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Neck posture and muscle activity with and without head support in a reclined sitting posture when watching IFE

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Abstract In designing a headrest it is important to define the ideal head position and neck angle. There is literature on the ideal head position, but not in the context of watching IFE in a business class aircraft seat. In this study (n=21) the neck muscle activity (EMG), expected long-term comfort and head/neck inclination were studied in a reclined position (as is possible in business class) when watching IFE in the condition of with and without head/neck support.

It appeared that there were no significant differences in EMG between both conditions. However, the posture was significantly different; without head support by a headrest the head was found to be more upright. Expected long-term comfort was rated highest in the condition with a headrest.

The fact that no difference was found in EMG indicates that humans tend to look for a head position that is neutral, in the sense of minimal (muscle) effort. Head support in a reclined position may have a positive psychological effect on the user.

Keywords: EMG, posture, neck angle, aircraft seat, neutral head position, headrest

1 Introduction

In designing a headrest it is important to define the ideal head position and neck angle. There is literature on the ideal head position with an upright or slightly reclined trunk, of which an overview can be found in Table 1. However, for a situation in which the trunk is reclined the literature is limited. For the position in the car e.g. Park, Kim, Kim, and Lee (2000) and Kilincsoy, Wagner, Bengler, Bubb, and Vink (2014) presented comfortable angles, van Veen, Hiemstra-van Mastrigt, Kamp, and Vink (2014) even in the context of tablet use, but for a more reclined position that can be found in a business class aircraft seat when watching in flight entertainment (IFE) the ideal neck position is not described.

As observed in studies by van Rosmalen, Groenesteijn, Boess, and Vink (2009), van Rosmalen, Groenesteijn, Boess, and Vink (2010), C. S. S. Tan, Van den Bergh, Schöning, and Luyten (2014), Meziat Filho, Coutinho, and e Silva (2015), Hiemstra-van Mastrigt (2015) and Smulders et al. (2016), most people prefer to sit in a reclined posture when watching Television (TV) at home and IFE during flight. Hiemstra-van Mastrigt (2015) found a preferred mean inclination for watching IFE in an economy class aircraft seat of 41˚, where Smulders et al. (2016) found 32˚ for watching IFE in a business class aircraft seat. van Rosmalen et al. (2009, 2010) propose a backrest angle of 40˚ for their prototype television seat for the home, based on an experiment with an office chair. A possible explanation for this preference may be the lower back muscle activity in such a slouched posture (Goossens, Snijders, Roelofs, & Buchem, 2003) and lower pressure on the intervertebral disks (Wilke, Neef, Caimi, Hoogland, & Claes, 1999).

Table 1. The comfortable (neutral) head position (as described in Vink (2016)). See Figure 1 for a visual explanation of the given angle.

Reference	*n*	*Craniocervical angle (α)*
Raine and Twomey (1997)	160	41,1°
Johnson (1998)	34	40,4°
Ankrum and Nemeth (2000)	24	43,7°
van Veen et al. (2014)	10	41,2°

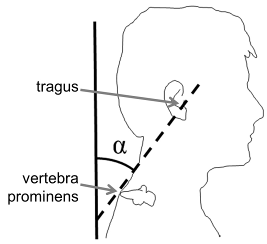

Figure 1. The craniocervical angle (α) between a line through the tragus and vertebra prominens (C7) and the vertical line (from Vink (2016))

1.1. Head flexion and the strain on the muscles

The head angle is – besides the orientation of the trunk – influenced by the viewing angle on the IFE screen. "The preferred line of sight becomes lower as the viewing distance decreases" (as cited in Ankrum and Nemeth (2000), and also been shown by Kroemer and Hill (1986)), indicating that in the economy class (where space is more scarce) an IFE screen should be below eye level and oriented perpendicular to the line of sight. Yoichi et al. (2012) states however, that a more horizontal line of sight is preferred for further distances of TV screens, and thus is more appropriate for business class with it's bigger screens, generous space (bigger eye-screen distance) and generous backrest recline.

When reclining (32-41°) in a business class seat while watching IFE, the passenger may flex their head forward with respect to the trunk without head/neck support for a prolonged period of time (e.g. when watching one or multiple movies) to establish a good (horizontal) view on the IFE screen (see Figure 2), which was observed in the study by Smulders et al. (2016). However, prolonged (unsupported) neck flexion beyond 30° could lead to severe muscle fatigue and discomfort according to Chaffin (1973). This may result in pain and spasm in the neck muscles, which can lead to headache and pains of the head, face and behind the eyes (Dalassio, 1980; J. Travell, 1967; J. G. Travell & Simons, 1992).

In the studies of van Rosmalen et al. (2009) and Smulders et al. (2016) it was observed that participants lacked neck/head support when watching TV/IFE in the slouched posture. In the study by Hiemstra-van Mastrigt (2015) subjects stated discomfort in the neck when watching IFE. In a context mapping study by van Rosmalen et al. (2010), participants requested a headrest for head support. The question is if head/neck support for watching IFE in a reclined posture will lower muscle activity and offer the passenger more comfort.

Figure 2. Subject watching IFE in slouched posture while flexing head forward with respect to the trunk (from Smulders et al. (2016))

1.2. *Theoretical biomechanical analysis*

Neck flexion theoretically stretches and contracts the neck muscles. In a simulation with the AnyBody™ model, it was found that the neck force increases in the musculus trapezius pars descendens (TRP-UP) and transverse (TRP-MID) due to stretching of the muscle, when the head keeps a horizontal view and the backrest reclines backwards.

To compensate for the force exerted by the trapezius muscle the sternocleidomastoideus (SCM) should theoretically be active if there is no headrest. The hypothesis is therefore that a headrest, which supports the head/neck while sitting in this slouched posture, will not change or lower neck muscle activity (e.g. SCM) and will benefit the comfort experience of the user.

2 Materials and methods

To study the effect of the headrest in a slouched position, EMG, posture and expected long-term comfort were recorded of 21 subjects sitting in a lounge seat with a backrest angle of 40 degrees. 12 subjects started with the condition with headrest and the other 9 without headrest. Surface RA-EMG was recorded of the TRP-UP and SCM for 5 minutes in each condition. Postures were recorded by camera in the different conditions. Expected long-term comfort was recorded by questionnaire.

2.1. *Subjects*

11 female and 10 male American, Chinese, Dutch and Iranian adults with no neck injuries and/or complaints in the past six months and who have flown in the past, participated in this study (Table 3). Subjects were asked to wear top clothing without a collar – preferably a T-shirt – for easy sensor placement.

Table 2. Anthropometrics of subjects

		Mean	*SD*
Male (n=10)	*Age [Years]*	31,9	6,4
	Stature [m]	1,81	0,04
	Weight [Kg]	87,2	21,6
Female (n=11)	*Age [Years]*	24,4	1,0
	Stature [m]	1,72	0,08
	Weight [Kg]	64,9	8,7

2.2. *Experimental setup and stimuli*

The study took place at two different locations with the same setup. Seven subjects were tested at the Human Factors and Ergonomics lab of Zodiac Seats US in the USA and fourteen at the ID-User Labs of the Delft University of Technology in the Netherlands.

Surface electromyography was used to measure muscle tension in the m. sternocleidomastoid (SCM) and m. trapezius upper fibers (TRP-UP) in three conditions: lying flat (condition A), sitting slouched watching with (condition B) and without (condition C) a headrest.

To stimulate full muscle relaxation in condition A (which functions as a benchmark of full relaxation), subjects lied down on a mattress with a pillow. To stimulate a TV/IFE watching posture, subjects sat slouched in an IKEA® POÄNG lounge seat with a 40° reclined backrest and leg support, facing a 15" LCD monitor (further named IFE screen) featuring a TED talk on the subjects' interests at 1,69m distance with its centre at each participant's eye height (as recommended by Yoichi et al. (2012)). In condition B the seat had a headrest, in condition C the headrest was removed (see Figure 3). It is important that subjects rest their arms on their lap in condition B and C, to limit influence of its 10% of the total body weight load (Roebuck, Kroemer, & Thomson, 1975; Snijders, Nordin, & Frankel, 1995) on muscle activity in the shoulder-neck region. The use of the fixed armrest would result in measuring different loads due to anthropometric differences among subjects.

After each condition subjects were asked to file a questionnaire on their expected long-term comfort in general (all-over experience), for the neck, head and eyes. For each body part a score needed to be given by drawing a vertical line on a horizontal score-line with 'not comfortable' and 'very comfortable' at its ends. For each given score, subjects were asked to substantiate in writing.

Figure 3. Left: condition B - subject sitting in the seat with headrest
Right: condition C - subject sitting in the seat without headrest

To put measured muscle tension into perspective, subjects conducted a maximal voluntary contraction (MVC) of the neck muscles by flexing the head against a load created by a TheraBand™ Red (medium strength) or Green (heavy strength; for some strong subjects), and extending the head against the headrest by the end of the study.

2.2.1. *EMG sensor positions*

The two electrodes were applied parallel to the muscle fiber direction on the dominant middle portion of the muscle belly (Delsys, 2012; Konrad, 2005). Muscle belly positions were palpated and the sensor for the TRP-UP was placed at C5/C6 level, ±2 cm lateral to midline (Sommerich, Joines, Hermans, & Moon, 2000) and the sensor for the SCM was placed on the lower 1/3rd between the sternal notch and mastoid process (Falla, Dall'Alba, Rainoldi, Merletti, & Jull, 2002). Since the head was kept parallel to the lateral plane, only muscle activity at one side was measured.

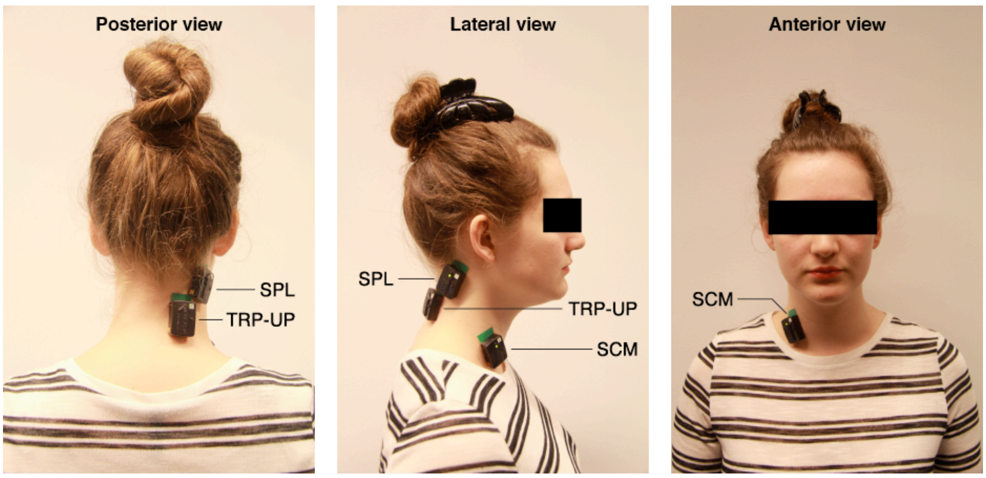

Figure 4. Posterior, lateral and anterior view of sensor placement on the splenius and semispinalis area (SPL), the upper trapezius fibers (TRP-UP) and the sternocleidomastoid (SCM)

2.3. Apparatus

In both the USA and The Netherlands locations the exact same Delsys® Trigno™ Wireless EMG System (2000 Hz sampling rate) and a laptop with Delsys® EMGworks™ were used to measure muscle activity of the neck muscles. A Mitutoyo® digital protractor angle gage and an iPhone 5 gyro were used to set the seat backrest to an angle of approximately 40˚. In the USA study an electric weight scale and a Seca® 700 analogue stadiometer were used to determine subjects weight and height. In The Netherlands an electric weight scale and a GPM antropometer were used. In the USA a Canon® 6D DSLR camera with a Canon® EF 24-105mm f/4.0L IS USM (set to 24mm) at a fixed position (1,38m lateral of the seat) was used to capture the posture at the sagittal plane. In The Netherlands, at the same distance and position a Canon® 60D DSLR camera with a Canon® EF-S 17-55mm f/2.8 IS USM (set to 17mm) was used.

2.4. Procedure

Subject briefing and preparation

Subjects were first briefed on the procedure of the study and were requested to sign a consent and NDA form, state their date of birth and nationality. Subjects were then requested to take off their shoes to measure their weight and length. Next, subjects were asked to take a seat in preparation of sensor placement.

Skin preparation and sensor placement

Areas for sensor placement on the subject's skin were cleaned by removing dead skin cells and other skin surface 'pollution' by sticking and pealing 3M Transpore™ surgical tape multiple times on the skin and then softly rubbing alcohol wipes on the skin (Delsys, 2012; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Konrad, 2005; Letizi, 2016). Sensors were placed on the subject's lateral right as described in §2.2.2.

Signal validity check

The validity of the EMG signal were checked by inspecting the baseline noise ratio, baseline offset and baseline shift (Konrad, 2005; Letizi, 2016). The raw EMG signal of the SCM was inspected by letting subjects flex their head forward to the opposite side (Soderberg, 1992). The same was done for the TRP-UP by having subjects raise their shoulders (Soderberg, 1992).

Condition A: lying on the ground

Subjects were asked to lie flat on a mattress with pillow and fully relax for 5 minutes first (see Figure 3). During this period the room was darkened to help subjects to fully relax. This measurement functions as the benchmark for full muscle relaxation. Thereafter the subjects were asked to stand up and to state their expected long-term comfort by questionnaire.

Preparing sitting position

Subjects were asked to sit in the lounge seat in a slouched posture (back against reclined backrest) while resting the head against the headrest, looking forward in a preferred head angle and rest the arms in their lap. For posture analysis, a lateral picture was taken of the subject's sagittal plane in the seat. The height of the IFE screen was adjusted to meet the subject's eye height with the IFE screen's centre (Yoichi et al., 2012). Thereafter the subjects were asked to stand up and select a TED talk movie on their interests.

Condition B and C

To prevent order effects, (approximately) half of the subjects started sitting in condition B and the other half of the subjects started in condition C.

Condition B: sitting slouched with headrest

Subject's were asked to sit in a slouched posture (back against reclined backrest) while resting the head against the headrest, rest the arms in their lap and looking at the IFE screen to watch a movie for 5 minutes (see Figure 3). During this activity, EMG signals were continuously recorded for 5 minutes. Thereafter a lateral picture of the posture was taken and the movie paused. The subject was asked to fill in the expected long-term comfort questionnaire. Thereafter the subjects were asked to stand up and take a break for 2 minutes, to minimize fatigue (C. F. Tan, Chen, & Rauterberg, 2010).

Condition C: sitting slouched without headrest

The headrest of the seat was removed. Subject's were asked to sit in a slouched posture (back against reclined backrest), rest the arms in their lap and looking at the IFE screen to watch a movie for 5 minutes, but without resting the head against the seat (see Figure 3). The same procedure as in *condition B* was followed.

Maximal Voluntarily Contraction

Lastly the subject was asked to conduct maximal voluntarily contraction (MVC) of the flexion and extension neck muscles. This was executed at the end of the study, since MVC has some discomfort effects due to extensive contractions of the muscles, which need some recovery afterwards.

Subjects were asked to push their head against the TheraBand™ (flexion) – which was connected to the seat frame – as hard as they can for 3 seconds. They were verbal encourage when needed. Thereafter they had a recovery break of 30 seconds and repeated the exercise another two times. Delsys EMGworks® automatically determined the highest MVC of the three contractions. A similar procedure was followed to determine MVC for extension by placing the headrest back on the seat and ask subjects to push their head against the headrest (extension) as hard as they could for 3 seconds. This too was repeated another two times and the highest MVC was determined.

2.5. Measures

Muscle activity

Two subjects had to be excluded from the EMG study due to a software crash that resulted in lost data. Collected EMG data of the TRP-Up and SCM in conditions A, B and C and of the flexion and extension MVC's of each subject were processed with Delsys® EMGworks™ . First the baseline offset was removed and the root-mean-square (RMS) was taken of the raw signal. Then the microvolt signal of the TRP-UP and SCM in conditions A, B and C were normalised by expressing them as a percentage of the corresponding maximum recorder MVC (%MVC); MVC extension for the TRP-UP and MVC flexion for the SCM. Expressing the signal in %MVC makes comparison between subjects possible, since EMG data is of a subject dependent nature. Of each data set an as large as possible sample without noise was taken to calculate a mean muscle activity of the TRP-UP and SCM in each condition, expressed in %MVC. In Microsoft Excel a paired t-test was taken to check for significant differences between the conditions ($p < 0.05$), as well for influence of testing order, gender and testing location.

Expected long-term comfort

One subject had to be excluded due to not filing one of the questionnaires. All rates were collected by measuring the given scores on the 10 cm long score-line with a ruler and all handwritten comments were typed down and were processed with Microsoft Excel. Since comfort values are not normally distributed, the Wilcoxon test was used in addition to a *t* test, to look for differences between conditions B and C. The significance between the scores for conditions B and C was calculated ($p < 0.05$) per rated area. In addition, influence of testing order, gender and testing location were tested on significance.

Head-neck posture

Two subjects had to be excluded from the study; one due to missing pictures of one condition, the other due to deformation of the seat by subject's weight, resulting in wrong backrest inclination. Lateral pictures taken from the fixed cameras were analysed using Adobe Illustrator. First reference points were placed on the hip, C7, tragus, canthus and visual target (the centre of the IFE screen), and then lines were drawn between those points (see Figure 5). Of each line the angle was recorded based on Psihogios, Sommerich, Mirka, and Moon (2001) and processed in Microsoft Excel. A paired t-test was taken of each angle to check for significant differences between the conditions ($p < 0.05$), as well for influence of testing order, gender and testing location.

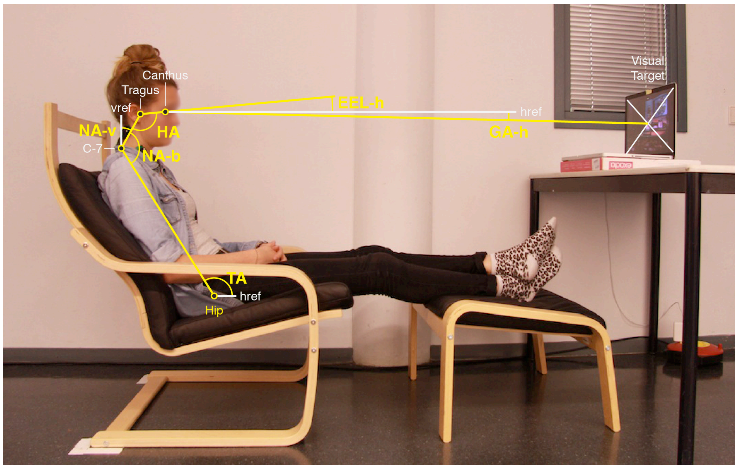

Figure 5. Lateral analysis of posture in Adobe Illustrator.
Angles describing the head-neck posture (based on Psihogios et al. (2001))

3 Results

The recorded mean muscle activity for conditions A, B and C, expressed as a percentage of the MVC, can be found in Figure 6. The EMG data shows no significant difference in both the TRP-UP as the SCM between condition B and C (see Table 3). However, the SCM significantly relaxed in condition B over A, however only with 0,5%MVC on average.

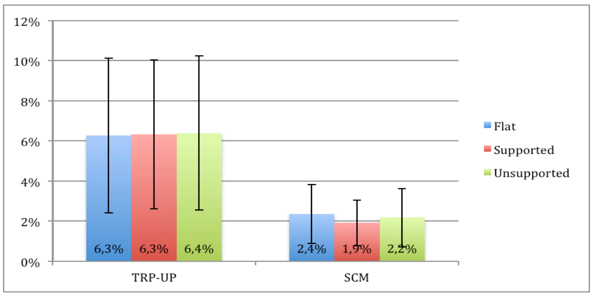

Figure 6. Mean muscle activity as a percentage of MVC (n=19)

Table 3. T-test of muscle activity as a percentage of MVC (n=19)

Condition	*SCM*	*TRP-UP*
AB	0,003 *	0,4
AC	0,2	0,2
BC	0,05	0,3

Expected long-term comfort scores for *general* (all-over) *comfort*, *neck comfort*, *head comfort* and *eye comfort* can be found in Figure 7. Subjects rated expected long-term comfort in *general*, in the *neck* and the *head* significantly higher in the condition with a headrest (condition B). There was no significant difference rated at the eyes. No significant influence of testing order on the comfort scores was found, except for *eye comfort* in condition B (p≈0,41).

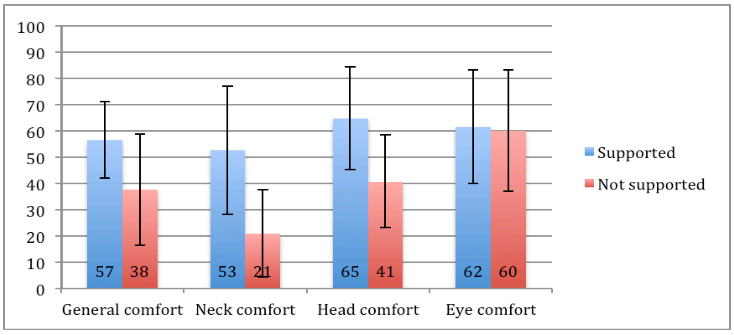

Figure 7. Mean comfort scores with SD (n=20)

The inclinations describing the head-neck posture in conditions B and C can be found in Table 4. The inclination data shows the posture was significantly different between condition B and C, except for HA (p≈0,13). Without head support (B) the head was found to be more upright in respect of without head support (C).

Table 4. Posture inclinations (for angle description, see Figure 5)

Angle	*TA*		*NA-b*		*NA-v*		*HA*		*EEL-h*		*GA-h*	
Condition	B	C	B	C	B	C	B	C	B	C	B	C
Mean	126,3°	124,4°	126,5°	117,4°	17,3°	28,2°	130,9°	132,0°	23,6°	13,8°	-2,6°	-2,2°
SD	2,1°	2,6°	4,7°	5,1°	5,0°	4,6°	6,0°	6,4°	5,6°	5,3°	1,0°	1,2°
Max	132,0°	131,4°	136,4°	128,0°	24,7°	35,7°	144,3°	142,8°	36,2°	27,6°	-0,9°	0,6°
Min	123,6°	120,6°	118,6°	108,1°	8,1°	18,7°	120,2°	121,5°	14,7°	5,2°	-5,5°	-5,0°
Difference (mean)	1,83°		9,11°		10,94°		1,09°		9,85°		-0,41°	
Wilcoxon	0,00026 *		0,00008 *		0,00008 *		0.12602		0,00012 *		0,00578 *	

4 Discussion

It appeared that there were no significant differences in EMG between both conditions B and C. Expected long-term comfort was rated highest in the condition with a headrest (B), indicating there may be a psychological effect by perceiving support and body contact, positively influencing perceived comfort. Franz, Durt, Zenk, and Desmet (2012) describe a similar effect on contact, were neck support benefitted the perceived comfort.

The expectation of having more comfort in the long term may actually positively influence the all over experienced comfort of a passenger during a flight, a phenomena described by Naddeo, Cappetti, Califano, and Vallone (2015) in the context of a bed. It is therefore recommended to further investigate the impact of head support on perceived comfort and discomfort. Additional simulations with AnyBody™ on e.g. the m. sternocleidomastoideus, m. splenius capitis and m. semispinalis would be preferable. Also the duration of EMG measurement in this study was limited. Since passengers may watch IFE for a prolonged period of time (e.g. watching multiple movies on a long-haul flight), it is recommended to study the long-term effects of this slouched posture, with and without head support, on muscle activity and fatigue and the passenger comfort and discomfort over time.

The posture between conditions B and C was significantly different. Without head support by a headrest the head was found to be more upright and placed above the rotation axes of the neck. The fact that no difference was found in EMG indicates that humans tend to look for a head position that is neutral. Neutral in the sense that the least energy is needed to keep the head upright. Regarding the seat experience, stability by head support is preferred. These data indicate that it is important for seats to facilitate a neutral position for the head and in a reclined seat head support may have a positive psychological effect on the user.

5 Conclusion

Head support for watching IFE in a slouched posture has no significant effect on muscle activity, since subjects will adapt their posture to have minimal muscle activity by placing the head above the rotation axes when support is lacking. However psychologically, head support will benefit the expected long-term comfort experience of the user.

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