al., 2009; Preuss and Fung, 2008; Sacher et al., 2012; St-Onge et al., 2011; Zedka et al., 1998), acceleration (Kumar et al., 2004a; Siegmund and Blouin, 2009; Siegmund et al., 2002) and complexity (Xia et al., 2008). Other factors are awareness of an upcoming perturbation (Siegmund et al., 2003a) and the initial posture (Kumar et al., 2005;

Kumar et al., 2006). Studies investigating postural reactions from sideways perturbations are scarcer than those involving forward-backward directions. Still, sideways shocks are reported to be at high acceleration levels for some driver categories and thus important to analyse (Rehn et al., 2005; Solecki, 2007).

The neck and trunk muscles seem to have a reciprocal activation pattern in response to a sideways load (Kumar et al., 2004a, b; Masani et al., 2009; Preuss et al., 2005; Vibert et al., 2001; Zedka et al., 1998). Conversely, the reactions also include some co-contraction (Preuss et al., 2005; Vibert et al., 2001). Vibert et al. (2001) suggested two main categories of reaction strategies; stiff and sloppy. The stiff strategy includes more co-contraction while the sloppy strategy comprises of reciprocal activation where the head and trunk are more flexible, which Vibert et al. (2001) claims is a more passive and potentially harmful strategy.

The postural reactions, here called a primary task, could be affected by a cognitive task, here called a secondary task (ST). Dual task studies of various kinds, including balance recovery, have demonstrated impaired performance in one or both tasks and that cognitive processing is involved in controlling postural stability in standing (Maki and McIlroy, 2007; Quant et al., 2004; Rankin et al., 2000). The effect of a dual task on the upper body during perturbation in a seated position has not been studied.

The aim of the study was to investigate postural reactions in the neck and trunk in healthy adults exposed to sideways perturbations in a seated position with or without a secondary task. It was hypothesised that increased muscle activity and larger angular peak displacements of involved body segments would be observed when subjects performed a ST and when exposed to higher peak acceleration perturbations. It was suggested that increased postural

reactions, i.e. muscle activity in the trunk, could affect the reactive muscle activity and angular displacement in the neck.

2. Methods

2.1 Participants

Twenty-three healthy male students, age 24 ± 5 years, height 1.81 ± 0.07 m, weight 79 ± 11 kg, participated in the study. Young participants were chosen to reduce occurrence of age-related problems such as degeneration and rigidity of the spine. Male participants were chosen because professional drivers are most commonly men. Subjects were excluded if they reported any neurological conditions or reduced ability to work during the last 12 months because of back or neck problems (Lundström R, 2004). A sample size analysis was carried out from neck kinematic data, using a similar setup with a mean value difference of 1.08 and standard deviation of 1.58. The analysis revealed that 19 participants were needed to be able to reject the null hypothesis, power = 0.8 (alpha level 0.05). Four extra participants were added, since the risks were considered negligible, to ensure that at least 19 measurements could be included in the analyses. Written informed consent was obtained from each participant, and the Regional Ethical Review Board approved the study (No 2012-24-31M).

2.2 Experimental protocol

This study used a repeated-measurement design (Fig. 1.) with low peak acceleration (LPA) and high peak acceleration (HPA), combined with or without a ST (i.e. attentional task

counting backwards in steps of three starting from a number provided by the experimenter (Brown et al., 1999)). The resulting four combinations of perturbations (I. LPA with ST, II. LPA without ST, III. HPA with ST, IV. HPA without ST), all delivered from the participant's right side, were randomised in five different groups, i.e. each unique combination was repeated in total five times but could not exceed being repeated more than two times in a row. Participants sat on an experimental flat chair that was fixed to a movable platform controlled by electrohydraulic actuators (Micro Motion System, Bosch Rexroth, Netherlands). The participants were seated centred on the chair facing forward, in what they considered to be a good but relaxed sitting posture. Feet were placed together on a height adjusted foot rest so that the thighs were horizontal and foot contact could still be maintained. A cushion was placed between the knees and a belt buckled around the thighs to minimize compensation of the effect of the perturbation by the feet, while maintaining a neutral position between legs and pelvis. The hands were placed on the thighs with palms upwards so that all motor response emanated from the trunk and neck. The perturbations parameters were acceleration ($a_{LPA} = 5.1 \text{ m/s}^2$, $a_{HPA} = 13.2 \text{ m/s}^2$), lateral translational stroke (distance = 0.24 m for both LPA and HPA), and time ($t_{LPA} = 1.2 \text{ s}$, $t_{HPA} = 0.8 \text{ s}$). The level of LPA was set to be less than used by Vibert et al. (2001) and the level of HPA was chosen to be approximately the same as that of Kumar et al. (2005). Subjects remained in the start position randomly 5 to 20 sec before perturbation. Further, they were instructed to retain their initial posture until the perturbation and to reassume it subsequently following the perturbation. Before registration of data, the subjects had one test perturbation of each acceleration in order to reduce potential anxiety that could affect the reactions, but also to reduce adaptation between the first and the remaining perturbations (Blouin et al., 2003; Siegmund et al., 2003b).

150

151 **2.3 Data acquisition**

152

153 Motion of the body segments, as well as the chair, were recorded with a portable movement
154 analysis system, developed by the Department of Biomedical Engineering, Research &
155 Development, University Hospital of Umeå, Sweden. In this setting, the system consists of
156 one data acquisition unit connected by cables to four inertial measurement units (IMUs). Each
157 IMU (MPU-9150 InvenSense, USA) included tri-axial accelerometers and gyros that together
158 detect motion such as the relative and absolute angles of the segments. A customised software
159 program calculated the real-time orientation and motion of the IMUs (Madgwick, 2010;
160 Öhberg et al., 2013). The IMUs were placed on the back of the head using an elastic Velcro
161 strap and at the spine on processus spinosus at level Th2 and S2 using adhesive tape on the
162 skin. One IMU was also mounted on the seat using adhesive tape. Data were collected with a
163 sampling rate of 128 Hz. Movements were described as relative angles between two units and
164 additionally the absolute angles for the head unit, due to more degrees of freedom in the neck.
165 The combination of units gives three segments with relative joints; Neck (Head to Th2),
166 Trunk (Th2 to S2) and Pelvis (S2 to seat). The IMUs were aligned with the participant's
167 position before the perturbation so that all movements during perturbation started from 0
168 degrees. Data were collected in three planes but are presented in the frontal plane where the
169 major movements occurred.

170

171 The electromyographic (EMG) activity was recorded bilaterally from four locations of the
172 neck and trunk (sampling frequency = 3000 Hz, set due to measuring movements with high
173 velocity and technical design in the equipment) using the TeleMyo Direct Transmission
174 System and model 542 DTS EMG Sensor (Noraxon USA Inc., US). The skin area of current

interest was shaved and cleaned with 70% alcohol solution and bipolar surface Ag/AgCl electrodes (Ambu De) were placed on the skin with inter electrode distance 2 cm apart. Electrodes were placed on the upper posterior neck muscles (UN) at the level of vertebrae C2 between the uppermost parts of m. trapezius and m. sternocleidomastoid, i.e. over the splenius capitis (Thuresson et al., 2003). Upper trapezius (UT) were placed halfway between C7 and the acromion (Hermens and Hägg, 1999). Erector spinae lumbar level (ES) were placed 3 cm lateral to the L2-L4 spinous processes and external oblique (EO) were placed 15 cm lateral of the umbilicus (Konrad et al., 2001).

Prior to measuring muscle activity during perturbations in sitting, the participants were asked to perform maximum voluntary contractions (MVC) for five seconds in static conditions using manual or rigid resistance. The UN muscle was tested in extension and lateral flexion where the participant sat on a flat chair with the head in a neutral position and a headband providing rigid resistance. The participants braced against manual support during maximum flexion and pressed their head in the direction tested. The UT muscle was tested in erect seated position with a height-adjusted arm sling over the shoulder to provide rigid vertical resistance immediately upon shoulder elevation, along with additional control so that the participant did not lean the upper body sideways during testing. For the ES muscle, the participants were asked to lie prone on a bench, hands held beside the head, with legs and pelvis buckled to the bench by a belt. The participants were asked to perform a back extension during which they were given manual resistance from the experimenter (Konrad et al., 2001). For the EO muscle, the participants were asked to lie on their side with arms crossed and legs and pelvis buckled to the bench by a belt. The bench gave horizontal support for the legs while the upper body was tilted down sideways at approximately 30°. On command the participants were asked to perform a sideways flexion of the upper body and at the horizontal

level were given manual resistance (Konrad et al., 2001). All tests were repeated twice with a minimum of one minute rest between tests.

2.4 Data analysis

Motion data was low pass filtered with a second order Butterworth filter at a cut-off frequency at 10 Hz. The Euler sequence used for all segment angles were X (rotations in the sagittal plane), Y (rotations in the frontal plane) and Z (rotations in the transversal plane). A more detailed description of the used algorithms can be found in Öhberg et al. (2013). Data are presented as relative angles (each unit relative to the other) and absolute angles (each unit relative space). Mean values for each participant's first and second peak angle are extracted.

Chair acceleration was registered by one IMU placed on the chair which together with a trigger event, was used to calculate the time for start and deceleration, needed in the further EMG analysis. The time between start and deceleration used in the analysis is based on a mean time value for the LPA respective HPA perturbations.

The EMG signals were first amplified 500 times and low pass filtered at a cut-off frequency of 500 Hz. The recordings started with an external trigger signal that was synchronised with the motion data. EMG signals and calculation of mean and peak amplitudes were all processed in MyoResearch 1.07.63 XPTM, (Noraxon USA Inc., US). EMG signals were firstly high pass digitally filtered using finite impulse response (FIR), with a cut-off 10 Hz.

Contamination of electrocardiogram (ECG) in the EMG signals was identified and removed and the EMG signals were further rectified and smoothed using root mean square (RMS) during a 100 ms window (Konrad, 2005). The EMG signals from the MVC test were then normalised to a peak value during a 500 ms window. The highest amplitude of the EMG from

the MVC tests for each participant and muscle was used for normalisation of the EMG signals from perturbations when calculating the mean and peak amplitudes. Amplitudes were calculated during a window of 400 ms after the start of acceleration and 400 ms after the deceleration had started. The time window was set equally for LPA or HPA perturbation and the time frame 400 ms was set so as not to risk overlap between acceleration and deceleration in the HPA.

2.5 Statistical analysis

Parametric tests were used since data was accepted as normally distributed and supported by Central Limit Theorem when repeated measurements on 23 participants were performed. Variables for each participant were first averaged for the five trials of each combination of perturbation. Trials or channels with low quality EMG signals or missing trigger event were excluded. Only the muscle with contaminated EMG and not all muscles for the participant were excluded, which is why the number of participants included in EMG analyses varies from 19 to 21 participants per muscle. The peak angular displacement and EMG mean amplitude were analysed using a two-way repeated measurement analysis of variance (ANOVA). The two within-subject factors were peak acceleration (LPA and HPA) and the condition (ST or no ST). Statistical differences between left and right side of EMG mean amplitude were checked with an independent paired t-test. Associations between muscles EMG mean amplitude, and neck kinematics for the HPA perturbation in the different conditions were analysed using Pearson's correlation coefficient (r). The p-value was set to 0.05 for all analysis. Analyses were performed using IBM SPSS version 20 (IBM Corp.

Released 2011. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp.) and Excel (Microsoft Inc., USA).

3. Results

3.1 Kinematics

For translation from the subjects right, the pelvis (S2 to seat) initially flexed to the right side while the trunk (Th2 to S2) and neck (Head to Th2) flexed left relative to its lower segment (Fig. 2). At group level, the head relative to space rotated initially to the left before going to the right, a movement that was not observed for every participant. The first and second mean peak angle displacements with standard deviations (sd) are displayed for each segment together with the within-subject factors effects in Table 1. There was a significant acceleration effect for all segments giving a larger displacement from zero at first and second peak angle displacements, but also several significant condition effects.

3.2 Electromyography

The UT mean amplitude level for the whole group HPA perturbations was low, < 1% of MVC, and therefore further analysis of the UT was excluded. The mean EMG 400 ms after acceleration and deceleration normalised to MVC for the UN, ES and EO muscles for both sides are displayed in Table 2 & 3. The two within subject factors, peak acceleration (LPA and HPA) and condition (ST and no ST), effects on the mean EMG is displayed for acceleration in Table 2 and deceleration in Table 3. Condition or interaction effect for the

mean amplitude was only seen in the left side muscles at deceleration. There was a significantly higher mean EMG amplitude at the HPA compared to LPA at acceleration and deceleration for both the left and the right side muscles. For HPA perturbations at acceleration, there was a higher mean amplitude in the left UN, no ST ($t(33.6) = 4.59, p < 0.01$); ST ($t(39) = 5.09, p < 0.01$); and in the ES, no ST ($t(32.3) = 3.60, p < 0.01$); ST ($t(39) = 2.29, p = 0.03$); but no differences in the EO. At deceleration for HPA perturbations there was no significant differences between sides. The rectified signals for UN, ES and EO is displayed in Fig. 3 for both sides in one participant during one trial (HPA ST).

3.3 Associations between trunk and neck

Associations were calculated for HPA perturbations. At acceleration, there was a correlation between the left side EO and ES in the ST condition ($r = 0.55, p = 0.02$). There was a correlation between the left side EO and ES ($r = 0.52, p = 0.03$) and between EO and UN ($r = -0.53, p = 0.02$) for no ST. Further, there was a correlation between the EMG amplitude for the left UN and the first neck peak angle ($r = -0.65, p < 0.01$) and the second neck peak angle ($r = 0.51, p = 0.02$) for no ST.

At deceleration, there was a correlation between the first neck peak angle displacement and EMG amplitude at the left side ES ($r = -0.45, p < 0.05$) and second neck peak angle and left ES ($r = 0.44, p < 0.05$) in the ST condition. There was a correlation between ES and UN on the left side ($r = 0.44, p = 0.02$) and on the right side ($r = 0.56, p = 0.02$) for no ST. Further, for the no ST condition, there was a correlation between first neck peak angle and left UN ($r = -0.78, p < 0.01$), and between the second neck peak angle and left UN ($r = 0.72, p < 0.01$) and second neck peak angle and left ES ($r = 0.52, p = 0.02$).

297

298 **4. Discussion**

299

300 The main objectives of the study were to investigate seated postural reactions e.g. muscle
301 activity in the neck and trunk, and angular displacement in the spine in healthy adults exposed
302 to sideways perturbations with two different peak accelerations combined with or without a
303 ST. The findings suggest that a ST affects the postural reactions resulting in larger second
304 angular peak displacements in the head, neck and trunk, but also increased EMG mean
305 amplitude in the left UN muscle at deceleration. The level of acceleration has a significant
306 effect on the first and second peak angle displacement in all segments of the spine and also at
307 the mean EMG amplitude. There were fewer associations between neck and trunk reactions
308 for the ST compared to the no ST condition.

309

310 **4.1 Kinematics**

311

312 The influence of a ST was found in the first peak angle displacement of the head and in the
313 second peak angle displacement of the head, neck and thorax. The second peak angle was
314 displayed after the deceleration of the platform started for HPA perturbations making it harder
315 to decide the contribution of acceleration or deceleration. Still, the displayed larger peak angle
316 displacement caused by the ST at perturbations in seated is also shown as impaired
317 performance found at perturbations with ST in standing (Jacobs and Horak, 2007; Maki and
318 McIlroy, 2007; Quant et al., 2004; Rankin et al., 2000). It seems like the cognitive process
319 involved in controlling seated postural reactions is affected by secondary tasks leading to
320 larger peak angular displacement of the neck and thorax. However the clinical implication of
321 the increased, but still small displacements, are unknown.

322

323 The larger peak angle displacements in seated participants due to higher accelerations
324 conform to earlier research (Siegmund and Blouin, 2009; Siegmund et al., 2002). However,
325 some of the differences can be due to perturbation characteristics. During LPA conditions in
326 the upper segments, the small but fast occurring second peak angle displacement happens
327 during constant speed. Contrarily, the larger but later peak angle in the HPA condition occurs
328 during deceleration of the seat. This implies that the thorax angle may increase when the trunk
329 has started to accelerate in the perturbation direction when the pelvis starts to decelerate. Still,
330 the larger displacements in the HPA is in line with what was expected. The movement pattern
331 after a perturbation starts with the pelvis flexing first in the direction opposite to the
332 perturbation and thus giving a positive angular displacement, followed by a negative angle for
333 the trunk and neck due to inertia confirming a caudocranial movement pattern (Forssberg and
334 Hirschfeld, 1994; Vibert et al., 2001). For the majority of participants the head slightly flexed
335 in the perturbation direction before going in the opposite direction. For others, the immediate
336 flexion was in the opposite direction of perturbation, indicating that kinematic responses may
337 vary between individuals. The different movement patterns, together with a large variation in
338 angular displacements from the trunk and upwards (up to five times larger differences
339 between participants), could be regarded as examples of the mix of stiff and sloppy strategies
340 according to Vibert et al. (2001). A small head, neck and trunk angular displacement is
341 characteristic of a stiff strategy and the opposite of a sloppy strategy.

342

343 **4.2 Electromyography**

344

345 The UT responded with less than 1 % of MVC in mean amplitude at group level and did not,
346 without exception, reach 5 % MVC at the individual level. The UT does not appear to

contribute to stabilisation of the spine during a sideways perturbation, which was intended to be tested. A more activated muscle may be caused when holding a joystick or steering wheel during perturbation or being exposed to complex shocks. The lack of response in the UT conforms to a study by Sacher et al. (2012) that used a lower acceleration level with hands resting at the legs. The trapezius muscle is reported to be most at risk of developing pain in occupational life in general (Jensen et al., 1993), however from these results it seems to be of less importance for postural stability when exposed to shocks. We decided against further analysis of UT due to the lack of reaction in many participants.

Introducing a ST seems to result in a higher UN amplitude. A higher amplitude is in line with Quant et al. (2004), who reported a higher amplitude in tibialis anterior in a standing dual task. The muscle activity at HPA with a ST during the acceleration phase show that UN and ES are reciprocally activated (sloppy strategy) with more activation in the left agonist side compared to the right side. Contrarily, the activity in EO is equally distributed between sides implying a co-contraction (stiff strategy). This implies that neck and trunk muscles seem to have a reciprocal activation pattern in response to a sideways load, but also includes some co-contraction which were suggested by Preuss et al. and Vibert et al. (Preuss et al., 2005; Vibert et al., 2001).

The muscle activations in general were low, at the group level 5 % MVC was reached in some muscles after perturbation but less in others with a large variability between participants. Low muscle reactions due to perturbations in seated positions has been reported by some studies (Masani et al., 2009; Sacher et al., 2012) while others have found larger reactions, over 10% mean amplitude in splenius capitis and trapezius (Kumar et al., 2004a). One explanation for

the different normalised amplitude in UN compared to Kumar et al. (2004) could be due to other MVC-tests and time-windows.

4.3 Associations

Most associations were found in the left side muscles during the no ST condition. At the left side a high activity in EO at acceleration was associated with a high activity in the ES and a reduced activity in the UN. One suggestion could be that high early muscle activity in the trunk may reduce angular displacement upwards in the spine which affects UN activity. At acceleration, no associations between muscle activity in the trunk and neck peak angular displacement was found, supporting that theory. A more accurate segment model may give another outcome. A reduced UN activity has otherwise been found earlier at a combined sideways and forwards perturbation, with the trunk muscles presumably activated in a pre-flexed forwards and sideways position (Kumar et al., 2006).

This study may be the first to investigate associations between muscles at perturbations during different cognitive conditions. There are generally more and stronger associations for the HPA perturbations in the no ST condition compared to the ST condition. One possible explanation for this may be higher variability in postural reactions for the ST conditions i.e. a dual task inhibits a consistent postural reaction.

4.4 Methodological considerations

The applied perturbation is not exactly the same as when driving on rough terrain, but the HPA is within reported values (Solecki, 2007). An authentic shock would be more complex

and not just go in one direction with a smooth deceleration when stopping. A more complex perturbation going in several directions may cause increased postural reactions. The used ST of counting backwards in steps of three may have limitations as it may not resemble the dual tasks a professional driver faces during work, such as handling of the vehicle, reading the terrain, and decision making. Counting backwards is, on the other hand, easy to adopt and has been used in other perturbation studies with standing subjects (Brown et al., 1999). The participants were all male students and in several cases physically active which may also influence the generalizability of the results. The initial posture was adapted after predefined verbal instructions, but not controlled in detail, which could explain some of the variability between participants.

The muscle activity was collected with surface EMG on superficial muscles and not with intramuscular electrodes inserted in deeper muscles. Deeper muscles have been suggested to be of importance in seated postural reactions during external perturbations (Vibert et al., 2001). The low activity found in the present study for tested muscles supports the theory that other muscles or passive structures (ligaments, joint capsules, or connective tissues) are involved and may therefore be at risk for musculoskeletal disorders.

4.5 Practical implications and future research

The small size of the peak angular displacements and muscle activities do not imply a high risk for musculoskeletal overload. The postural reactions are however increased by a secondary task i.e. cognitive. Therefore, cognitive tasks should probably be avoided when the driver is exposed to shocks. In a real situation a driver is exposed to several shocks which may alter postural reactions which was not studied here. The variability in response patterns

between participants could indicate that there is a possibility to solve the postural task slightly differently and that some individuals have a higher potential risk of overload than others. Future studies should involve a more complex perturbation in several directions, combined with different postures, and add a visual ST which mimics professional driving on rough terrain.

5. Conclusions

A ST during a sideways perturbation provoked significantly larger angular displacements in the head, neck and trunk but also increased EMG mean amplitude in the upper neck antagonist at deceleration. The postural muscle responses were generally small for UN, ES and EO, with side differences, but never reached 10% MVC in mean EMG amplitude. There were associations between neck and trunk reactions but fewer during the ST compared to the no ST condition. The movement pattern was generally the same for the various conditions but with large variability between participants. The size of the peak angular displacements and muscle activities by themselves do not imply a high risk for musculoskeletal overload. Reported musculoskeletal problems from the neck region among drivers seem consequently not to be affected causally by a single mechanical shock.

6. Conflict of interest

There is no conflict of interest from any of the authors.

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Table 1. The first and second mean angular displacement and standard deviation in degrees following a sideways perturbation in seated position for pelvis, trunk, neck and head at Low Peak Acceleration (LPA) and High Peak Acceleration (HPA) with and without Secondary Task (ST). The F- value and p-value for the acceleration, condition and interaction effects were calculated using a two way repeated measurement analysis of variance (ANOVA).

Table 2

Table 2. The mean muscle amplitude and standard deviation 400 ms after acceleration normalised to amplitude during Maximum Voluntary Contraction (MVC) in percent for the upper neck (UN), erector spinae lumbar level (ES) and external oblique (EO) muscles for both sides. The F- value and p-value for the acceleration (Low Peak Acceleration (LPA) and High Peak Acceleration (HPA)), condition with and without Secondary Task (ST) and interaction effects were calculated using a two-way repeated measurement analysis of variance (ANOVA).

[illegible]

Table 3. The mean muscle amplitude and standard deviation 400 ms after deceleration normalised to amplitude during Maximum Voluntary Contraction (MVC) in percent for the upper neck (UN), erector spinae lumbar level (ES) and external oblique (EO) muscles for both sides. The F- value and p-value for the acceleration (Low Peak Acceleration (LPA) and High Peak Acceleration (HPA)), condition with and without Secondary Task (ST) and interaction effects were calculated using a two-way repeated measurement analysis of variance (ANOVA).

Figure 1

Fig. 1. Experimental protocol using a repeated-measurement design of 20 translational sideway perturbations from the participants right side. There were two different accelerations (Low Peak Acceleration (LPA) and High Peak Acceleration (HPA)) combined with two conditions, i.e. Secondary Task (ST) or No Secondary Task (No ST).

Fig. 2. Angular displacement following a sideways perturbation in seated position for head, neck, trunk and pelvis at Low Peak Acceleration (LPA) and High Peak Acceleration (HPA). The angular displacements are grouped for Secondary Task (ST) and No Secondary Task (No ST). The first and second peak angular displacements are marked 1 & 2. The chair motion is displayed to visualise when the chair accelerates and decelerates.

Fig. 3. The rectified Electromyography (EMG) amplitude in μV following a high peak acceleration (HPA) perturbation in sideways direction for one seated subject. The muscles that are displayed are upper neck (Cervical PS), Erector spinae at lumbar level (Lumbar ES) and External oblique (Ext Oblique) for left (LT) and right side (RT). The start of deceleration is marked with a thin vertical line (Brake).