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Title: Neck posture and muscle activity in a reclined business class aircraft seat watching IFE with and without head support

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Abstract: The purpose of this study is to research if a headrest benefits the comfort of the passenger and lowers muscle activity in the neck when sitting in a reclined (slouched) posture while watching in flight entertainment (IFE) in an aircraft business class seat.
No significant differences in muscle activity in the musculus sternocleidomastoid and musculus trapezius pars descendant were found between the conditions with headrest and without headrest. A significant difference in expected comfort rating was found. Subjects indicated they expect to experience more comfort with a headrest when watching IFE for duration of two movies during a long haul flight. This study also found a significant difference in posture. In the condition without headrest the head was more upright compared to the condition with headrest.
The lack of significant difference in muscle activity and the significant difference in posture may indicate that humans tend to look for a head position that is neutral in an unsupported condition, probably to minimise muscle effort. This study shows that the use of a headrest may benefit the comfort experience of the passenger during flight. However, further research is necessary on the design of the headrest and the long-term effects of head support on comfort, discomfort, muscle activity and fatigue for watching IFE in a slouched posture.

Covering Letter

Date 4 July, 2018
Our mark
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Dear Editor,

Thank you for the reviewing process and thanks to the two anonymous reviewers for their constructive comments and suggestions on our manuscript entitled *"Neck posture and muscle activity in a reclined business class aircraft seat watching IFE with and without head support"* by M. Smulders, A. Naddeo, N. Cappetti, E.D. van Grondelle, U. Schultheis and P. Vink.

Following your instructions in the mail and the reviewers' comments, we modified the manuscript accordingly. Here we submit our revised manuscript and our response to the reviewers, for your consideration for publication in the special issue on Comfort of Applied Ergonomics.

Thank you again and we are looking forward to your response.

On behalf of the rest of the team, yours faithfully,

ir. Maxim Smulders
Technical Ergonomist

Detailed Response to Reviewers

Response to Reviewers & Editor on comments of peer reviews

Reviewer	Comment	Comment reviewer	Concerns	Response author	**Change** (bold) / Example (underlined)
R1	R1.1 (R3.1)	In the method the time in which the individual remained in the activity of watching in flight entertainment (IFE) is not specified. Such information is essential to understand the results obtained.	§2	In *§2.4. Procedure* the duration is specified as 5 min. per condition. However, to clarify this to the reader, *"for 5 minutes each"* was added in *§2.2. Experimental setup and stimuli*.	(...) Surface electromyography (sEMG) was used to measure muscle tension in the m. sternocleidomastoid (SCM) and m. trapezius pars descendens (TRP-UP) in three conditions for **5 minutes each**: lying flat (condition A), sitting slouched watching IFE with a headrest (condition B) and without a headrest (condition C). (...)
R1	R1.2	In the method the time in which the individual remained in the activity of watching in flight entertainment (IFE) is not specified. Such information is essential to understand the results obtained. Could the results obtained from EMG have been influenced by this variable?	§4.4	Yes, due to the limitation of the duration of EMG measurements fatigue and discomfort could not be measured, as discussed in *§4.4. Study limitations and suggestions*.	Due to the limited context of this study, muscle fatigue (Sjøgaard et al., 1986) and discomfort (G. Sammonds, Fray, & Mansfield, 2014; Vink, 2004; Vink, 2016) were not recorded, since their impact could only be assessed properly over a longer period of time. (...)
R1	R1.3	The literature that the authors bring (Jørgensen, Fallentin, Krogh, Lund, and Jensen, 1988) to explain the results are based on the time of exposure to the stimulus, in this case 1 hour. It is suggested that the authors specify the experiment time and consider this variable in the analysis.	§4.1	The experiment duration of 5 minutes was emphasised in the comparison. The 5% MVC still gives an indication, as also the static contraction of the neck muscles will be continuous.	(...) The muscle tension of the SCM in this study was below 5% MVC **for 5 minutes contraction**, indicating that the muscle tension may not cause fatigue. The TRP-UP however shows a MVC over 5% **for 5 minutes contraction**, indicating that fatigue may occur in the long term in the shoulder-neck region.
R1	R1.4 (R3.3)	Another variable that can interfere in the evaluation is the height and weight of the participants. Has any analysis been made regarding these factors? Were significant differences found?	§3	Good point. However, it's important to state that the screen and headrest height were changed based on subject eye height and neck height. Additional additional statistical analysis has been conducted in SPSS on the influence of weight, stature height and age on comfort experience, posture and EMG. Results have been added.	*Please see R3.3.*
R1	R1.5	The evaluation of long term comfort was performed without a long experiment. Although the authors pointed out the limitation of the use of such an assessment, they could have brought existing literature on comfort to support the analyzes. There are studies that point to the evaluation of comfort over time in air travel. It would be more interesting to have compared the situations between them.	§4.2	Literature on long term comfort and discomfort assessment has been added, including a literature study by Vink et a (2017), which compares these studies.	(...) As shown by Bouwens, Schultheis, Hiemstra-van Mastrigt, and Vink (2017), it is not always possible to predict the experienced comfort based on expected comfort. **Studies that investigate long term comfort and discomfort show the importance of long term assessment with subject (e.g. Hiemstra-van Mastrigt, Meyenborg, and Hoogenhout (2016), Smulders et al. (2016) and Sammonds, Fray, and Mansfield (2017)), as long term the comfort usually decreases and discomfort increases over time (Vink, Anjani, Smulders, & Hiemstra-van Mastrigt, 2017).**
			§4.4	In addition, the limitation of the 5 min. experiment duration has been added to §4.4.	**Although it is not uncommon to conduct a comfort study for headrest for the limited duration of 5 minutes (Franz et al., 2012),** due to the limited context **(the limited duration of EMG measurement and comfort assessment of 5 minutes)** of this study, **no significant conclusion on long-term effects can be given.** Also muscle fatigue (Sjøgaard et al., 1986) and discomfort (G. Sammonds, Fray, & Mansfield, 2014; Vink, 2004; Vink, 2016) were not recorded, since their impact could only be assessed properly over a longer period of time. (...)
R3	R3.1 (R1.1)	Please specify the duration of the test in the Experimental setup paragraph	§2.2	In *§2.4. Procedure* the duration is specified as 5 min. per condition. However, to clarify this to the reader, *"for 5 minutes each"* was added in *§2.2. Experimental setup and stimuli*.	(...) Surface electromyography (sEMG) was used to measure muscle tension in the m. sternocleidomastoid (SCM) and m. trapezius pars descendens (TRP-UP) in three conditions for **5 minutes each**: lying flat (condition A), sitting slouched watching IFE with a headrest (condition B) and without a headrest (condition C). (...)
R3	R3.2	Please highlight if there were effects on the perceived comfort due to EMG devices. If yes, specify it in the limitations of the study.	§4.4	The EMG electrodes were indeed perceived by some subjects as uncomfortable, as these pushed into the skin due to cantact of the headrest and the load of the head. They were asked to ignore the sensors in their comfort assessment. However, this still could have been of influence on their rating. Therefore, as fairly suggested by the reviewer, this remark has been added to *§4.4. Study limitations and suggestions*.	(...) **In addition, the Trigno™ EMG sensors (electrodes) used in this study were 15mm thick and thus may be uncomfortable when in contact with the headrest, as electrodes pushed into the skin under load of the head. Subjects were asked to ignore this and to exclude the sensors form their comfort assessments. However, the sensors still could have influenced the perceived comfort of the subjects. Less invasive sEMG electrodes (e.g. more traditional wired pinch ECG/EEG/sEMG/EOG electrodes) are therefore advised in studying comfort in situations where the electrode may be between the human body and a contact surface, such as a seat and headrest.**
R3	R3.3 (R1.4)	Please give information about (if present) correlations between results and anthropometric data.	§3	An additional statistical analysis has been conducted in SPSS on the influence of weight, stature height and age on comfort experience, posture and EMG. No sig. correlation was found for EMG and antropometrics. A positive correlation was found between stature lengths and comfort rating of supported general, neck and head comfort.	(...) However, the SCM showed a low activity level (2%MVC on average). **No significant influence of study location, gender, age, stature length and testing order on the comfort scores was found, except for weight which has moderate correlations with the TRP-UP in conditions A (r=.565, p=.01), B (r=.538, p=.02) and C (r=.574, p=.01).** Expected long-term comfort scores for whole-body comfort, neck comfort, head comfort and eye comfort are shown in Figure 14. Whole body **(p=.003)**, head (p<.001) and neck comfort **(p=.001)** was significantly higher in the condition with a headrest (condition B). There was no significant difference found for the eyes **(p=.411)**. No significant influence **of study location, gender, age and stature length on the comfort scores was found, except for a moderate correlation between testing order (r=-.589, p=.006) and eye comfort in condition B.** (...) **A significant difference was found between the study locations for TA (B) (p=.001), TA (C) (p=.03) and EEL-h (B) (p=.03), between genders for TA (B) (p=.007) and between testing order for NA-v (C) (p=.001) and EEL-h (B) (p=.02). Moderate correlations have been found between age and TA (B) (r=.615, p=.005) and TA (C) (r=.662, p=.002), weight and TA (C) (r=.582, p=.009) and length and TA (C) (r=.578, p=.01). However, no moderate or strong correlation has been found between the amplitude of movement of TA (condition B minus C) and study location, gender, age, stature length and testing order.**

Response to Reviewers & Editor on changes by authors				
Author	**Comment**	**Concerns**	**Change by author**	**Change** (bold)
Smulders	A1.1	Corresponding Author	Corresponding author email address changed into "m.smulders@tudelft.nl".	* Corresponding author. E-mail address: **m.smulders@tudelft.nl**
Smulders	A1.2	Keywords	Added "TV" as we think this information may also be relevant for watching TV and In Vehicle Entertainment (a.k.a. IVE/ICE/IVI).	Keywords: EMG, posture, neck angle, aircraft seat, headrest, comfort, **TV**
Smulders	A1.3	Abbreviations	Added sEMG	EMG **(sEMG)**: **(surface)** Electromyography: an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles.
Smulders	A1.4	Abbreviations	Added ICE/IVE in the abbreviations, as these are mentioned in §5.1.	**ICE/IVI In-Car Entertianment or In-Vehicle Infotainment is a collection of hardware and software in automobiles that provides audio or video entertainment.**
Smulders	A1.5	Abbreviations	Added VAS, as this is mentioned in §2.2.	**VAS Visual Analogue Scale, an instrument to measure a characteristic or attitude across a continuum range of values.**
Smulders	A1.6	Abbreviations	Added meaning of significance asterisks.	*** Correlation is significant at the 0.05 level (2-tailed).** **** Correlation is significant at the 0.01 level (2-tailed).** ***** Correlation is significant at the 0.001 level (2-tailed).**
Smulders	A1.7	§1	Addition of reference.	**As seat characteristics influences comfort experience (Bouwens, Hiemstra-van Mastrigt, and Vink, 2018) in watching IFE, As seat characteristics influences the comfort experience (Bouwens, Hiemstra-van Mastrigt, and Vink, 2018) in watching IFE,** such an insight could lead to a new design requirement and/or recommendation for headrest of (premium) aircraft seats, but can also be used in car seats (e.g. in autonomous driving) and home and office furniture design.
Smulders	A1.8	§1.2	Added source, as Groenesteijn et al (2012) demonstrates that task (e.g. VDU work, which is more restricted due to e.g. input devices and screen) influences posture	(...) The question is whether this is applicable in the context of the use of IFE in the aircraft cabin, due to the lack of intensive use of input devices (e.g. a mouse and keyboard in VDU use) and bigger variety in backrest recline (where office seats are more limited), which might results in other preferred posture **(Groenesteijn et al., 2012)**, head, neck and eye angles. (...)
Smulders	A1.9	§2.2	Added the screen resolution of the LCD monitor used, as this information was missing.	(...) facing a 15" LCD monitor **with a 1440x900 resolution** (further named IFE screen) featuring a TED (a media organisation which posts talks on Technology, Entertainment and Design online for free distribution) talk on the subjects' interest (www.ted.com/topics). (...)
Smulders	A1.10	§2.2	Replaced 'horizontal score line' by VAS + added reference	A score needed to be given for the neck, head and eyes specifically and for the whole-body experience by drawing a vertical line on a **horizontal visual analogue scale (VAS)-line** with 'not comfortable' and 'very comfortable' at its ends **(Bouwens, Schultheis, Hiemstra-van Mastrigt, & Vink, 2017)**.
Smulders	A1.11	§2.2.1	Solved multiple grammar errors.	(...) Although Sommerich et al. (2000) **cite** multiple studies **that** measured the splenius with sEMG, Mayoux Benhamou et al. (1995) **argue** it can only be measured by fine-wire or needle electrodes. (...)
Smulders	A1.12	§2.4	Removed "For postural analysis, a picture was taken" in procedure 'Preparing sitting position', as this was not used on the analysis.	
Smulders	A1.13	§2.4	Senences combined	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) **and the height of the headrest was adjusted to make the headrest support the neck and head**.
Smulders	A1.14	§2.4	Spelling Error: changed US English into UK English.	Thereafter the subjects were asked to stand up and take a break for 2 minutes, to **minimise** fatigue (Tan, Chen, & Rauterberg, 2010).
Smulders	A1.15	§2.4	Added type of TeraBand used (Red) in main tekst and alterated sentences to fit this addition.	(...) Subjects were asked to push their head against a TheraBand® **Red (medium strength)** – which was connected to the seat frame – as hard as they could for 3 seconds (**flexion;** see Figure 10). They were verbally encouraged when needed. Thereafter subjects had a recovery break of 30 seconds and repeated the exercise another two times. Delsys® EMGworks™ automatically determined the highest EMG of the three MVC contractions (a manual correction was made when necessary). 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 as hard as they could for 3 seconds (**extension;** see Figure 11). This procedure was repeated another two times and the highest MVC-EMG was determined.
Smulders	A1.16	Figure 10	Added 'Red (medium strength)' to be more complete to figure caption.	Figure 10 MVC flexion by pushing against an elastic TheraBand® **Red (medium strength)**
Smulders	A1.17	Figure 14	Updated figure caption, as it stated 'comfort', instead of 'expected long-term comfort'.	Figure 14 Mean **'expected long-term comfort'** scores with SD (n=20)
Smulders	A1.18	§2.5	Major revisions and additions, as statistical tests have been re-done in IBM SPSS.	(...) In **IBM® SPSS® Statistics a paired t-test (2- tailed)** was taken of the mean %MVC signals to check for significant differences (p < 0.05) between the conditions, as well as **an independent T-Test (two tailed)** for influence of testing order, gender and testing location. **In addition, a Pearson product-moment correlation coefficient was computed to assess influence of age, weight and stature length on the muscle activity**. (...)
Smulders	A1.19	§2.5	Some changes to be more precise and consistent in terminology	All ratings were collected by measuring the given scores on the 10 cm long (...) **VAS-line** with a ruler and all handwritten comments were typed down and processed with **IBM® SPSS® Statistics**. (...)
Smulders	A1.20	§2.5	Replaced "testing order, gender and testing location were tested with a paired t-test (p<0.05)."	(...) In addition **an independent T-Test (two tailed) for influence of testing order, gender and testing location and a Pearson product-moment correlation coefficient to assess the relationship of age, weight and stature length with the comfort ratings were computed.**

Smulders	A1.21	§2.5	Major revisions and additions, as statistical tests have been re-done in IBM SPSS.	(…) The angle of each line in space was recorded (based on Psihogios et al. (2001)) and processed in **IBM® SPSS® Statistics**. A **Wilcoxon (2-tailed)** test was taken of each angle to check for significant differences between the conditions ($p < 0.05$), as well as **an independent T-Test (two tailed) for influence of testing order, gender and testing location and a Pearson product-moment correlation coefficient was computed to assess the influence of age, weight and stature length on the taken posture.**
Smulders	A1.22	§3	Major revisions and additions, as statistical tests have been re-done in IBM SPSS.	(…) **No significant influence of study location, gender, age, stature length and testing order on the comfort scores was found, except for weight which has moderate correlations with the TRP-UP in conditions A (r=.565, p=.01), B (r=.538, p=.02) and C (r=.574, p=.01).** (…)
Smulders	A1.23	Table 4	Major revisions and additions, as statistical tests have been re-done in IBM SPSS.	Condition SCM TRP-UP AB **0.006** * **0.7** AC **0.4 0.5** BC **0.1 0.7**
Smulders	A1.24	§3	Major revisions and additions, as statistical tests have been re-done in IBM SPSS.	(…) Expected long-term comfort scores for whole-body comfort, neck comfort, head comfort and eye comfort are shown in Figure 14. Whole body **(p=.003)**, head **(p<.001)** and neck comfort **(p=.001)** were significantly higher in the condition with a headrest (condition B). There was no significant difference found for the eyes **(p=.411)**. No significant influence of **study location, gender, age and stature length** on the comfort scores was found, except for **a correlation between testing order (r=-.589, p=.006) and** eye comfort in condition B. The inclinations describing the head-neck posture in conditions B and C can be found in Table 5 and are visualised in Figure 15. The inclination data show that the posture was significantly different between condition B and C. Without head support (C) the head was found to be more upright in respect to with head support (B). **A significant difference was found between the study locations for TA (B) (p=.001), TA (C) (p=.03) and EEL-h (B) (p=.03), between genders for TA (B) (p=.007) and between testing order for NA-v (C) (p=.001) and EEL-h (B) (p=.02). Correlations are also found between age and TA (B) (r=.615, p=.005) and TA (C) (r=.662, p=.002), weight and TA (C) (r=.582, p=.009) and length and TA (C) (r=.578, p=.01). However, no moderate or strong correlations have been found between the amplitude of movement of TA (condition B minus C) and study location, gender, age, stature length and testing order.**
Smulders	A1.25	Figure 14	Replaced "comfort"	Figure 14 Mean **'expected long-term comfort'** scores with SD (n=20)
Smulders	A1.26	Table 5	Updated Wilcoxon test results after new statistical tests in IBM SPSS	Angle TA NA-v EEL-h GA-h Condition B C B C B C B C Mean 126.3˚ 124.5˚ 18.0˚ 29.0˚ 23.6˚ 13.8˚ -2.6˚ -2.2˚ SD 2.5˚ 2.7˚ 4.0˚ 3.5˚ 5.6˚ 5.3˚ 1.0˚ 1.2˚ Max 132.8˚ 131.4˚ 24.7˚ 35.7˚ 36.2˚ 27.6˚ -0.9˚ 0.6˚ Min 123.3˚ 120.6˚ 11.5˚ 23.4˚ 14.7˚ 5.2˚ -5.5˚ -5.0˚ Difference (mean) 1.9˚ 11.0˚ 9.9˚ 0.4˚ Wilcoxon (2-tailed) **0.001** *** **0.001** *** **0.001** *** **0.007** **
Smulders	A1.27	§4.1	Added, due to new IBM SPSS results.	(…) **The positive moderate correlation between weight and muscle activity in the TRP-UP could be explained by the additional load of tissue of the head and perhaps the arms on the neck-shoulder muscles.**
Smulders	A1.28	§4.3	Added, due to new IBM SPSS results.	(…) **The difference of posture between testing locations, genders and age possibly could be explained by weight and stature length, as the USA testing location only had male participants who were also significantly older than the subject of the NLD location. Males are also generally longer and weight more than females, thus could explain the difference. That said, weight and length only had a moderate correlation with TA in condition C. However, no moderate or strong correlation has been found between the amplitude of movement of TA (condition B minus C).**
Smulders	A1.29	§5.1	Added In-Car Entertianment or In-Vehicle Infotainment as this study might be relevant for these industries.	(…) . Implementing head support for slouched postures when watching an IFE, TV, **ICE/IVI** or VDU screen in premium cabin aircraft seats, (autonomous) car seats and home/office/cinema furniture may improve the user comfort. (…)
Smulders	A1.30	Acknowledgements	Added dr. Y. Song as he helped in improving this paper these last couple of weeks.	(…) We want to thank ir. J.M.A. Bouwens, dr.ir. S. Hiemstra-van Mastrigt, ir. S. Akkerman, ir. D.M. Lips **and dr. Y. Song** for their contribution (…)
Smulders	A1.31	References	Addition of reference.	**Bouwens, J., Hiemstra-van Mastrigt, S., & Vink, P. (2018). Ranking of Human Senses in Relation to Different In-flight Activities Contributing to the Comfort Experience of Airplane Passengers. International Journal of Aviation, Aeronautics, and Aerospace, 5(2), 9.**
Smulders	A1.32	References	Addition of reference.	**Groenesteijn, L., Ellegast, R. P., Keller, K., Krause, F., Berger, H., & de Looze, M. P. (2012). Office task effects on comfort and body dynamics in five dynamic office chairs. Applied ergonomics, 43(2), 320-328.**
Smulders	A1.33	References	Addition of reference.	**Hiemstra-van Mastrigt, S., Meyenborg, I., & Hoogenhout, M. (2016). The influence of activities and duration on comfort and discomfort development in time of aircraft passengers. Work, 54(4), 955-961.**
Smulders	A1.34	References	Addition of reference.	**Vink, P., Anjani, S., Smulders, M., & Hiemstra-van Mastrigt, S. (2017). Comfort and discomfort effects over time: the sweetness of discomfort and the pleasure towards of the end. Paper presented at the 1st International Comfort Congress, Salerno, Italy.**
Smulders	A1.35	Graphical Abstrat	Added significance symbols correctly (** instead of *).	
Naddeo	A2.1	§4.3	Added text with new reference	Apostolico et al. (2014) also confirmed that the most comfortably posture (….)
Naddeo	A2.2	References	Added a reference	Apostolico et al. (2014

Vink	A3.1	Abstract	Replaced "in the sense of minimal musle effort"	(…) The lack of significant difference in muscle activity and the significant difference in posture may indicate that humans tend to look for a head position that is neutral **in an unsupported condition, probably to minimalise muscle effort.** (…)
Vink	A3.2	§1	Addition	(…) Improving the comfort experience is especially interesting for airlines to differentiate themselves (Vink & van Mastrigt, 2011), since comfort is **one of the** decisive factors for passengers when they book a flight (e.g. business class) especially on long haul flights (Alamdari, 1999; Bieger, Wittmer, & Laesser, 2007; Vink & Brauer, 2011). (…)
Vink	A3.3	§1.1	Deleted "It is important to determine the posture taken in a seat for the activity of watching IFE in the aircraft, since " and revised sentence.	(…) **The** head inclination is influenced by the inclination of the trunk (Delleman et al., 2004) **and the total body** posture influences comfort (Naddeo, Cappetti, & D'Oria, 2015; van Veen et al., 2014). **Additionally**, facilitating a good posture may – on the long run – prevent musculoskeletal injuries (Delleman et al., 2004). (…)
Vink	A3.4	§1.1	Minor changes	(…) A possible explanation for this preference for a reclined/slouched posture may be the **relative** low back muscle activity **in this position**, as shown in the study by Goossens, Snijders, Roelofs, and Buchem (2003). A study based on an experiment with one subject of Wilke, Neef, Caimi, Hoogland, and Claes (1999) and a study based on five subjects of Rohlmann, Zander, Graichen, Dreischarf, and Bergmann (2011) may give an indication that a slouched posture also lowers pressure **in** the intervertebral disks. (…)
Vink	A3.5	§1.2	Minor changes	(…) In the context of watching IFE in a slouched posture, flexing the head forward with respect to the trunk without head/neck support, it **could be assumed that** the activity of the flexion muscles **increase** to maintain (static) position. (…)
Vink	A3.6	§1.2	Added source and reconstructed sentence, as according to RULA an neck flexion angle of more than 20 degrees increases the risk.	(…) However, there are indications that prolonged (e.g. when watching one or multiple movies) eye deorsumversion over 15˚ is not recommended (Delleman et al., 2004; Psihogios et al., 2001), as is prolonged (unsupported) neck flexion beyond **20˚ (McAtamney and Corlett, 1993) or** 30˚ (Chaffin, 1973)**, which** could cause muscle fatigue and the perception of discomfort by the development of a headache with pains of the head, in the area of the face, behind the eyes and in the neck (Dalassio, 1980; J. Travell, 1967; J. G. Travell & Simons, 1992). (…)
Vink	A3.7	§1.3	Minor changes. Eeplaced **m. trapezius clavicularconsistency** by *m. traezius pars decendens* for terminology improvement. Replaced *lateral* by *flexion-extension*.	(…) The muscle tension in the **m. trapezius pars descendens** (TRP-UP) with support of a headrest surpasses the simulated muscle tension without a headrest at approximately -11˚, but keeps close to each other. Hypothetically a headrest should generate a force forward on the head reducing the muscle activity of muscles anterior to the **flexion-extension** rotation axis in the neck. (…)
Vink	A3.8	§2	Moved "12 subjects started in the condition with headrest and the other 9 without headrest." to §2.2	
Vink	A3.9	§2.2.1	Sentense revision	(…) Surface EMG (sEMG) **is more suitable to record** superficial muscles with their belly located directly beneath the skin surface (Stanton, Hedge, Brookhuis, Salas, & Hendrick, 2004). (…)
Vink	A3.10	§2.4	Removed "Thereafter subjects were asked to stand up and to state their expected long-term comfort on the questionnaire." at procedure 'Condition A: lying flat'.	
Vink	A3.11	§2.4	Removed "Order effect prevention To prevent order effects, (approximately) half of the subjects started sitting in condition B and the other "	
Vink	A3.12	§2.4	"at the end|" replaced	(…) **In the last minute** a lateral picture of the posture was taken and then the TED-talk movie paused. The subject was asked to fill in the expected long-term comfort questionnaire. (…)
Vink	A3.13	§4.3	Replaced "may indicate"	(…) The reason for not finding any difference in the EMG (and the low EMG signals) **could be** that humans have the tendency to look for a neutral head position. (…)
Vink	A3.14	§4.2	Removed "continuous"	(…) Stability offered by support of a headrest may avoid **…** corrections by the neck to maintain stability, (…)
Vink	A3.15	References	Added a reference	McAtamney, L., & Corlett, E. N. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. Applied ergonomics, 24(2), 91-99.

Highlights

- A slouched posture is preferred for watching in flight entertainment (IFE) and TV
- Head support does not significantly lower muscle activity of neck muscles
- Humans tend to look for a head position with minimal muscle effort
- The expected comfort experience of the user is higher with head support

Title Page

Neck posture and muscle activity in a reclined business class aircraft seat watching IFE with and without head support

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Abstract

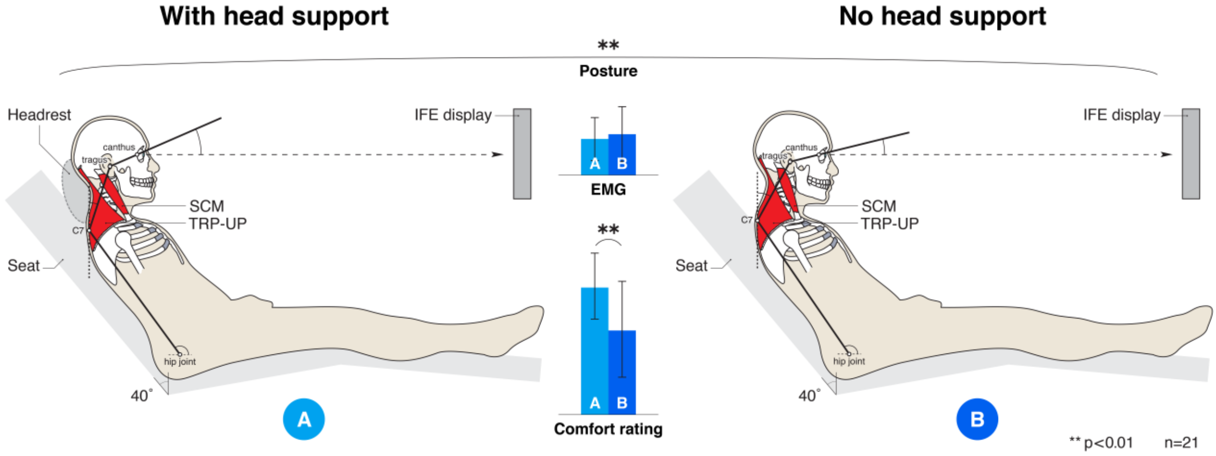
The purpose of this study is to research if a headrest benefits the comfort of the passenger and lowers muscle activity in the neck when sitting in a reclined (slouched) posture while watching *in flight entertainment* (IFE) in an aircraft business class seat.

No significant differences in muscle activity in the musculus sternocleidomastoid and musculus trapezius pars descendant were found between the conditions with headrest and without headrest. A significant difference in *expected comfort rating* was found. Subjects indicated they expect to experience more comfort with a headrest when watching IFE for duration of two movies during a long haul flight. This study also found a significant difference in posture. In the condition without headrest the head was more upright compared to the condition with headrest.

The lack of significant difference in muscle activity and the significant difference in posture may indicate that humans tend to look for a head position that is neutral , in the sense of minimal muscle effort. This study shows that the use of a headrest may benefit the comfort experience of the passenger during flight. However, further research is necessary on the design of the headrest and the long-term effects of head support on comfort, discomfort, muscle activity and fatigue for watching IFE in a slouched posture.

Graphical abstract

The significant difference in posture and the lack of significant difference in muscle activity (EMG) may indicate that humans tend to look for a head position with minimal muscle effort. A headrest may improve the expected comfort experience of the user.



Highlights:

- A slouched posture is preferred for watching in flight entertainment (IFE) and TV
- Head support does not significantly lower muscle activity of neck muscles
- Humans tend to look for a head position with minimal muscle effort
- The expected comfort experience of the user is higher with head support

Keywords: EMG, posture, neck angle, aircraft seat, headrest, comfort, TV

Abbreviations:

EMG (sEMG)	(surface) Electromyography: an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles.
ICE/IVI	In-Car Entertianment or In-Vehicle Infotainment is a collection of hardware and software in automobiles that provides audio or video entertainment. It is to some extend comparable with IFE.
IFE	In Flight Entertainment: the screens on board of an aircraft to entertain passengers, featuring (depending on what the airline offers) movies, (live) TV, games, interactive maps, magazines, et cetera. In economy class these screens are mainly mounted at the upper part of the backrest and for bulkhead seats mounted on an arm that can be stowed in the armrest. In business class these screens are often mounted against the shell of the seat in front or on the bulkhead.
MVC	Maximum Voluntary Contraction: maximum force, which a human subject can produce in a specific isometric exercise. In practice, the strongest contraction out of three efforts in a single test session is used.
SCM	Musculus sternocleidomastoid.
TRP-UP	Musculus trapezius pars descendens.
TTL	Taxi, Take-off and Landing position: the most upright seat position, which is the required position during Taxi, Take-off and Landing of the aircraft for safety reasons.
VAS	Visual Analogue Scale, an instrument to measure a characteristic or attitude across a continuum range of values.
VDU	Visual Display Unit, a device for displaying input signals as characters on a screen.

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Neck posture and muscle activity in a reclined business class aircraft seat watching IFE with and without head support

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1. Introduction

This paper investigates if a headrest supporting the head benefits the comfort of an aircraft passenger and lowers muscle activity in the neck when sitting in a reclined (slouched) posture while watching *in flight entertainment* (IFE) in a Business Class seat.

As seat characteristics influences comfort experience (Bouwens, Hiemstra-van Mastrigt, and Vink, 2018) in watching IFE, such an insight could lead to a new design requirement and/or recommendation for headrest of (premium) aircraft seats, but can also be used in car seats (e.g. in autonomous driving) and home and office furniture design. Improving the comfort experience is especially interesting for airlines to differentiate themselves (Vink & van Mastrigt, 2011), since comfort is one of the decisive factors for passengers when booking a flight (e.g. business class), especially on long haul flights (Alamdari, 1999; Bieger, Wittmer, & Laesser, 2007; Vink & Brauer, 2011).

There is a body of literature available, which discusses (preferable) neutral head angles (neutral in the sense of minimal muscle effort) with an upright or slightly reclined trunk (Ankrum & Nemeth, 2000; Braun & Amundson, 1989; Johnson, 1998; Mon-Williams, Burgess-Limerick, Plooy, & Wann, 1999; Raine & Twomey, 1997; Vink, 2016). For the position in the car, amongst others 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) discuss neutral head angles in the context of tablet use. Recommendations on head angles when using VDU's are described in Delleman, Haslegrave, and Chaffin (2004) and Psihogios, Sommerich, Mirka, and Moon (2001). However, in the context of watching IFE in a business class aircraft seat with a reclined trunk, literature remains limited.

1.1. Preference for a slouched posture when watching IFE/TV

The head inclination is influenced by the inclination of the trunk (Delleman et al., 2004) and the total body posture influences comfort (Naddeo, Cappetti, & D'Oria, 2015; van Veen et al., 2014). Additionally, facilitating a good posture may – on the long run – prevent musculoskeletal injuries (Delleman et al., 2004).

As observed in studies by Knijnenburg (2005), van Rosmalen, Groenesteijn, Boess, and Vink (2009, 2010), 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 *in flight entertainment* (IFE) during flight (see Table 1). Knijnenburg (2005) describes a preferred backrest recline of 30˚ for watching TV in a lorry. 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. 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. See Figure 1 and Table 2 for a comparison.

A possible explanation for this preference for a reclined/slouched posture may be the relative low back muscle activity in this position, as shown in the study by Goossens, Snijders, Roelofs, and Buchem (2003). A study based on an experiment with one subject of Wilke, Neef, Caimi, Hoogland, and Claes (1999) and a study based on five subjects of Rohlmann, Zander, Graichen, Dreischarf, and Bergmann (2011) may give an indication that a slouched posture also lowers pressure in the intervertebral disks. Although a multitude of in vivo spinal load studies have been conducted (Dreischarf, Shirazi-Adl, Arjmand, Rohlmann, & Schmidt, 2016), a substantial study sample is lacking to support this claim. The works of Schüldt, Ekholm, Harms-Ringdahl, Németh, and Arborelius (1986, 1987) show that neck muscle activity was reduced when neck flexion was increased by a backward inclination of the trunk (thoraco-lumbar spine).

Table 1 Preference for a slouched posture when watching IFE/TV.

Reference	*Activity*	*Sample size (n)*	*Study setup*	*Conclusion*
Knijnenburg (2005)	Watching TV in a passenger side lorry seat	20	Observation / Interview	A slouched posture was taken by subjects as most comfortable for watching TV in a truck.
Van Rosmalen et al. (2009, 2010)	Watching TV at home in a lounge seat	13	Observation / Questionnaire / Context mapping	Subjects change posture frequently, and mostly have their feet off the ground. A slouched/ reclined posture was most preferred and head support by a headrest was recommended to lower discomfort.
Filho et al. (2015)	Watching TV at home	1102	Questionnaire	51.4% prefers a slouched, reclined or lying posture, 31.9% regularly changes posture, 7.1% prefers an upright posture, 2.3% does not watch TV and 7.4% stated they preferred a different posture than shown in the survey.
Hiemstra-van Mastrigt (2015)	Watching IFE in an economy class aircraft seat	28	Observation / Questionnaire	A slouched posture with an upright head was taken by subjects as most comfortable for watching IFE
Smulders et al. (2016)	Watching IFE in a business class aircraft seat	10	Observation / Questionnaire / Interview	A slouched posture was taken by subjects as most comfortable for watching IFE. Half the subjects rested the head against the backrest and conducted deorsumversion of the eyes (looking 'downward'), where the other half flexed the head forward to watch the IFE screen.

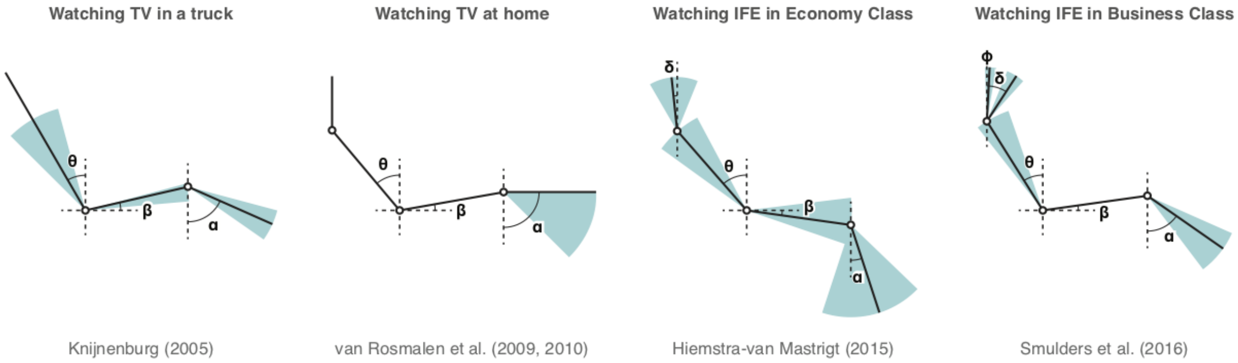

Figure 1 2D visual representation of seat angles as given in Table 3. Black lines represent mean values, where the blue areas represent the observed range (minimal and maximal angles, without outliers) (figure representation based on Hiemstra-van Mastrigt (2015)).

Table 2 Seat/body angle comparison. See Figure 1 for a visual representation of the given angle.

Reference	*Activities*	*Sample size (n)*	*Mean legrest/ lower leg angle (α)*	*Mean seat pan/ upper leg angle (β)*	*Mean backrest/torso angle (θ)*	*Mean head angle (δ/Φ)*
Knijnenburg (2005)	Watching TV in a lorry	16	66˚ (SD=7.2) [1]	13˚ (SD=3.1) [1]	30˚ (SD=8.5) [1]	Not investigated, but was set parallel to backrest
van Rosmalen et al. (2009, 2010)	Watching TV in a television seat	13	90˚/45˚	10˚	40˚	0˚
Hiemstra-van Mastrigt (2015)	Watching IFE in an economy class seat	28	18˚ (SD=16.8˚) [2]	-8˚ (SD=6.6˚) [2]	41˚ (SD=6.1˚) [2]	-6˚ (SD=13˚) [2]
Smulders et al. (2016)	Watching IFE in a business class seat	10	55˚ (SD=11.6˚)	Not investigated, but was set at 5˚	32˚ (SD=5.6˚)	38˚ (SD=9˚) /12˚ (SD=7˚) [3]

[1] Data were acquired by secondary analysis of the study data of Knijnenburg (2005)

[2] Data were acquired by secondary analysis of the study data of Hiemstra-van Mastrigt (2015)

[3] Data were acquired by secondary analysis of the study data of Smulders et al. (2016)

1.2. Head flexion and the strain on the muscles

According to Delleman et al. (2004) the head angle is – besides the orientation of the trunk – influenced by the viewing angle on the (IFE) screen and thus its position and orientation. Kroemer and Hill (1986) show the preferred gaze angle becomes lower as the viewing distance decreases, indicating that in economy class – where space is more scarce – an IFE screen should be below eye level and oriented perpendicular to the line of sight (see Figure 2). Psihogios et al. (2001) and Delleman et al. (2004) concluded in their reviews of literature on VDU viewing angles that a downward visual angle between 0˚ and 15˚ was preferred when looking at the centre of the screen, sitting in an upright position while working on input devices such as a keyboard and a mouse. The question is whether this is applicable in the context of the use of IFE in the aircraft cabin, due to the lack of intensive use of input devices (e.g. a mouse and keyboard in VDU use) and bigger variety in backrest recline (where office seats are more limited), which might results in other preferred posture (Groenesteijn et al., 2012), head, neck and eye angles. Yoichi et al. (2012) state however that a more horizontal line of sight is preferred for further distances between the eyes and a TV screen, and thus could be more appropriate for business class with its bigger screens, generous space (bigger eye-screen distance, D) and generous backrest recline (θ) (see Figure 2). Also Kroemer and Hill (1986) and Mon-Williams, Burgess-Limerick, Plooy, and Wann (1999) show that a more horizontal view is preferred when reclining the backrest and increasing the eye-screen distance.

When reclining the backrest (30-41˚) in a business class seat while watching IFE, people tend to glare under a downward angle (eye deorsumversion) or flex the head forward to establish a good (horizontal) view on the IFE screen (see A and B in Figure 3), which was observed in the study by Smulders et al. (2016) (see also Table 2).

However, there are indications that prolonged (e.g. when watching one or multiple movies) eye deorsumversion over 15˚ is not recommended (Delleman et al., 2004; Psihogios et al., 2001), as is prolonged (unsupported) neck flexion beyond 20˚ (McAtamney & Corlett, 1993) or 30˚ (Chaffin, 1973) which could cause muscle fatigue and the perception of discomfort by the development of a headache with pains of the head, in the area of the face, behind the eyes and in the neck (Dalassio, 1980; J. Travell, 1967; J. G. Travell & Simons, 1992). It can be presumed that passengers are trying to look for support when flexing the head forward (see C in Figure 3) by using a pillow (which is commonly supplied to passengers on long haul business class flights).

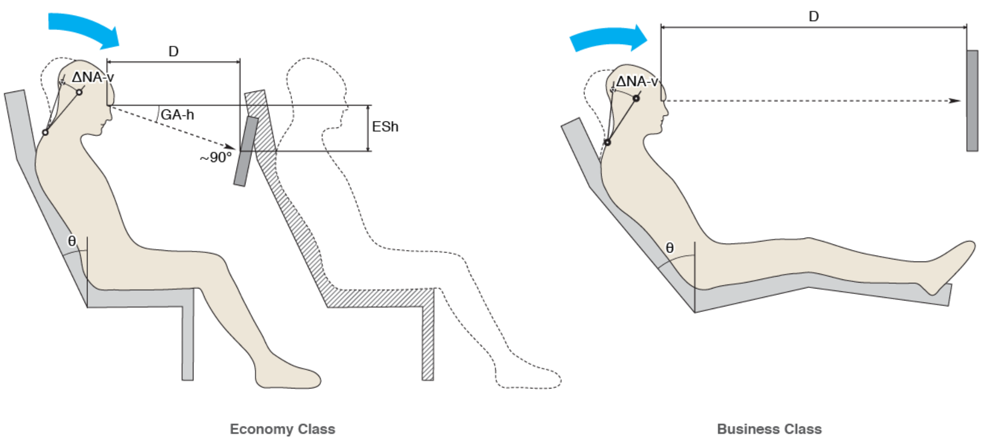

Figure 2 Economy class and business class screen orientation (anatomical representation indicative only).

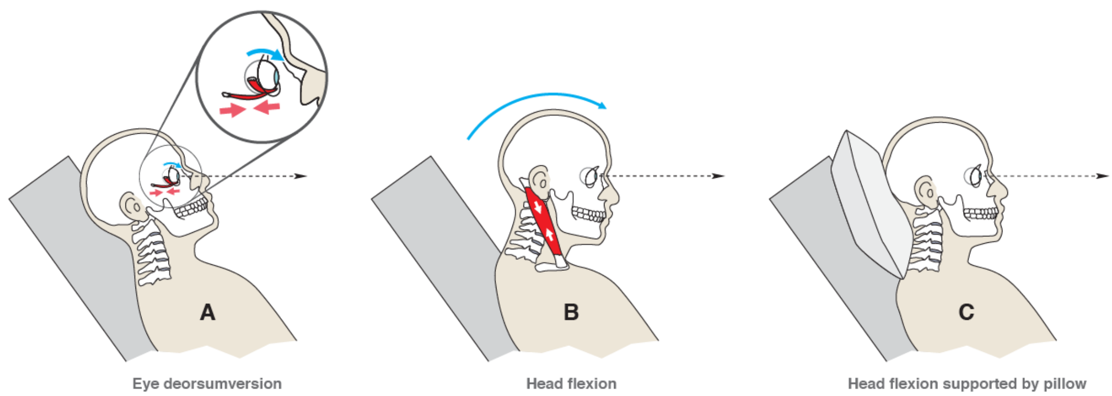

Figure 3 Subject watching IFE in slouched posture while A) deorsum ducting the eyes by contracting a.o. the m. inferior rectus and m. inferior oblique B) flexing the head forward with respect to the trunk by contracting a.o. the m. sternocleidomastoid and C) flexing the head forward while gaining support of a pillow (anatomical representations indicative only).

In the studies of van Rosmalen et al. (2009) and Smulders et al. (2016) it was observed that subjects lacked neck/head support when watching TV/IFE in the slouched posture. In the study performed by Hiemstra-van Mastrigt (2015) subjects reported discomfort in the neck when watching IFE in an economy aircraft seat. In a context mapping study by van Rosmalen et al. (2010) for a TV lounge seat, subjects requested a headrest for head support.

Goossens et al. (2003) show that free shoulder space and a reclined backrest lowers back muscle activity. A headrest 'pushing' the head forward could increase the muscle activity of the neck extension muscles (e.g. m. splenius, m. semispinalis and m. trapezius pars descendens). But at the same time head support may lower the tension on the flexion muscles (e.g. m. sternocleidomastoid, m. scalenus anterior and medius). No head support could have the effect that the head is less stable and more muscle activity is required to maintain (static) position. In a study by Lin and Huang (2007) on an economy aircraft seat, the sternocleidomastoid relaxed over time when using neck support in the *Taxi, Take-off and Landing position* (TTL) (i.e. the most upright position in an aircraft seat) while the m. trapezius pars descendens activity did not change.

In the context of watching IFE in a slouched posture, flexing the head forward with respect to the trunk without head/neck support, it could be assumed that the activity of the flexion muscles increase to maintain (static) position. The question is whether this is the case. This could be answered by using a biomechanical model and *electromyography* (EMG).

1.3. Theoretical biomechanical simulation

Neck flexion theoretically stretches the muscles posterior to the movement axis and contracts the neck muscles anterior to the movement axis. In a simulation with the musculoskeletal AnyBody™ model (see Figure 4), it was found that neck muscle activity decreases (see Figure 5) when the head flexes to gain a horizontal view, while the backrest was reclined at 40˚ and the back, buttocks, upper legs and lower arms were supported. In an AnyBody™ simulation with the model in the same context, but where a headrest supports the head/neck, the muscle activity was less for most muscles (see Figure 5). The muscle tension in the m. sternocleidomastoid (SCM) with support of a headrest increases above -15.5˚, but keeps below the muscle tension without a headrest. The muscle tension in the m. trapezius pars descendens (TRP-UP) with support of a headrest surpasses the simulated muscle tension without a headrest at approximately -11˚, but keeps close to each other.

Hypothetically a headrest should generate a force forward on the head reducing the muscle activity of muscles anterior to the flexion-extension rotation axis in the neck.

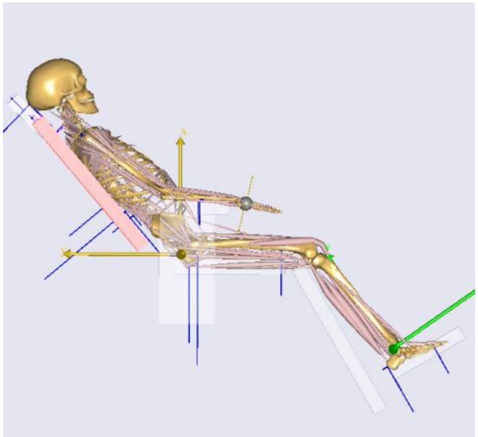

Figure 4 Musculoskeletal model with supported back, buttocks, upper legs and lower arms (AnyBody Technology A/S, Aalborg, Denmark).

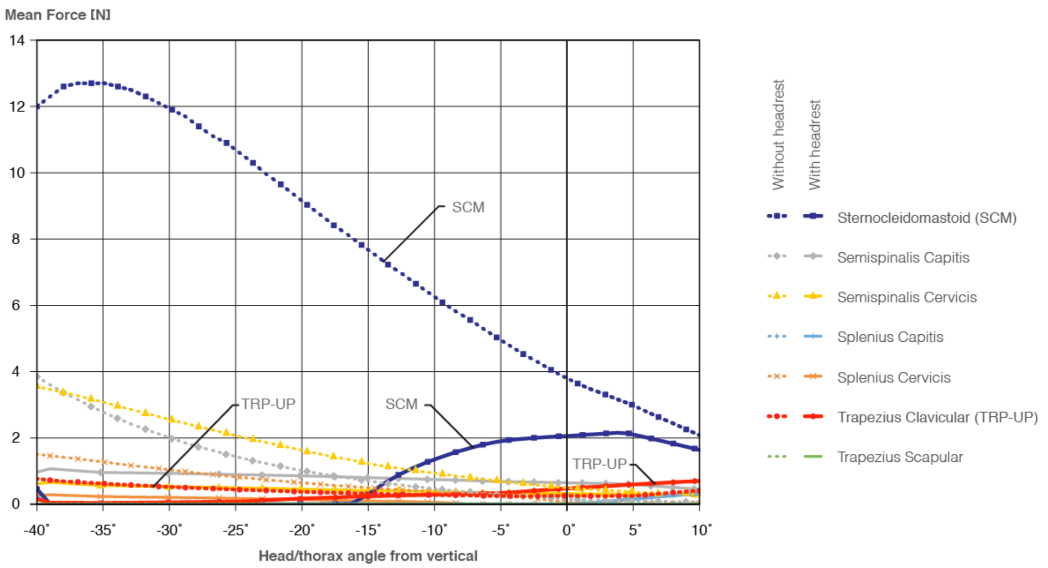

Figure 5 AnyBody™ simulation of mean muscle forces [N] when head flexes from parallel to backrest (set at -40°) to upright (0˚) and beyond (till 10˚).

2. Materials and methods

To study the effect of a headrest in a slouched position, *surface electromyography* (sEMG), posture and (subjective) *expected long-term comfort* ratings were recorded of 21 subjects sitting in a lounge seat with a backrest recline of 40˚, simulating an aircraft business class seat. Surface EMG was recorded of the m. trapezius pars descendens (TRP-UP) and m. sternocleidomastoid (SCM) for 5 minutes in each condition. Postures in the different conditions were recorded by camera. *Expected long-term comfort* ratings were recorded using a questionnaire.

2.1. Subjects

11 female and 10 male American (4), Chinese (1), Dutch (15) and Iranian (1) adults with no injuries and/or physical complaints in the neck area in the past six months and who had experience as aircraft passengers in the past participated in this study (see Table 3). Subjects were asked to wear top clothing without a collar – preferably a T-shirt – for easy sensor placement.

Table 3 Characteristics 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 exact same setup and EMG equipment. 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 (sEMG) was used to measure muscle tension in the m. sternocleidomastoid (SCM) and m. trapezius pars descendens (TRP-UP) in three conditions for 5 minutes each: lying flat (condition A), sitting slouched watching IFE with a headrest (condition B) and without a headrest (condition C). Here 12 subjects started in the condition with headrest (order A, B and C and 9 without headrest (order A, C and B).

To stimulate full muscle relaxation in condition A (which functions as a benchmark of full relaxation), subjects were asked to lay down on a mattress with a pillow (see Figure 6) in a dark room.

Figure 6 Mattress with pillow for full relaxation measurement.

To stimulate a TV/IFE watching posture for conditions B and C, subjects sat slouched in an IKEA® POÄNG lounge seat with a ±40˚ reclined backrest and leg support, facing a 15" LCD monitor with a 1440x900 resolution (further named IFE screen) featuring a TED (a media organisation which posts talks on Technology, Entertainment and Design online for free distribution) talk on the subjects' interest (www.ted.com/topics). The IFE screen was placed at a 1.69m distance and the screen height was set at each subject's eye height (as recommended by Yoichi et al. (2012)). In condition B the seat had a headrest (see Figure 7), in condition C the headrest was removed (see Figure 8). It is important that subjects rest their arms on their lap in condition B and C, to limit influence of carrying the load of the arms (which is 10% of the total body weight load (Roebuck, Kroemer, & Thomson, 1975; Snijders, Nordin, & Frankel, 1995)) on muscle activity in the shoulder-neck region.

After each condition subjects were asked to complete a questionnaire on their *expected long-term comfort*; the comfort they expect to experience after prolonged watching IFE for 3-4 hours (the extended duration of one or two movies) in the same seat position in an aircraft. A score needed to be given for the neck, head and eyes specifically and for the whole-body experience by drawing a vertical line on a horizontal visual analogue scale (VAS)-line with 'not comfortable' and 'very comfortable' at its ends (Bouwens, Schultheis, Hiemstra-van Mastrigt, & Vink, 2017). For each given score, subjects were asked to elaborate in writing.

To put measured muscle tension (sEMG) into perspective, subjects conducted a *maximal voluntary contraction* (MVC) of the neck muscles at the end of the study, by flexing the head against a load created by a TheraBand™ Red (medium strength) or Green (heavy strength, for some physically stronger subjects), and extending the head against the headrest (exercise inspired by Murray, Lange, Nørnberg, Søgaard, and Sjøgaard (2015)).

Figure 7 Condition B: subject sitting in the seat with headrest.

Figure 8 Condition C: subject sitting in the seat without headrest.

2.2.1. *Muscle selection*

For holding the head upright for watching TV/IFE in a slouched posture, the flexion and extension muscles seem most relevant to investigate.

Surface EMG (sEMG) is more suitable to record superficial muscles with their belly located directly beneath the skin surface (Stanton, Hedge, Brookhuis, Salas, & Hendrick, 2004). Therefore the m. sternocleidomastoid (SCM) – which is responsible for head flexion – and the m. trapezius pars descendens (TRP-UP) – which is responsible for extension – were selected.

Although the m. splenius capitis (SPL) – which performs extension (Conley, Meyer, Feeback, & Dudley, 1995) – has some tissue directly under the skin, it is mainly covered – including its muscle belly – by the m. trapezius. Measuring the SPL at the small lateral surfacing part at the lateral portion of the neck (approximately at C4 level, 2 cm lateral to midline (Lockhart, Hamilton, & Fyfe, 1972; Sommerich, Joines, Hermans, & Moon, 2000)) may results in measuring crosstalk of the TRP and SCM (Mayoux Benhamou, Revel, & Vallee, 1995). Although Sommerich et al. (2000) cite multiple studies that measured the splenius with sEMG, Mayoux Benhamou et al. (1995) argue it can only be measured by fine-wire or needle electrodes. It was therefore decided to exclude the SPL from this study.

2.2.2. *EMG sensor positions*

The two Trigno™ EMG sensors (electrodes) were applied parallel to the assumed muscle fibres' 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 (positions based on Keshner, Campbell, Katz, and Peterson (1989); Konrad (2005); Queisser, Blüthner, Bräuer, and Seidel (1994); Soderberg (1992); Zipp (1982)) and the sensor for the SCM was placed on the lower 1/3rd between the sternal notch and mastoid process (positions based on Davis (1959); Falla, Dall'Alba, Rainoldi, Merletti, and Jull (2002); Keshner et al. (1989); Soderberg (1992); Zipp (1982)), as shown in Figure 9. Since the head was kept parallel to the lateral plane, only muscle activity at one side (right side) was measured.

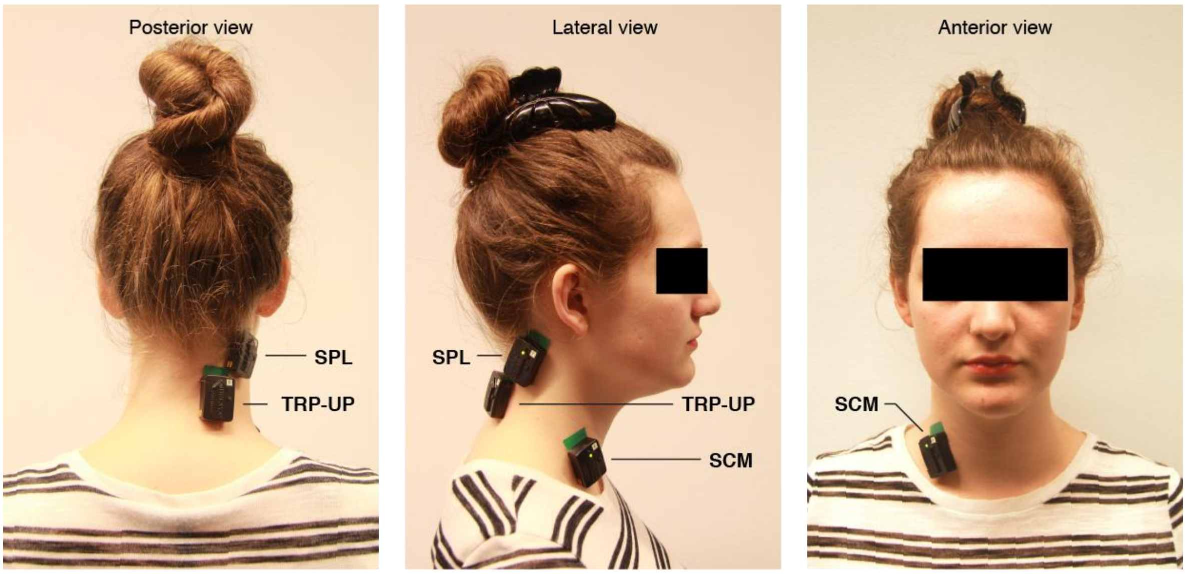

Figure 9 Posterior, lateral and anterior view of sensor placement on the splenius and semispinalis area (SPL) (excluded from study, as described in §2.2.1), the trapezius pars descendens (TRP-UP) and the sternocleidomastoid (SCM).

2.3. Apparatus

A Delsys® Trigno™ Wireless EMG System (2000 Hz sampling rate) and a laptop with Delsys® EMGworks™ were used to measure and process muscle activity of the neck muscles. A Mitutoyo® digital protractor angle gage was used to set the seat backrest to an angle of approximately 40˚. 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. All instrumentation used was set to SI units.

2.4. Procedure

Subject briefing and preparation

Subjects were first briefed on the procedure of the study and were then asked to sign a consent and NDA form, and state their date of birth and nationality. Subjects were then requested to take off their shoes (shoes were off for the duration of the study) 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, oils and other skin surface 'pollution' by sticking and peeling 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). 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). 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 flat

Subjects were asked to lie flat on a mattress with pillow and fully relax for 5 minutes first (see Figure 6). During this period the room was darkened to help subjects to fully relax. This measurement functioned as the benchmark for full muscle relaxation.

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. 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) and the height of the headrest was adjusted to make the headrest support the neck and head. Thereafter the subjects were asked to stand up and select a TED talk movie of their interests.

Condition B: sitting slouched with headrest

Subjects 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 watch a TED-talk movie (see Figure 7) while EMG signals were continuously recorded for 5 minutes during this activity. In the last minute a lateral picture of the posture was taken and then the TED-talk 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 minimise fatigue (Tan, Chen, & Rauterberg, 2010).

Condition C: sitting slouched without headrest

The headrest of the seat was removed and subjects were asked to watch a TED-talk movie for 5 minutes, but without resting the head against the seat (see Figure 8). The same procedure as in *condition B* was followed.

Maximal Voluntary Contraction

Lastly subjects were asked to conduct a maximal voluntary contraction (MVC) of the flexion and extension neck muscles. This was executed at the end of the study, since MVC might have some discomfort effects due to extensive contractions of the muscles, which require some recovery afterwards.

Subjects were asked to push their head against a TheraBand® Red (medium strength) – which was connected to the seat frame – as hard as they could for 3 seconds (flexion; see Figure 10). They were verbally encouraged when needed. Thereafter subjects had a recovery break of 30 seconds and repeated the exercise another two times. Delsys® EMGworks™ automatically determined the highest EMG of the three MVC contractions (a manual correction was made when necessary). 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 as hard as they could for 3 seconds (extension; see Figure 11). This procedure was repeated another two times and the highest MVC-EMG was determined.

Figure 10 MVC flexion by pushing against an elastic TheraBand® Red (medium strength).

Figure 11 MVC extension by pushing against the headrest.

2.5. Measures

Analysis of EMG

Two subjects had to be excluded due to a software crash that resulted in lost or incomplete data. In analysing the EMG data first the baseline offset was removed and the root-mean-square (RMS) was calculated, creating a RA-EMG (rectified averaged EMG). Then the 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). Of each data set an as large as possible sample (duration of ±3 min) without noise was taken. Of these samples the mean muscle activity of the TRP-UP and SCM in each condition, expressed in %MVC, was calculated. In IBM® SPSS® Statistics a paired t-test (2-tailed) was taken of the mean %MVC signals to check for significant differences ($p < 0.05$) between the conditions, as well as an independent T-Test (two tailed) for influence of testing order, gender and testing location. In addition, a Pearson product-moment correlation coefficient was computed to assess influence of age, weight and stature length on the muscle activity.

Analysis of expected long-term comfort rating

One subject had to be excluded due to not completing all questionnaires. All ratings were collected by measuring the given scores on the 10 cm long VAS-line with a ruler and processed with IBM® SPSS® Statistics. Since comfort values cannot be assumed as being normally distributed, a more conservative Wilcoxon test was used 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 body area (eyes, neck, head) and whole body. In addition an independent T-Test (two tailed) for influence of testing order, gender and testing location and a Pearson product-moment correlation coefficient to assess the relationship of age, weight and stature length with the comfort ratings were computed.

Analysis of head-neck posture (2D)

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 joint, C7 (spinous process), tragus, canthus and visual target (the centre of the IFE screen), and then lines were drawn between those points (see Figure 12). The angle of each line in space was recorded (based on Psihogios et al. (2001)) and processed in IBM® SPSS® Statistics. A Wilcoxon (2-tailed) test was taken of each angle to check for significant differences between the conditions ($p < 0.05$), as well as an independent T-Test (two tailed) for influence of testing order, gender and testing location and a Pearson product-moment correlation coefficient was computed to assess the influence of age, weight and stature length on the taken posture.

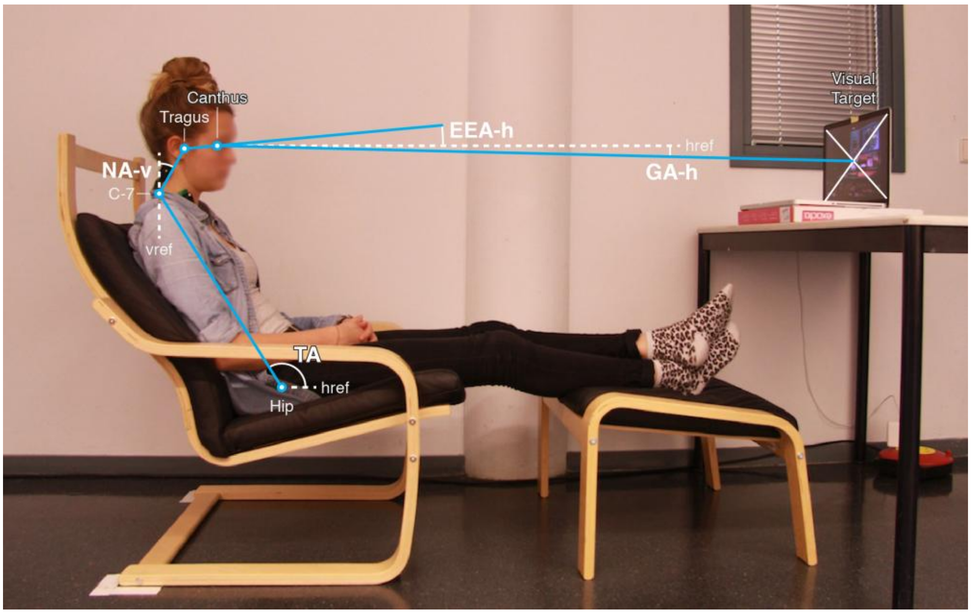

Figure 12 Lateral analysis of posture, where the following angles describe the head-neck posture: TA: Trunk Angle (through hip-joint and C7) relative to horizontal, NA-v: Neck Angle (through C7 and Tragus) relative to vertical, EEA-h: Eye-Ear Angle (through Tragus and Canthus) relative to horizontal, GA-h: Gaze Angle (through Canthus and centre of the visual target) relative to horizontal. Angle representation based on Psihogios et al. (2001).

3. Results

The recorded mean muscle activity of the TRP-UP and SCM for conditions A, B and C, expressed as a percentage of the MVC, is shown in Figure 13. The EMG data show no significant difference in both the *TRP-UP* and the *SCM* between condition B and C (see Table 4). The *SCM* showed a low activity level (2%MVC on average). No significant influence of study location, gender, age, stature length and testing order on the comfort scores was found, except for weight which has moderate correlations with the TRP-UP in conditions A (r=.565, p=.01), B (r=.538, p=.02) and C (r=.574, p=.01).

Table 4 T-test (2-tailed) of muscle activity as a percentage of MVC (n=19)

Condition	*SCM*	*TRP-UP*
AB	0.006 *	0.7
AC	0.4	0.5
BC	0.1	0.7

Expected long-term comfort scores for *whole-body comfort*, *neck comfort*, *head comfort* and *eye comfort* are shown in Figure 14. *Whole body* (p=.003), *head* (p<.001) and *neck comfort* (p=.001) were significantly higher in the condition with a headrest (condition B). There was no significant difference found for the eyes (p=.411). No significant influence of study location, gender, age and stature length on the comfort scores was found, except for a correlation between testing order (r=-.589, p=.006) and *eye comfort* in condition B.

The inclinations describing the head-neck posture in conditions B and C can be found in Table 5 and are visualised in Figure 15. The inclination data show that the posture was significantly different between condition B and C. Without head support (C) the head was found to be more upright in respect to with head support (B). A significant difference was found between the study locations for TA (B) (p=.001), TA (C) (p=.03) and EEL-h (B) (p=.03), between genders for TA (B) (p=.007) and between testing order for NA-v (C) (p=.001) and EEL-h (B) (p=.02). Correlations are also found between age and TA (B) (r=.615, p=.005) and TA (C) (r=.662, p=.002), weight and TA (C) (r=.582, p=.009) and length and TA (C) (r=.578, p=.01). However, no moderate or strong correlations have been found between the amplitude of movement of TA (condition B minus C) and study location, gender, age, stature length and testing order.

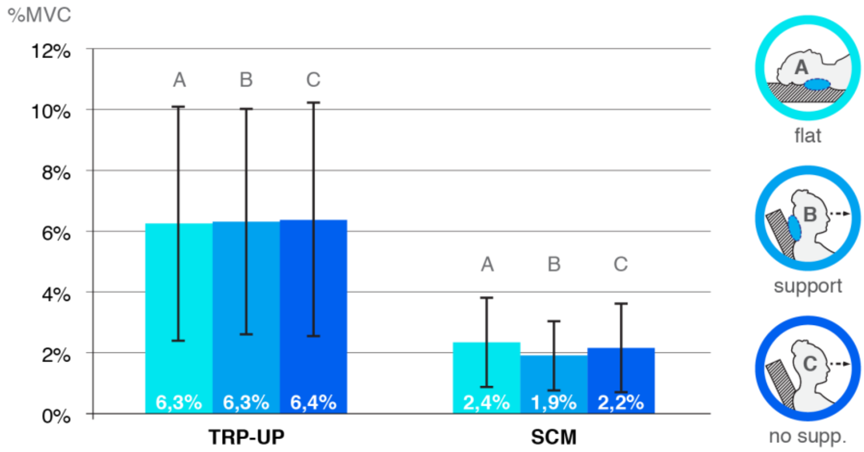

Figure 13 Mean muscle activity as a percentage of MVC (n=19).

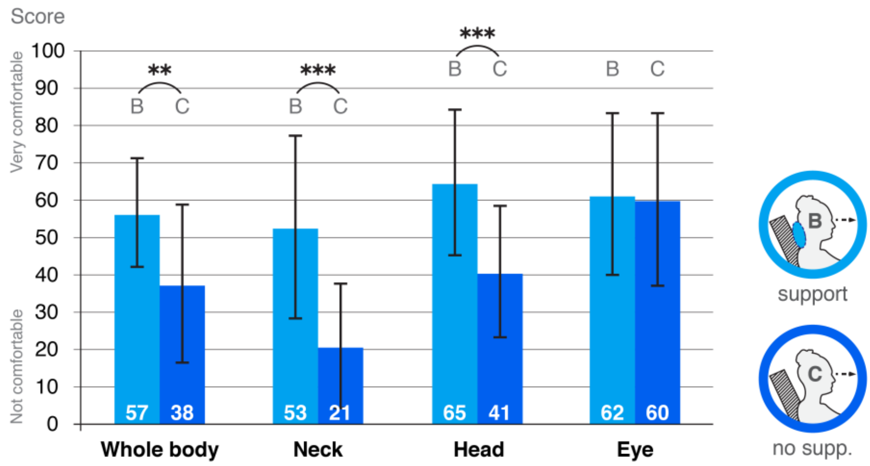

Figure 14 Mean '*expected long-term comfort*' scores with SD (n=20).

Table 5 2D posture inclinations. See Figure 15 for a visual representation of the given angle (n=19).

Angle	*TA*		*NA-v*		*EEL-h*		*GA-h*	
Condition	B	C	B	C	B	C	B	C
Mean	126.3°	124.5°	18.0°	29.0°	23.6°	13.8°	-2.6°	-2.2°
SD	2.5°	2.7°	4.0°	3.5°	5.6°	5.3°	1.0°	1.2°
Max	132.8°	131.4°	24.7°	35.7°	36.2°	27.6°	-0.9°	0.6°
Min	123.3°	120.6°	11.5°	23.4°	14.7°	5.2°	-5.5°	-5.0°
Difference (mean)	1.9°		11.0°		9.9°		0.4°	
Wilcoxon (2-tailed)	0.001 ***		0.001 ***		0.001 ***		0.007 **	

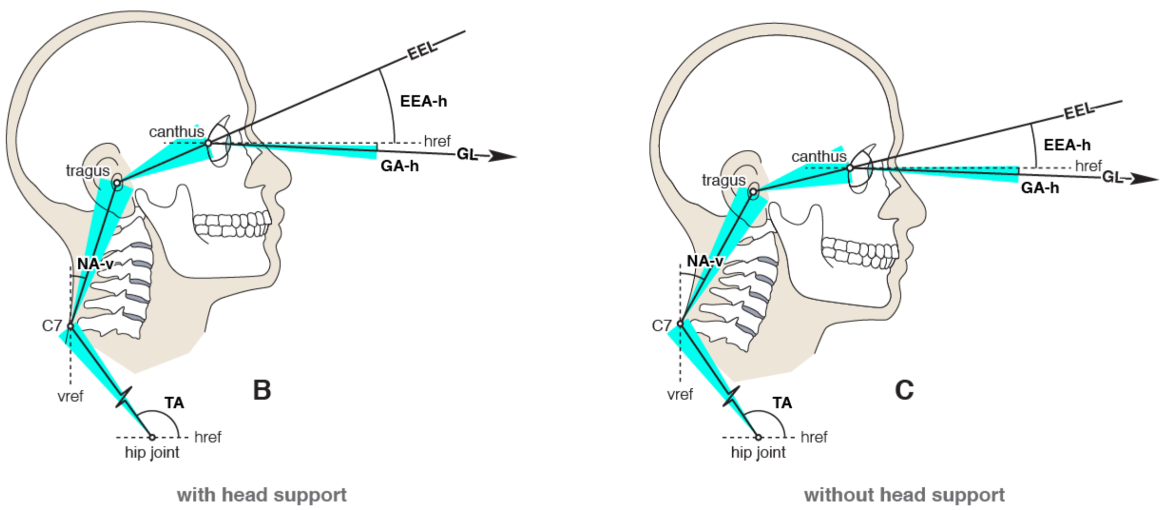

Figure 15 2D posture angles (anatomical representation indicative only) (n=19).
Left: condition B, with head support. Right: condition C, without head support. Black lines represent mean values, where the blue areas represent the observed range (minimal and maximal angles). The given angles: TA: Trunk Angle (through hip-joint and C7) relative to horizontal, NA-v: Neck Angle (through C7 and Tragus) relative to vertical, EEA-h: Eye-Ear Angle (through Tragus and Canthus) relative to horizontal, GA-h: Gaze Angle (through Canthus and centre of the visual target) relative to horizontal. The given lines: EEL: Eye-Ear Line (through Tragus and Canthus), GL: Glare Line (through Canthus and centre of the visual target). Angle representation based on Psihogios et al. (2001).

4. Discussion

4.1. *Muscle activity and fatigue*

The hypothesis that the use of a headrest will reduce the neck muscle activity anterior to the movement axis of the neck could not be supported in this study. While it could be expected based on the AnyBody™ simulations (as described in §1.3), there was no significant difference found in muscle activity between the conditions with (B) and without head support (C). It is important to note that the EMG signals were very low (1-10%MVC), making observing differences between the conditions difficult.

According to Jørgensen, Fallentin, Krogh-Lund, and Jensen (1988), a static isometric contraction of 5-10% MVC for one hour may result in fatigue. Jonsson (1978) suggests that a static load level ought not to exceed 5% MVC for work tasks of long duration. A study of Sjøgaard, Kiens, Jørgensen, and Saltin (1986) showed similar results, were isometric knee extension of 5% MVC sustained for 1 h caused fatigue. The muscle tension of the SCM in this study was below 5% MVC for 5 minutes contraction, indicating that the muscle tension may not cause fatigue. The TRP-UP however shows a MVC over 5% for 5 minutes contraction, indicating that fatigue may occur in the long term in the shoulder-neck region.

The positive moderate correlation between weight and muscle activity in the TRP-UP could be explained by the additional load of tissue of the head and perhaps the arms on the neck-shoulder muscles.

4.2. *Expected long-term comfort*

Expected long-term comfort was rated highest in the condition with a headrest (B), indicating there may be a positive effect on comfort through stability, support and body contact. Franz, Durt, Zenk, and Desmet (2012) describe a similar effect of body contact, were neck support benefitted the perceived comfort of most subjects. Stability offered by support of a headrest may avoid corrections by the neck to maintain stability, as (among other) breathing, blood pumping and micro limbs movements require corrections of the centre of gravity of the head (and body) position in respect to the neck (and ground). Making such corrections may be a tiresome activity for neck muscles and may cause discomfort in the long term.

The expectation of a passenger of having more comfort in the long term may actually positively influence the actual experienced comfort of the passenger during a flight, a phenomenon described by Naddeo, Cappetti, Califano, and Vallone (2015) in the context of a bed. However, it is important to note that the '*expected long-term comfort rating'* is qualitative and gives just an indication of what subjects expect to experience. As shown by Bouwens, Schultheis, Hiemstra-van Mastrigt, and Vink (2017), it is not always possible to predict the experienced comfort based on expected comfort. Studies that investigate long term comfort and discomfort (around 2-3 hours) show the importance of long term assessment with subjects (e.g. Hiemstra-van Mastrigt, Meyenborg, and Hoogenhout (2016), Smulders et al. (2016) and Sammonds, Fray, and Mansfield (2017)), as in time comfort usually decreases and discomfort increases (Vink, Anjani, Smulders, & Hiemstra-van Mastrigt, 2017).

4.3. *Posture*

The posture between conditions B and C was significantly different. Without head support the head was found to be more upright and placed above the rotation axes of the neck. The reason for not finding any difference in the EMG (and the low EMG signals) could be that humans have the tendency to look for a neutral head position. This can be supported by Delleman et al. (2004) who stated that a more neutral position is preferred, and in existing guidelines for preventing Work-Related Musculoskeletal Disorders (WMSDs) like OCRA and RULA (Stanton et al., 2004) which promote neutral neck positions. Here *'neutral'* refers to the position in which the least energy is needed to keep the head upright. Apostolico et al. (2014) also confirmed that the most comfortably posture is inside the Range of the Rest Posture that, for the neck is in the neighbour of the neutral position. The posture taken in the condition with headrest (B) was dictated by the position and design of the headrest on the seat. It can be questioned if this position and the headrest design is ideal, since another position or design could create a different load on the body and thus another comfort experience. Vink (2016) suggested (based on Raine and Twomey (1997), Johnson (1998), Ankrum and Nemeth (2000) and van Veen et al. (2014)) a neutral head position lies between 40-44° while sitting upright. The mean neck angle (NA-v) in this study in the condition without the headrest (C) was 29.0° while sitting slouched, and thus was different to earlier findings as cited by Vink (2016). Therefore, further research is needed on the ideal position and design of the headrest in the context of watching IFE in the aircraft.

The difference of posture between testing locations, genders and age possibly could be explained by weight and stature length, as the USA testing location only had male participants who were also significantly older than the subject of the NLD location. Males are also generally longer and weight more than females, thus could explain the difference. That said, weight and length only had a moderate correlation with TA in condition C. However, no moderate or strong correlation has been found between the amplitude of movement of TA (condition B minus C).

4.4. *Study limitations and suggestions*

Although it is not uncommon to conduct a comfort study for headrest for the limited duration of 5 minutes (Franz et al., 2012), due to the limited context (the limited duration of EMG measurement and comfort assessment of 5 minutes) of this study, only indications for long-term effects can be given. Also muscle fatigue (Sjøgaard et al., 1986) and discomfort (G. Sammonds, Fray, & Mansfield, 2014; Vink, 2004; Vink, 2016) were not recorded, since their impact could only be assessed properly over a longer period of time. 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 passenger comfort and discomfort against muscle activity and fatigue over time. It is also recommended to include a study on posture changes and (micro)movements, since they may give an indication of discomfort (G. M. Sammonds, Fray, & Mansfield, 2017) and give requirements on posture allowance by the seat design. In addition, it is also recommended to study the (thoracic and lumbar) spine comfort, since these could be affected by the change in posture due to the presence of head support.

In addition, the Trigno™ EMG sensors (electrodes) used in this study were 15mm thick and thus may be uncomfortable when in contact with the headrest, as electrodes pushed into the skin under load of the head. Subjects were asked to ignore this and to exclude the sensors from their comfort assessments. However, the sensors still could have influenced the perceived comfort of the subjects. Less invasive sEMG electrodes (e.g. more traditional wired pinch ECG/EEG/sEMG/EOG electrodes) are therefore advised in studying comfort in situations where the electrode may be between the human body and a contact surface, such as a seat and headrest.

5. Conclusion

In this study no significant differences in muscle activity (based on EMG) were found between the condition with and without head support when watching IFE in a slouched posture. A significant difference in *expected long-term comfort* rating was found, where it was rated highest in the condition with a headrest, indicating that a headrest may have a positive effect on the user expectations and thus (comfort) experience during flight. This study also found a significant difference in posture. Without headrest the head was found to be more upright. No significant difference in EMG and significant difference in posture between the conditions with and without headrest may indicate that humans tend to look for a head position that is neutral, in the sense of minimal (muscle) effort. Further research is advised on the design of a headrest and the long-term comfort and discomfort effects of such head support.

5.1. *Relevance for the industry*

The use of a headrest could positively influence the *expected long-term comfort* of the user/passenger. A headrest has an effect on the posture people take, but effects of the headrest on the neck muscle activity could not be affirmed through EMG. Implementing head support for slouched postures when watching an IFE, TV, ICE/IVI or VDU screen in premium cabin aircraft seats, (autonomous) car seats and home/office/cinema furniture may improve the user comfort. However, the long-term comfort and discomfort effects of such head support are unclear and further research is therefore needed.

Conflict of interests

This study was financially supported by Zodiac Aerospace. The sponsor had no influence on any decision nor execution of this study, including study design, data collection, analysis, data interpretation, writing and publication.

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Highlights

- A slouched posture is preferred for watching in flight entertainment (IFE) and TV
- Head support does not significantly lower muscle activity of neck muscles
- Humans tend to look for a head position with minimal muscle effort
- The expected comfort experience of the user is higher with head support

Graphical abstract

The significant difference in posture and the lack of significant difference in muscle activity (EMG) may indicate that humans tend to look for a head position with minimal muscle effort. A headrest may improve the expected comfort experience of the user.

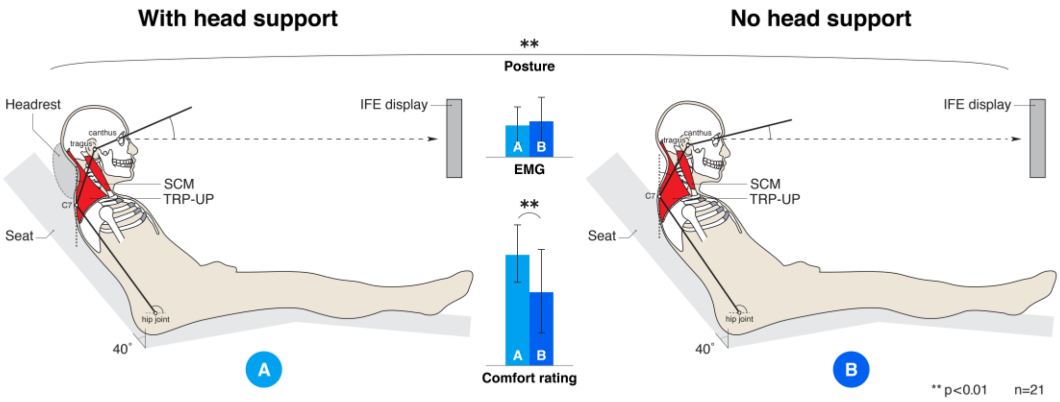


Figure 01

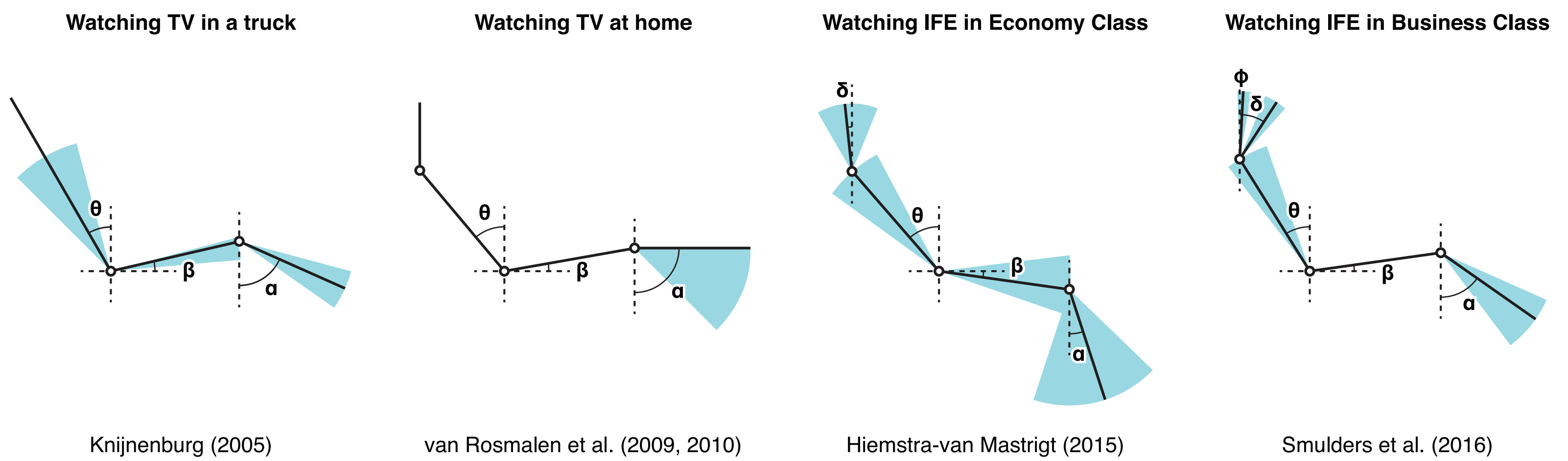
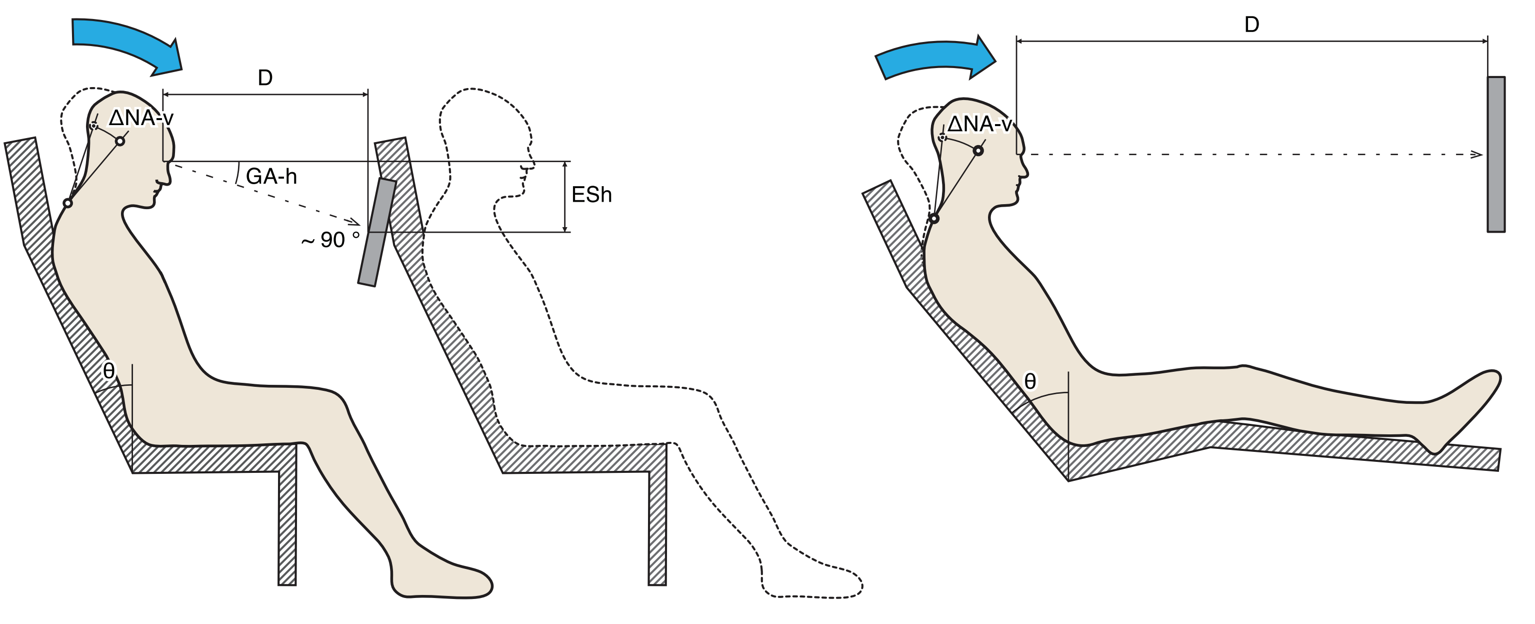

Watching TV in a truck
θ
β
α
Knijnenburg (2005)
Watching TV at home
θ
β
α
van Rosmalen et al. (2009, 2010)
Watching IFE in Economy Class
δ
θ
β
α
Hiemstra-van Mastrigt (2015)
Watching IFE in Business Class
ϕ
δ
θ
β
α
Smulders et al. (2016)

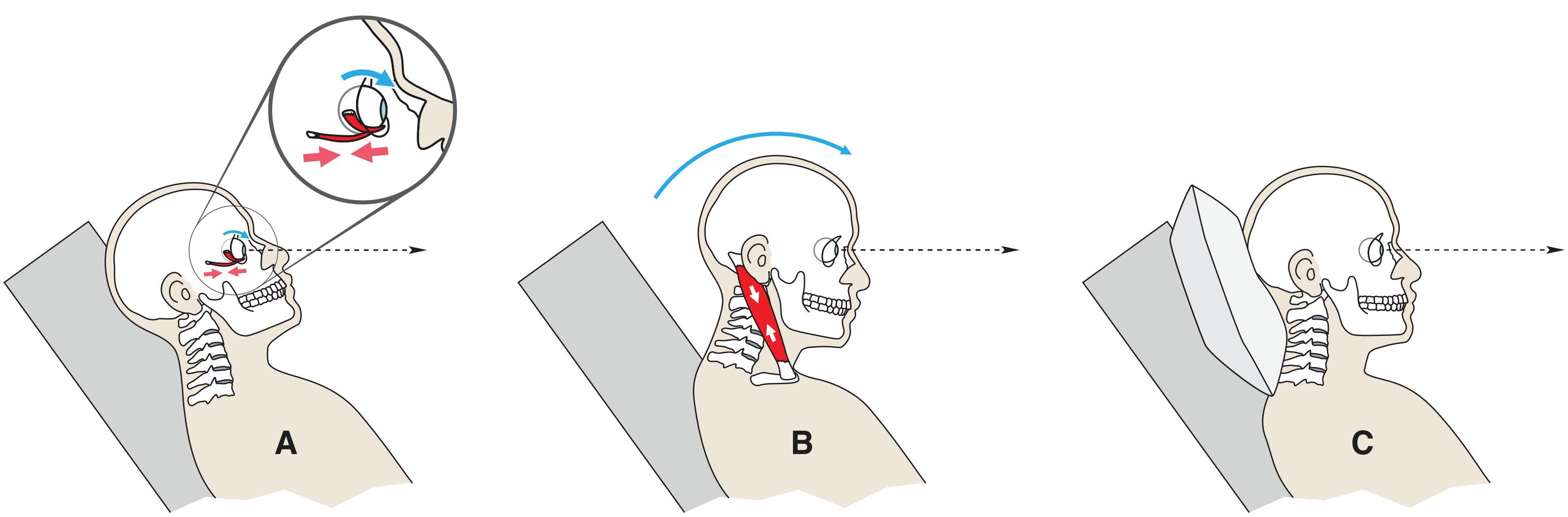
Figure 02



Economy Class

Business Class

Figure 03



Eye deorsumversion

Head flexion

Head flexion supported by pillow

Figure 04
Click here to download high resolution image

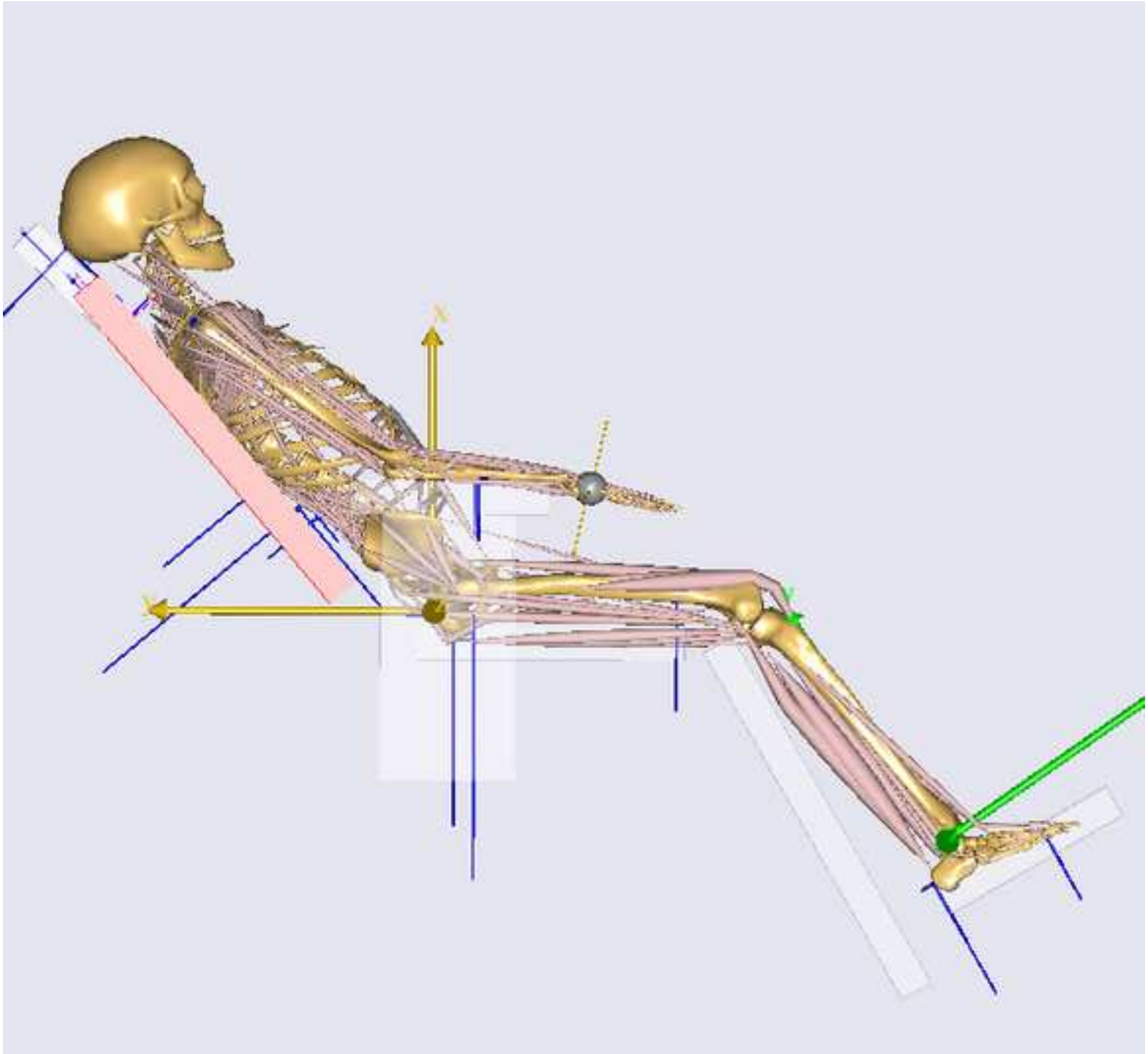
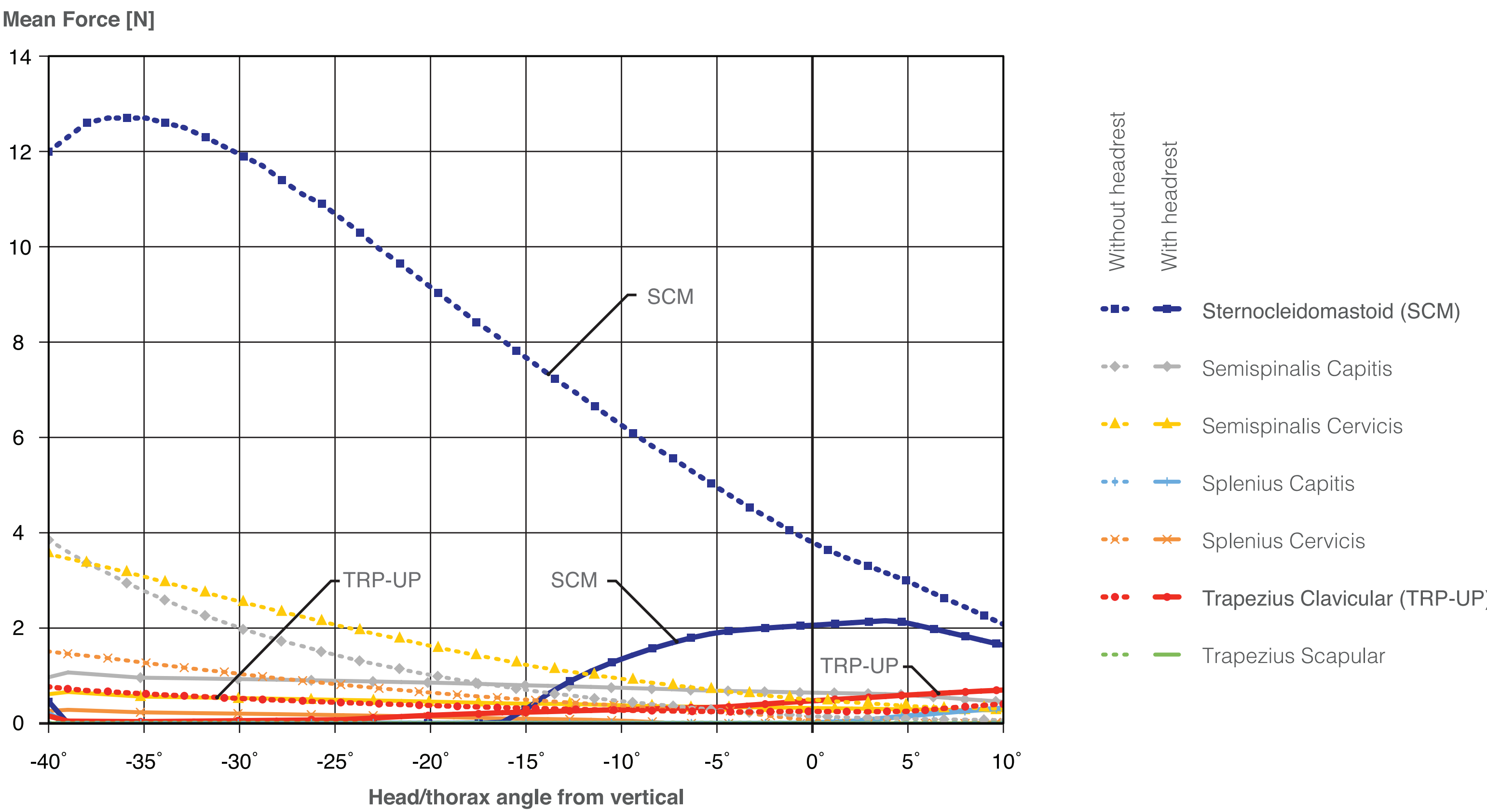


Figure 05



Mean Force [N]
14
12
10
8
6
4
2
0
-40°
-35°
-30°
-25°
-20°
-15°
-10°
-5°
0°
5°
10°
Head/thorax angle from vertical
SCM
SCM
TRP-UP
TRP-UP
Without headrest
With headrest
Sternocleidomastoid (SCM)
Semispinalis Capitis
Semispinalis Cervicis
Splenius Capitis
Splenius Cervicis
Trapezius Clavicular (TRP-UP)
Trapezius Scapular

Figure 06
Click here to download high resolution image

Figure 07
Click here to download high resolution image

Figure 08
Click here to download high resolution image

Figure 09

Click here to download high resolution image

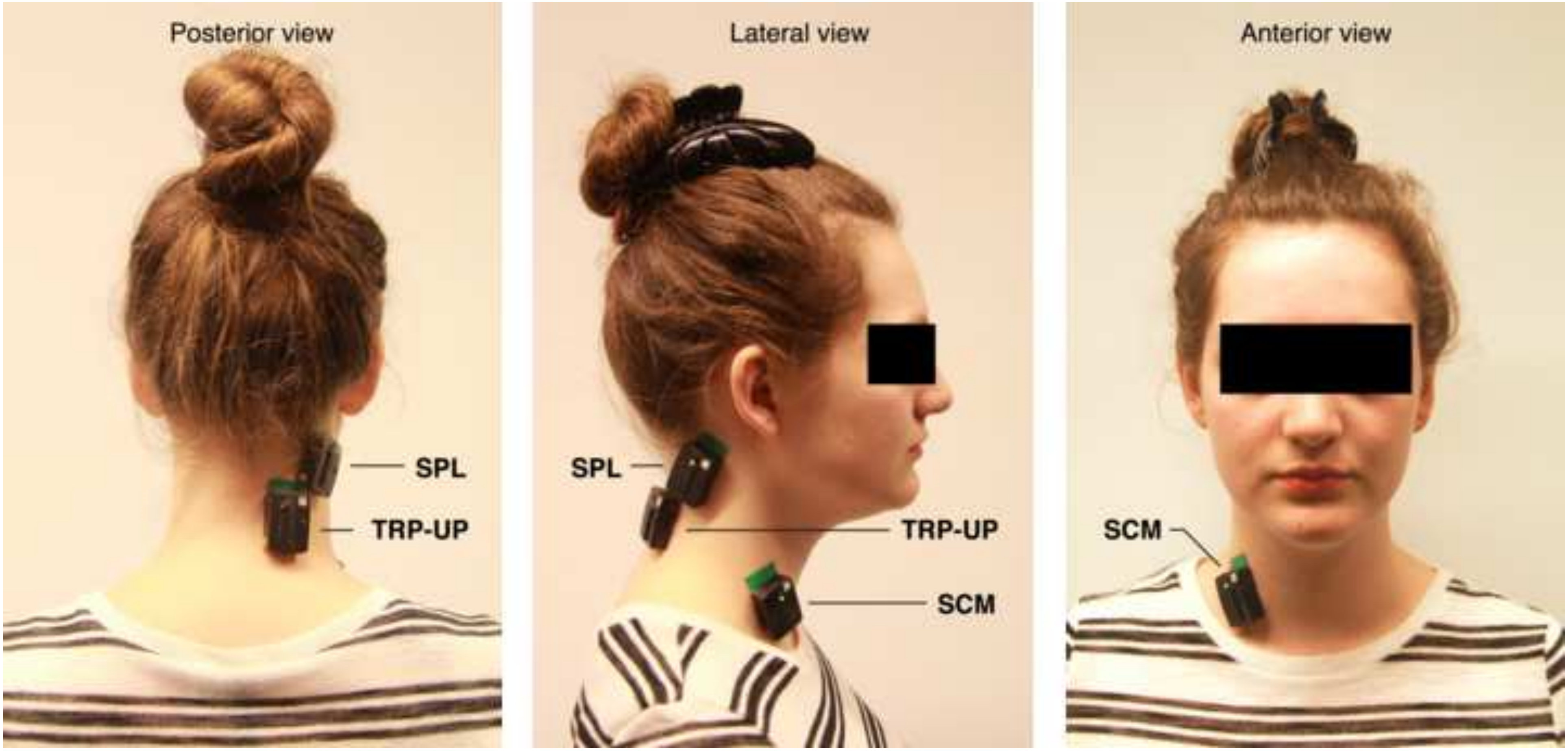


Figure 10
Click here to download high resolution image

Figure 11
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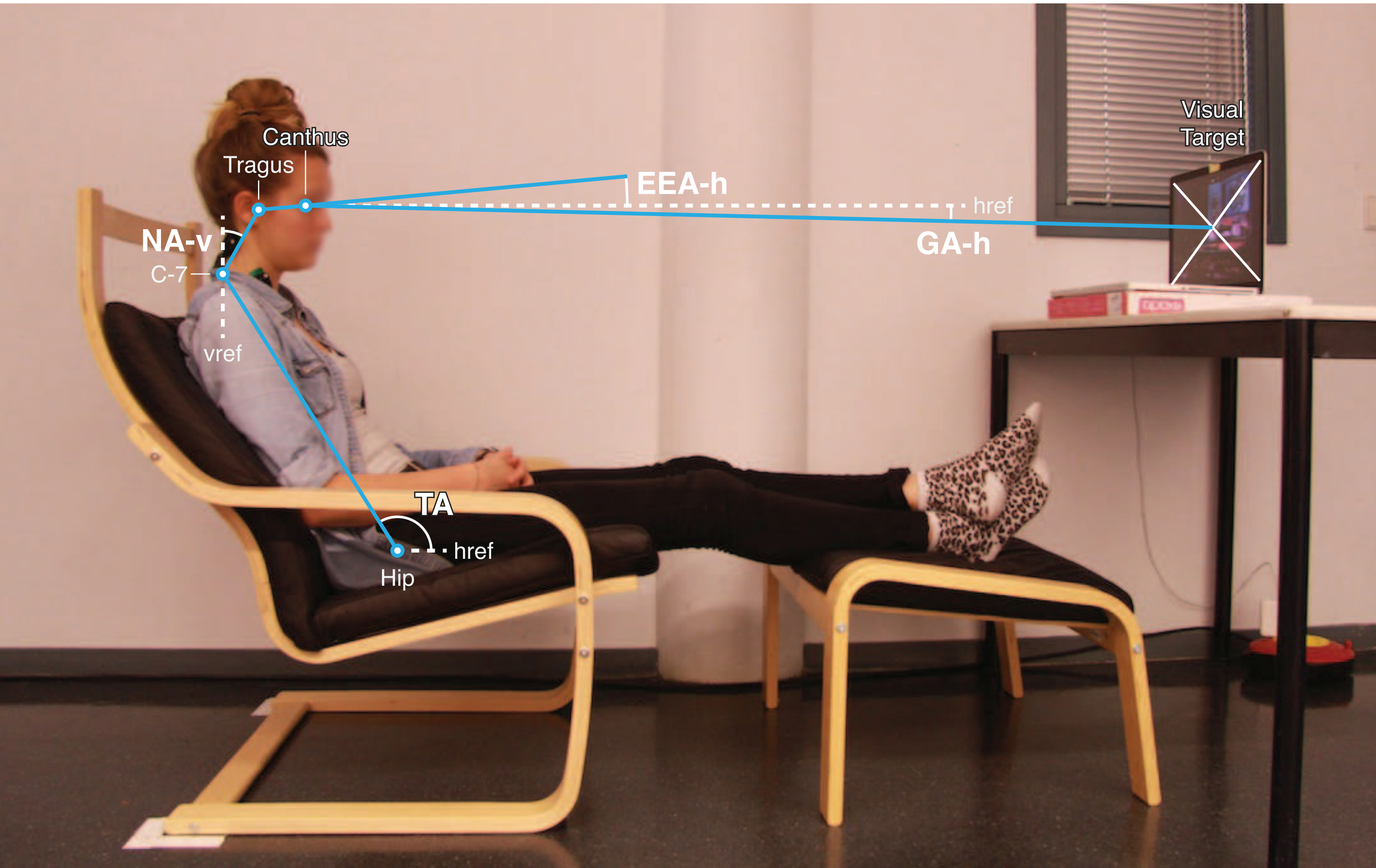
Figure 12



Visual
Target
Canthus
Tragus
EEA-h
href
NA-v
GA-h
C-7
vref
TA
href
Hip

Figure 13

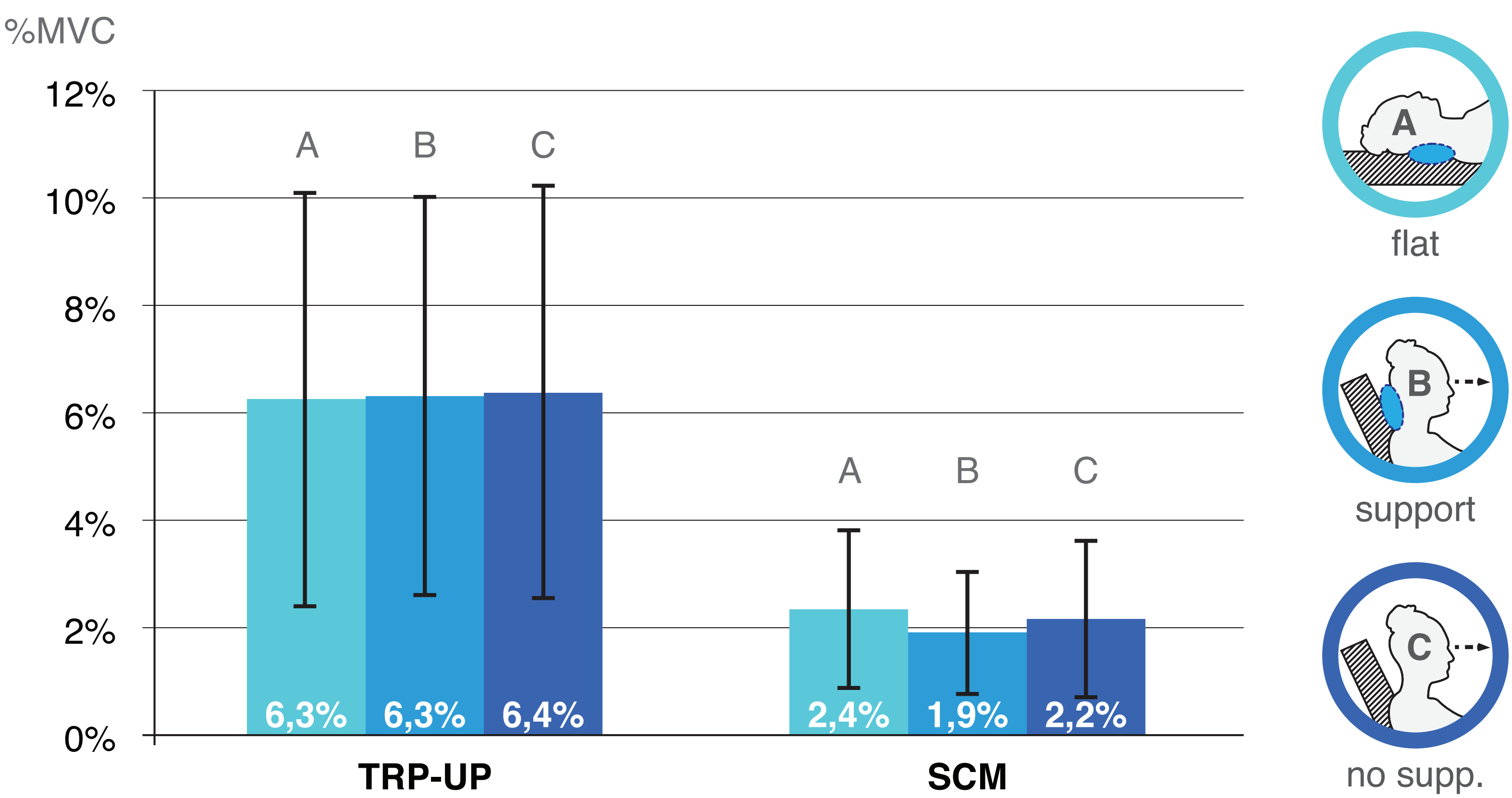
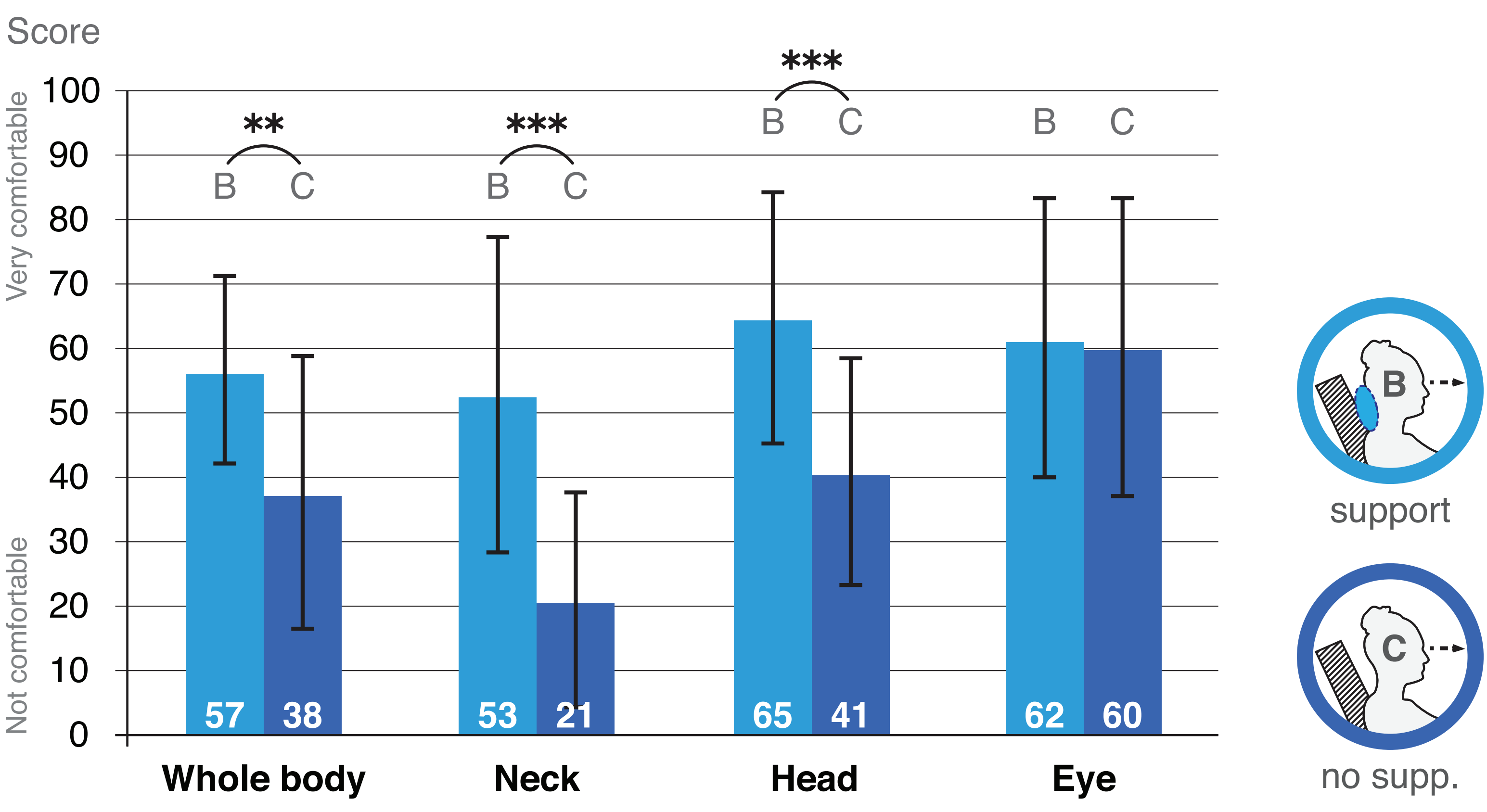
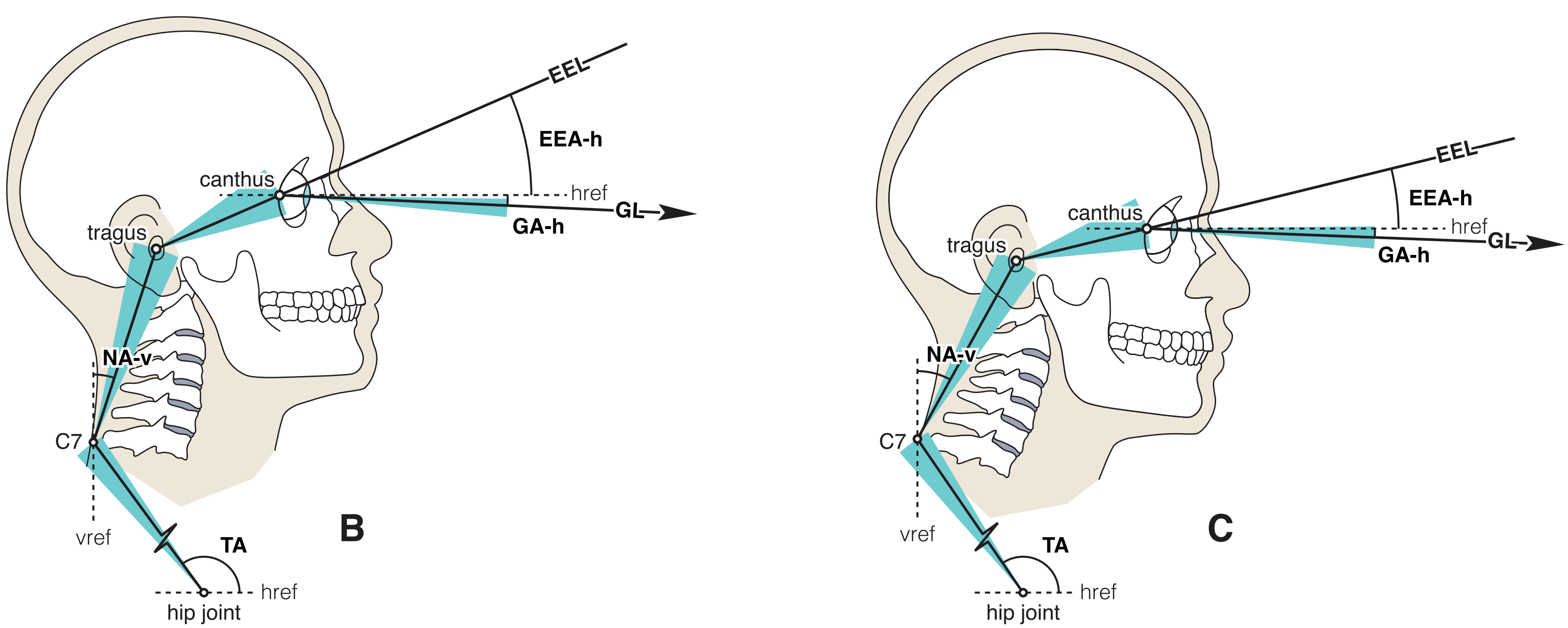

%MVC
12%
10%
8%
6%
4%
2%
0%
A
B
C
A
B
C
6,3%
6,3%
6,4%
2,4%
1,9%
2,2%
TRP-UP
SCM
A
flat
B
support
C
no supp.

Figure 14



Score
100
90
80
70
60
50
40
30
20
10
0
Very comfortable
Not comfortable
**
***
***
B C
B C
B C
B C
57 38
53 21
65 41
62 60
Whole body
Neck
Head
Eye
B
support
C
no supp.

Figure 15



with head support

without head support

Graphical abstract