Delft University of Technology

Master of Science Thesis

Design of a Body Supported Head Rest for People with a Neuromuscular Disease

Author:
Rik Steenbergen

Supervisors:
Dr.Ir. J.L.Herder, 3me Delft
University of Technology
P. Mastenbroek, Armon Products
M. Cloosterman, Armon Products

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Abstract

People with a neuromuscular disease have to deal with decreasing muscle force as their disease progresses. Muscles around the head and neck are weakened too. As a consequence it becomes energy consuming to keep their head and neck in a forward bended position. For instance during reading, eating or doing computer work. This study proposes an analytical approach to this problem by using a simple biomechanical model of the head and neck. Analysis of forces acting around the head and neck joints resulted in a new balancing strategy for head supports. The proposed design helps the patient's muscles in creating counteracting head and neck joint torques when the head and neck are in a forward bended position. Reaction forces are guided to the body. A prototype was designed to do a technical evaluation of the conceptual design. Measurement results show a positive indication that joint torque head weight balancing can be done by normal linear and compact torsion springs while reaction forces guided to the body are low. The design is slim, out of the face of the user, concealable underneath clothing and it can be used sitting in a (wheel)chair or while standing and walking.

1 Introduction

A Dutch charity fund specialized in helping people with neuromuscular diseases, the Prinses Beatrix Fonds, estimated that about 200.000 people in the Netherlands suffer from a neuromuscular disease [1]. A neuromuscular disease is a genetically determined disease affecting muscles and nerves or a combination of them. This results in muscle weakness, restricted mobility or even total paralysis.

About 600 different neuromuscular diseases exist [1]. Each disease has its own specific effects on muscle force and control. Moreover, the same muscular disease can have different progressions over time and different symptoms from person to person. In summary, it can be said that there is a large variation between patients.

Neuromuscular diseases are progressive. This means that muscle force decreases as the disease progresses. Generally, extremities like arms and legs are affected first. So people often end up sitting in a wheelchair. At a later stage the lungs and the heart are affected too. A muscle disease cannot be cured or treated with medicine. As soon as the heart, which is a muscle too, is affected the disease will be fatal for the patient.

Treatment of people with a muscle disease is challenging and requires close collaboration between different disciplines such as doctors, home carers, physical therapists etc. More and more, engineers are involved in this collaboration too. This is because there is a need for different and better technical solutions. Costs of such treatments and technical solutions are important for health insurance companies. However, cost was not the main focus in this project.

Due to large variation in patients, muscle disease progression and symptoms, it is challenging to find technical solutions. The multidisciplinary team mentioned above is needed to translate patient needs into technical requirements.

This research focusses at supporting the head of patients being in a relative early to intermediate progression of their muscle disease. These patients do have some muscle force and muscle control left, but keeping their head up requires too much force and energy compared to what their own muscles can deliver. In other words, their neck muscles became to weak to keep the head up during their daily activities.

The focus is on this symptom because natural upright head position and controlling head movement is very important for basic activities of daily life (ADL) like: social communication, eating, drinking, travelling, etc. Regarding the examples given above, one can imagine that there is a need for a head support that enables patients to keep their heads up in different situations. Several solutions already exist and will be discussed next.

While neglecting the kind of head rests that comes standard with a wheelchair, currently commercial available head supports can be classified into three groups:

1. Head fixed, wheelchair supported
2. Head moveable, wheelchair supported
3. Head fixed, body supported

The first class of head supports fixates the head to the wheelchair. The head is prevented from falling forwards, backwards and sidewards. The head is completely restricted into *one* position. Consequently, trunk position has to be adapted to head position which is often uncomfortable if not painful. Another important limitation of this type of head support is that it can only be used in combination with a wheelchair. This affects a patient's mobility and can be barrier to make use of it.

In case of the second class, the head is attached in a flexible way to the wheelchair. This means that the head can be moved with respect to the wheelchair in several directions to a certain extend. Reaction forces from supporting the head are guided to the (wheel)chair. This solution can only be used in combination with a wheelchair too.

A third class of head supports are carried on the body, also called 'body supported' headrests. They fix the head with respect to the trunk. They do so by placing a collar around the neck. It allows the user to move the trunk without restrictions. However head movement is *not* possible. One interesting feature is that they can be used independently from a wheelchair.

Although there are head supports available and used, patient interviews showed that none of the head supports described above are satisfying to users. Often they do not use the head supports because of bad comfort (sweating, rubbing, etc.) and bad aesthetics. The latter is not a minor reason for putting the head supports aside.

So there is a need for a head support that offers sufficient head support without *fixating* the head. The head support should allow the patient's head a certain degree of freedom. The supporting construction should be independent from wheelchairs. It should also fit patients in a comfortable and good looking way.

Regarding the problems for patients and problems with current solutions mentioned above, this study has two objectives:

1. Propose a mathematical model to analyse muscle weakness from a technical perspective and derive a balancing concept from force analysis.

2. Design and verify a prototype according to technical specifications resulting from model analysis and patient needs.

A wearable head support is thought to have a wider potential. Such as for people that experience severe loading of the neck muscles in their profession. One can think of overhead crane drivers, surgeons, dentists etc. which are forced to hold their head in a fixed and exhausting position for longer periods.

After this introduction the 'Method' section describes a technical analysis of the problem of compensating head weight. A balancing strategy is proposed and worked out. A conceptual design is proposed and translated into a prototype which will be discussed in the 'Results' section. This section also presents a technical evaluation of the prototype and patient tests. The results and learnings will be discussed in the Discussion and Conclusions.

2 Method

The used method was divided into two main steps: 1) analysis of user group and 2) analytical modelling. Eventually design requirements will be set up for the prototype by using knowledge from these two steps.

Analysis of user-group

Ten larger muscles around the neck and cervical column (C1-C7) are responsible for head movement [2]. Many smaller muscles help to control finer movements and stabilize the head. These muscles are able to move and keep up an average head mass of 5 kg.

As stated in the introduction it was decided that the system to be designed is intended for people who can keep their 5 kg. head in natural upright position themselves. But for whom head positions *deviating* from this natural upright position becomes very energy demanding, the prototype can be of help. Examples are head positions during activities like feeding, reading, social communication and travelling.

Regarding the activities and based on patient interviews the author regarded the patient's biggest problem is with bending the head up- and downward, so called *flexion* and *extension* Fig.1b

For head rotation Fig.1a the wheelchair or complete trunk can be rotated. Sidewards bending of the head Fig.1c was regarded to be of least importance, because it serves no functional use in important primary activities as eating, drinking, communication, etc. It was decided that supporting head mass in forward bended position has the highest priority, and therefore the focus was on this movement.

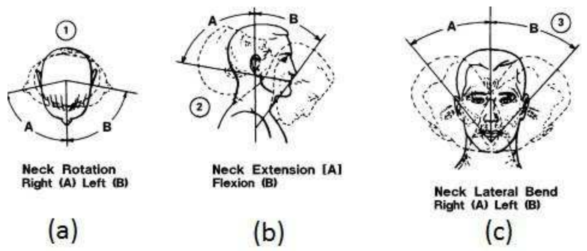


Figure 1: Head movements with indicated range of motion. Adopted from NASA Man-Systems Integration Standards, Volume 1, Section 3: Anthropometry and Biomechanics.

The described patient group was chosen because of two reasons. First, people with little decrease in muscle force (very early phase of the disease) do not need and will not use a head support. Second, the weakest patients with almost no muscle force left will not be able to operate the head support properly because their muscle force and control are too heavily affected.

To the author's best knowledge, nor scientific data neither measurement methods are available about or to measure patient's remaining head and neck muscle force. In other words: It is known that patient's muscle force decreases over time, but it is unknown how much and which muscles are affected. A method to be determine this could be EMG (elektromyography). Muscle activity measurements could be a measure of remaining muscle force. EMG-data is not available as far as the author knows.

Because the lack of data or other measurement methods of remaining head and neck muscle force for patients with a neuromuscular disease, a new approach for the design of a head support is proposed in this study. A mathematical/biomechanical model of the head and neck was used for kinematic and force analysis. Results from this analysis were used for the design of a prototype. This model could be adapted as soon as any scientific data comes available.

Biomechanical model of head and neck

A literature study was conducted to find available biomechanical models. These models differ in complexity and they are used for different purposes [3, 4]. For instance, very complex models can be used for analysis of forces in ligaments between vertebra [5, 6]. This level of detail is beyond the scope of this project and a simpler model is preferred.

As mentioned before, patients have most difficulties with bending the head up and down. If we assume this is true and focus on head and neck flexion only, the kinematic and force analysis of the head and neck can be reduced to planar head and neck movement instead of 3D-movements. Therefore, a relatively simple 2D model was adopted.

Wismans [7] simplified the head and neck to two massless, hinged, inverted links with a concentrated head mass at the end of the upper link. The concentrated mass represents the head's center of mass (**COM**). The Head Link(HL)is rigidly connected to the COM, but is pivotally connected at **P2** to the Neck Link (NL) and rotates around P2 over an angle φ_2. The angle φ_2 is zero when link HL is vertical. The lower link represents the neck. Link NL is rotatable around pivot **P1** over an angle of φ_1. The angle φ_1 is zero when link NL is vertical. The pivots are assumed to rotate independent from each other. Pivots **P1** and **P2** represent the anatomic points: The first thoracic vertebra and the occipital joint, respectively. Figure 2 shows the model and used symbols. Head and neck link angles φ_2 and φ_1 are chosen to be between zero and twenty five degrees. This range of motion were estimated to be sufficient for activities such as reading, eating and computer work.

Table 1: List of used symbols there meaning and numerical values

Symbol	Description	Value
NL	Neck link	125 mm
HL	Head link	80 mm
P1	Lower pivot	-
P2	Upper pivot	-
φ_1	Head link angle	$0 \leq \varphi_1 \leq 25 deg.$
φ_2	Neck link angle	$0 \leq \varphi_2 \leq 25 deg.$

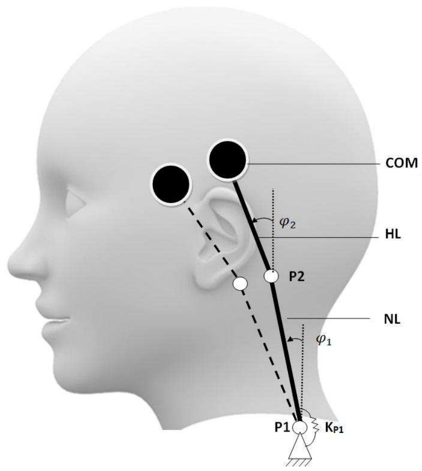


Figure 2: Kinematic model for the head and neck. The background head-neck contour gives the reader an idea about the relative positioning of points P1, P2 and COM in natural upright position indicated by solid lines. Dashed lines show the rotated head and neck.

From Figure 2 it is noticed that the COM shifts forward when the head bends and rotates around P2 and P1. Joint torques around **P1** and **P2** need to increase in order to keep the head balanced. This requires muscles to work harder in order to keep the head up, as a result the patient gets tired faster.

So far, a relative complex problem of head instability due to neuromuscular diseases, is translated into a simple 2D biomechanical model of the head and neck. Next, force (joint torque) analysis and rapid experiments were done to define technical design specifications and a balancing strategy.

Reviewed Concepts

Three different methods for head balancing were reviewed. Supporting the chin, statically balancing head weight with a parallelogram linkage and joint torque balancing.
Supporting the chin was regarded to be uncomfortable and inconvenient for the patient. It requires a support under the chin which will make eating and talking impossible while wearing the head support.

Statically balancing the full weight of the head is possible but requires large forces on the head. Moreover, reaction force calculations showed that reaction forces acting on the body can go up to 300 N. The reason for these relatively high forces is because of the proposed balancing mechanism which consists of a parallelogram linkage. This linkage acts as a lever while lifting the head weight of 50 N. This levering action amplifies (approximately six times) the reaction forces which are guided to the body. Exposing the patient to such high reaction forces is could be uncomfortable. This resulted in the third and chosen concept: joint torque balancing. Statically balancing supports the full weight of the head. But if it is assumed that the skeletal (spinal column) support structure of the patient is still intact, part of the head weight could still be supported by it. This means that less force could be used to support the head. This resulted in the idea that adding torque around the head and neck joints could be a solution. In other words, the head support helps in counterbalancing a part of the head weight by adding joint torques as normal muscles would. In a normal situation head balancing is done by muscles attached to the skull and spinal column. These muscle forces have a resultant joint torque around the head and neck joints. As will be shown later on, reaction forces acting on the body can be much lower compared to statically balancing the head. Therefore this this concept was chosen and elaborated. It will be discussed and elaborated in more detail now.

Rapid Experiment and Balancing Strategy

A rapid experiment was done with a full scale wooden model of Wismans[7] head and neck model. The model is show in figure 3. A gripper (1) enveloped and grabbed the head (2) from behind, out of the patient's field of view, at two points: The forehead and the dent in the back of the head, so called *occiput*. Weight W is manually balanced by applying torque M and force F to the head and neck with the gripper attached to the head. Through the gripper's contacts at the forehead and back head, forces can be applied such that head weight is balanced while the head is still able to move. In other words, it showed the possibility of manipulating the head and neck orientations by hand. The hand in this case can be replaced by a mechanism. This mechanism will have a base that is supported by the body. First, the conceptual design will be explained. After that, force analysis will be presented to show how the manually applied forces to the gripper will eventually result in force and torque equilibrium.

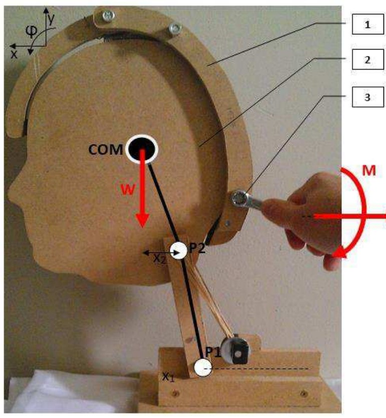


Figure 3: Wooden model representing the model of Wismans. (1) gripper, (2) Head link has realistic head shape and (3) Torque and force application point on the gripper.

Conceptual Design

The conceptual design using joint torque balancing, as tested with the wooden model in figure 3 was translated into a conceptual design which is shown in figure 4. A description of the three main parts is given below:

1. Head interface (red): a slim designed gripper curving along and enveloping the head at the forehead, back head and sides. The gripper has soft paddings at the contact points.

2. Body interface (green): neck collar plus lever curved along the back contours and frontrunning straps to transmit reaction forces to the body. The neck collar fits shoulders and neck contours, supporting the head support (gripper and mechanical link) in vertical direction. It also prevents the head support from rotating when the head bends left or right.

3. Support Mechanism (blue): The support mechanism consists of a mechanical link between two pivots R1 and R2. R2 allows head rotation, R1 allows neck rotation. R1 is close to, but above P1(natural pivot of the neck). R2 is positioned at the back of the head. Pivot R2 allows for ten degrees head rotation. Pivot R1 allows for twenty degrees neck-rotation. Rotation around R2 is mechanically locked at ten degrees. Further head and neck rotation is done around R1.

Parallel acting pairs of torsion springs K_1 and K_2 are mounted on the pivots, providing counteracting torques. Torsion springs were regarded as the most suitable force elements mountable around the pivot points, providing counteracting torques in the design of the Support Mechanism. Tension springs, for instance, can store 1.5 times more energy per unit volume than torsion springs [8]. However, an additional mechanism is needed to convert linear tension spring force into a balancing torque around the pivots. The mechanism would make tension springs a less compact solution. Considering the proposed and relatively small range of movement of the head support it was chosen to use torsion springs. The increased spring volume needed for joint torque balancing with torsion springs requires less space than an additional mechanism for the tension springs.

Note that the joint between mechanical link and head interface does not coincide with P2. This means that the 'natural' rotation center of the head of the patient does not coincide with the rotation center of the head support. This could result in feeling of unnatural movement and sliding of the gripper enveloping the head. Sliding could be prevented by using high-friction contact materials at the forehead and back head contact points of the gripper. This would mean increasing shear forces at the head-contact points, which in turn could affect patient's comfort experience. Since the range of motion around R2 is relatively small it was assumed that the 'unnatural' feeling of the patient is compensated by the inconspicuous design of a rotation point behind the head. Coincidence of P2 and R2 would require two rotation axes just below both ears at the side of the head. This would make the head support look bulky and hard to hide. Moreover the construction could interfere with glasses, wheelchair controls and audio accessories. The lower pivot of the head support is positioned to coincide with P1, since P1 is the natural pivot point of the neck.

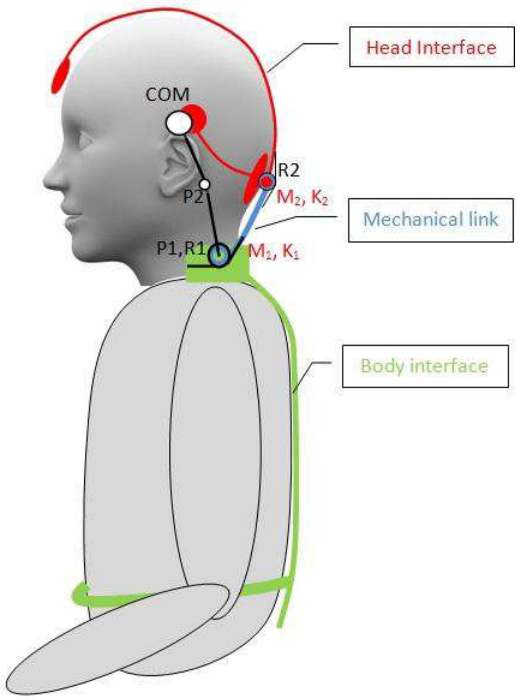


Figure 4: Conceptual design of the head interface, balancing mechanism and body interface

Force analysis

Average head mass was estimated to be 5 kg [7, 2]. Since patients in the target group still have muscle force left, it was assmumed that 50% of the head weight is still supported by the patient's muscles. One could also choose a different percentage. Even the total weight can be supported, which was tried with the prototype design.

Free body diagrams (FBD) of the head link, neck link, gripper, mechanical link and body support are given in figure 6. First the head and neck are considered to the in their natural upright position. Such that, $\varphi_1 = 5$ deg. and $\varphi_2 = 15$ deg. It is assumed that pivot points P1 and P2 are frictionless pivots, so the neck link is loaded under compression, giving the direction of force F_2 Figure 6e shows the force balances per part. The application of a horizontal force F_2 at the forehead acting through 'S', balances head and neck. The required torques and forces for the head support are shown in figures 6 b, d and f. The force systems for the individual parts are shown in figure 6e. This analysis supports the balancing strategy shown in figure 3. Figure 7 shows what happens to forces and torques as the head link (and gripper) and/or neck link rotate.

Head and Neck Rotation

The angle φ_2 of the head link varies between 15 and 25 degrees with respect to the vertical in point P2. If the head rotates F_2 needs to change direction in order to act through 'S' the intersection point of W and F_1. Note that the neck link remains in it's original position. It can be seen that point 'S' travels upwards along the working line of W. Examining the contact angle of F_2 and the forehead shows that shear forces will be applied to the skin of the forehead.

Note that the reaction force at the neck collar is split up in a horizontal and vertical force. The horizontal force is exerted by the neck/shoulder where the collar touches the body. The vertical force is applied to the shoulders.

The neck link angle φ_2 was said to change between 5 and 25 degrees. If the neck link rotates force F_1 changes direction and the intersection point 'S' moves in downward direction along the force line of W. In order to balance the head by applying F_2, this force needs to change direction and magnitude. The effect of neck link rotation is shown in figure 8. The orientation of the head link is equal to figure 7. It can be seen that F_2 acts almost perpendicular again w.r.t. the contact surface being the forehead.

Balancing equations

The *direction* and *magnitude* of the force F_2 acting on the forehead, required for balancing, depends both on the orientation of the head link (φ_2) and the orientation of the neck link (φ_1). Next, the relations to determine both direction and magnitude of F_2 will be shown, based on figures 5a and 5b. The goals is to determine angle θ which is the angle between W and F_2

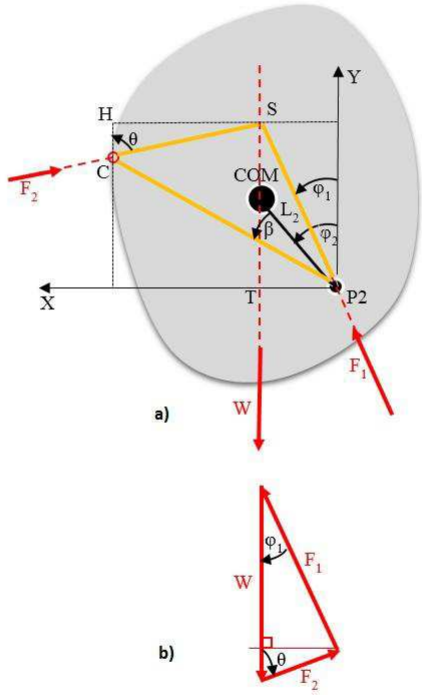


Figure 5: Four triangles were defined in order to find/calculate the direction of F_2.

Distance P2C and angle β are known, those determine th position of **C** on the forehead. The X- and Y coordinates of **C** are:

$$X_c = P2C \cdot \cos(90 - \varphi_2 - \beta) \quad (1)$$

$$Y_c = P2C \cdot \sin(90 - \varphi_2 - \beta) \quad (2)$$

The X- and Y coordinates of **S** are:

$$X_s = L_2 \cdot \sin(\varphi_2) \tag{3}$$

$$Y_s = L_2 \cdot \frac{\sin(\varphi_2)}{\tan(\varphi_1)} \tag{4}$$

Angle θ can be calculated based on equations 1 to 4:

$$\theta = \arctan(\frac{X_c - X_s}{Y_s - Y_c}) \tag{5}$$

Now the angle θ is known, the magnitude of F_1 and F_2 can be calculated based on figure 5b. It can be seen that:

$$F_1 \cdot \sin(\varphi_1) = F_2 \cdot \sin(\theta) \tag{6}$$

$$F_1 \cdot \cos(\varphi_1) + F_2 \cdot \cos(\theta) \tag{7}$$

Combining 6 and 7 and solving for F_2 gives:

$$F_2 = \frac{W}{\cos(\theta) + \cos(\varphi_1) \cdot \frac{\sin(\theta)}{\sin(\varphi_1)}} \tag{8}$$

F_2 can be calculated from 6:

$$F_1 = F_2 \cdot \frac{\sin(\theta)}{\sin(\varphi_1)} \tag{9}$$

Now the direction and magnitude of force F_2 on the forehead is known as a function of head- and neck rotation angles φ_1 and φ_2, torques M_2 and M_1 can be determined based on the dimensions y_2 and y_1 of the gripper and mechanical link. These dimensions will depend specifically on the sizes of head and neck of a patient. Taking figure 6 as an example, M_1, M_2, F_3 and F_4 can be determined as follows:

$$M_2 = F_2 \cdot y_2 \tag{10}$$

$$M_1 = M_2 + F_2 \cdot y_1 \tag{11}$$

$$F_4 = \frac{M_1}{d_3} \tag{12}$$

$$F_3 = F_2 + F_4 \tag{13}$$

Free body diagrams and above equations for balancing show the fundamentals of how head and neck balancing was envisioned in the conceptual design. The 'Results' section shows the materialisation of a prototype. This prototype was designed with springs in order to compensate a head weight of 50 N. To determine the torque characteristics the method above was followed. It appeared that linear torsion springs could be used. The torsion springs are mounted in parallel pairs around R2 and R1. Figure 12 shows these characteristics.

Design requirements

Based on user-group analysis, force analysis, rapid experiment and balancing equations, six design requirements were set for the design of a prototype of a body supported head rest. The design and materialisation will be presented in the 'Results' section. Requirements are split up in 'Patient requirements' and 'Technical requirements'. Patient requirements are more qualitative needs and the technical ones are quantitative.

Patient requirements, the head support must:

1. be body-supported.
2. transfer reaction forces in a comfortable manner.
3. be compact, following the contours of the body.

Technical requirements, the head support must:

1. support the required percentage of total head weight based on patient needs.
2. support the head weight for head rotations of 10 degrees and 20 degree neck rotation.
3. Torsion spring torques must be according to shown calculations depending on the percentage of head weight to be supported.

Test Method

A known but adjustable weight m in the form of a water filled vessel was applied at fixed distances d2 and d1 from R2 and R1 while the head support was clamped just below the neck collar as shown in figure 9. Mass 'm' was measured on a MAULtronic S 2000 scale with a resolution of 0.5 grams. This way known torques could be applied around R1 and R2. Torques were measured separately by blocking R2

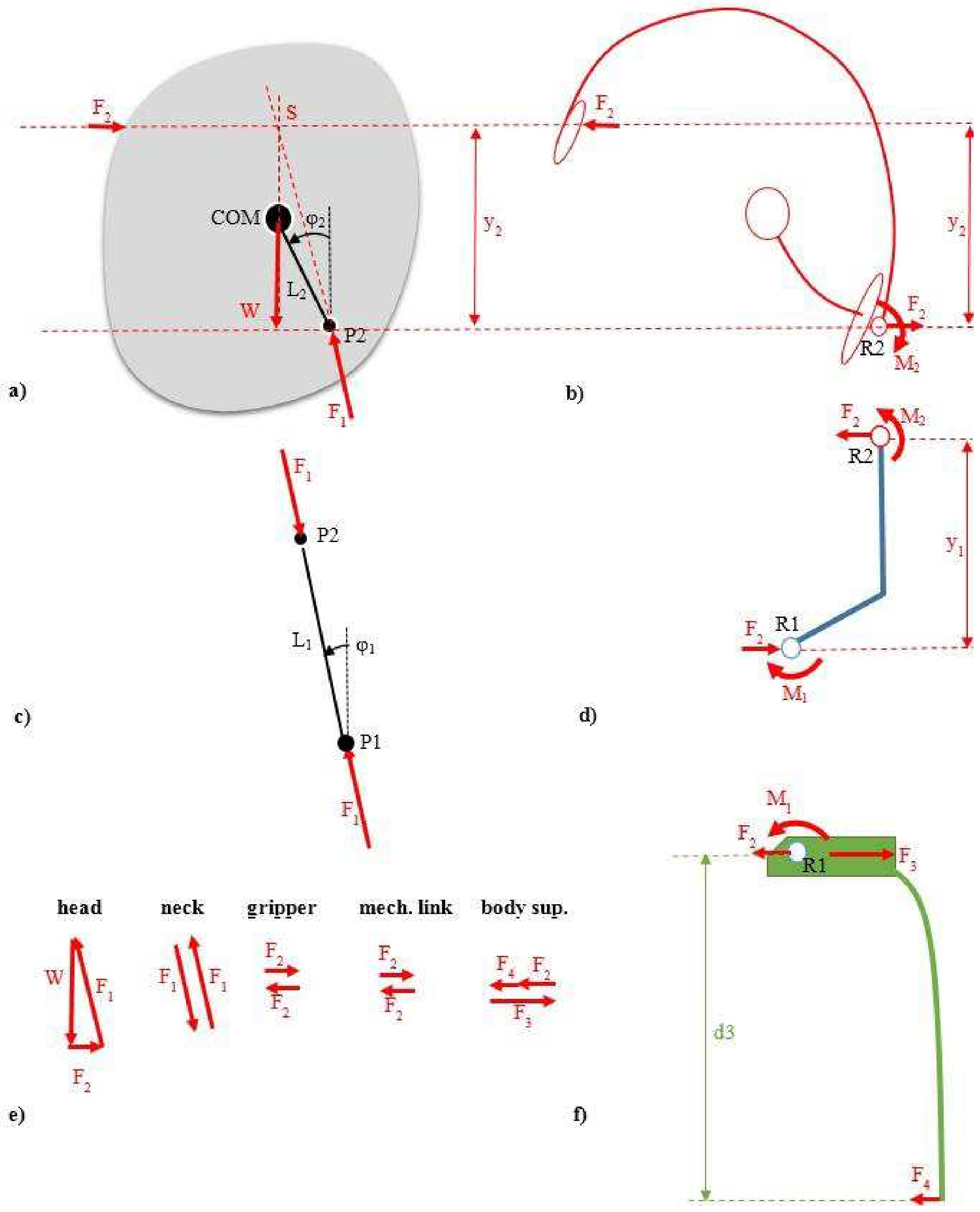


Figure 6: Forces and torques are drawn for the various subsystems in order to balance the head and neck in natural upright positions i.e. $\varphi_1 = 5$ deg. and $\varphi_2 = 15$ deg. The subsystems with forces on it are drawn in. With the directions of W and F_1, and contact point of F_2 at a distance y_2 from P2, it is possible to determine the direction of F_2. This force was applied to the gripper, mechanical link and body support in order to find equilibrium forces and torques for these parts. e) shows the force diagrams fore the individual subsystems

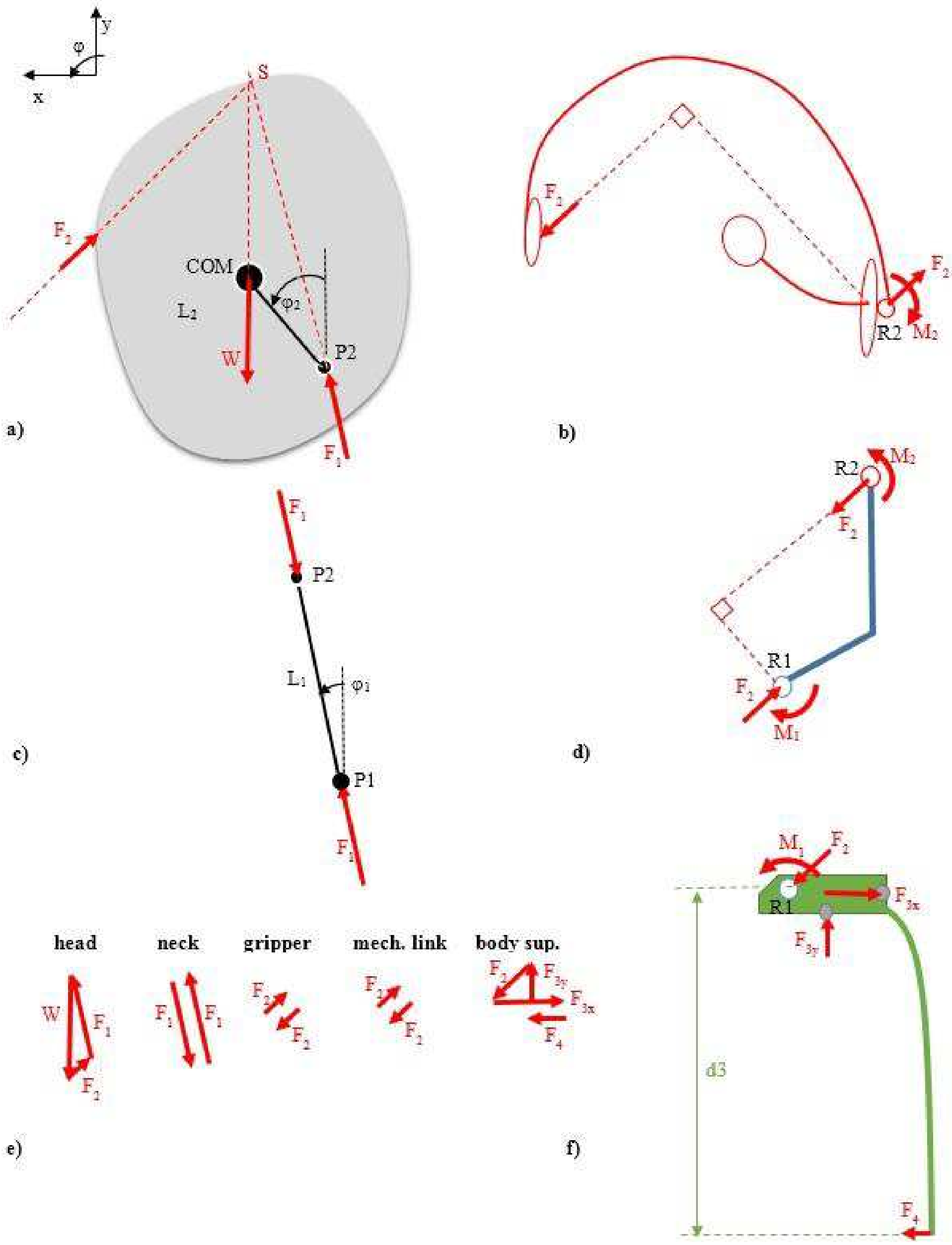


Figure 7: The effect of head rotation is shown in this figure. If neck link position is maintained and the angle φ_2 of the head link increases, it can be seen that F_2 needs to change direction and magnitude to act through intersection point 'S'. Note that a vertical force F_{3y} is at the neck collar is needed. This force is supported by the upper part of the shoulders.

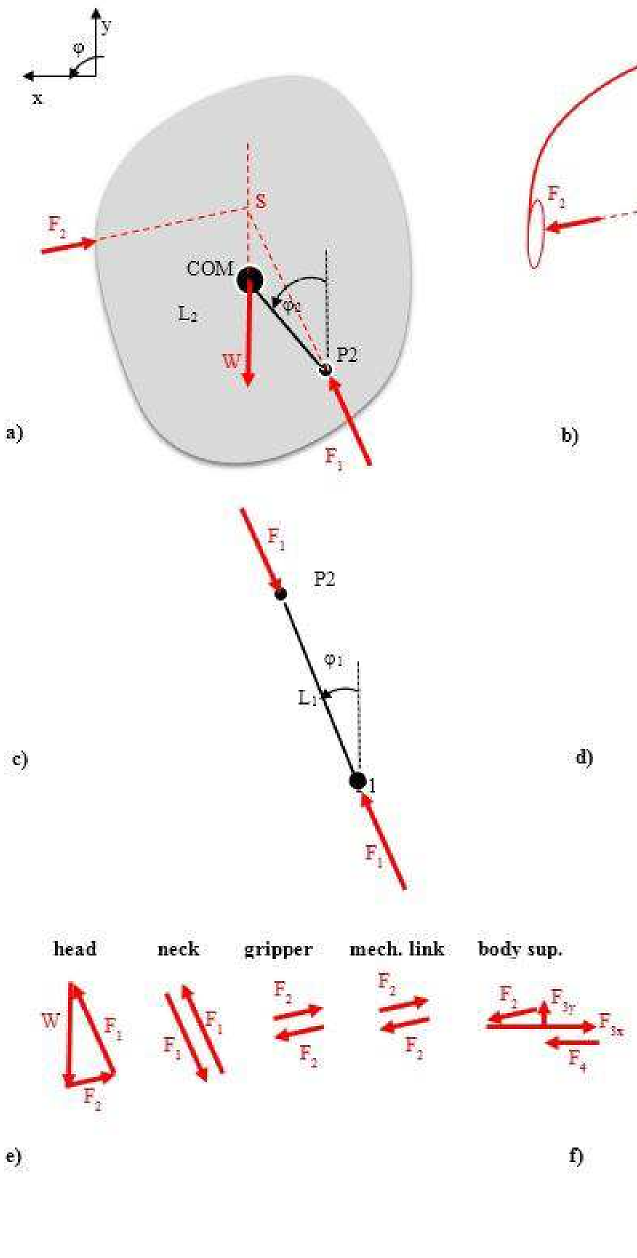


Figure 8: The effect of neck rotation is shown in this figure. The mechanical link has rotated along with neck rotation.

while measuring torque around R1 and vice versa. For each 'm'and applied torque rotations were measured five times. While measuring θ_1, θ_2 the angle of the gripper was maintained at five degrees such that d2 was constant.

Rotations θ_1 and θ_2 were calculated by measuring reference heights h_1 and h_2 with a calliper at θ_1 and θ_2 equal to zero, and in rotated configurations when the load was applied. Height differences were converted to rotations θ_1 and θ_2 around R1 and R2.

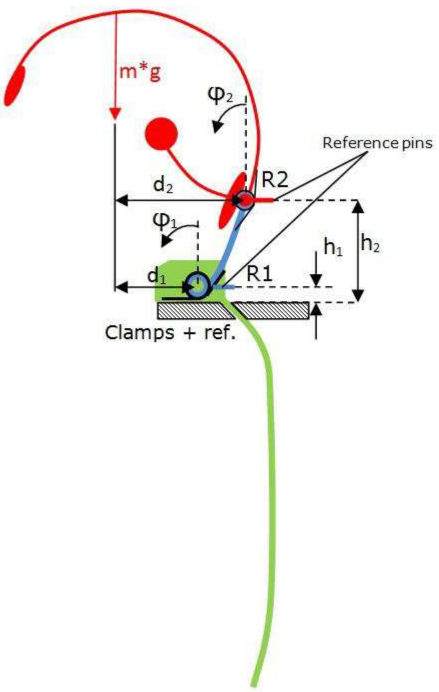


Figure 9: Schematic overview of measurement setup. Force m*g applies torques around R1 and R2 resulting in φ_1 and φ_2 to be measured.

3 Results

Materialization of Conceptual Design

For technical evaluation of the conceptual design a prototype was designed and constructed. Main dimensions of the gripper, neck collar and pivot locations were derived from ADAPS, a 3D anthropometric database. Dimensions of the Mechanical Link running along the back and length of the straps were determined by fitting it to a mannequin.

Head interface

Figure 10 shows main components of the prototype in side view, lever at the back as shown figure 4 is not shown.

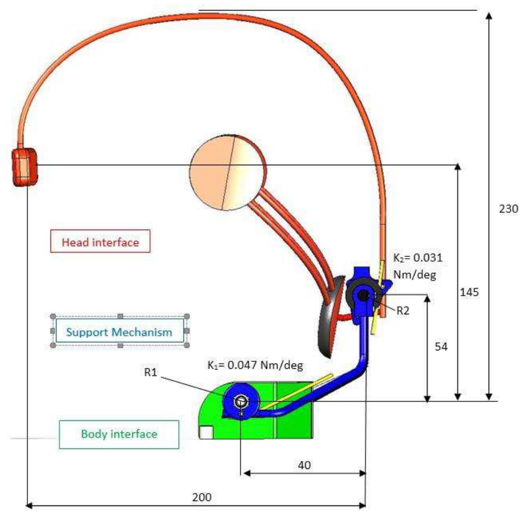


Figure 10: Three main parts: Head interface (red), Support mechanism (blue) and Body support (green). Main dimensions, pivot locations and spring stiffness's are given.

The middle part of the head interface connecting forehead and back head paddings consists of two parallel slender three millimetre rods of stainless steel curved close to head contours. The curved rectangular forehead padding is made from anti-allergic neoprene, glued onto a curved plastic plate of 25 mm by 95 mm. Its curved shape and elongated design offers good grip and sidewards stability of the head. When the head bends forward, compensating force is applied via this pad. Together with the soft 45 mm circular rubber side supports just behind the ears, this prevents the head to fall out forwards in a skew manner. The 42 mm circular pad at the back is also made of reinforced rubber compound. This soft pad fits the dent of the back of the head and grabs the head at the front and back as experimented with the wooden mock-up. In summary: The gripper design is slim, provides soft contact points and grabs the head at the fore- and back head.

Support Mechanism

The support mechanism (blue parts in figure 10) consists of two 5 mm bend connection links connected to R2 at the Gripper at the back of the head. And the other ends to the Body Interface' neck collar left and right of the neck at R1. Rotation point R2 consists of a stainless steel 6mm axis rotating in a POM bushing. Rotation points R1 have stainless steel 6mm H7 axes on which a stainless steel bushing rotates along with the connection links when the neck bends.

Because the calculated spring characteristic from figure 12 was almost linear over the desired range of motion, linear torsion springs were selected. Torsions springs 'K_1' were mounted left and right of the neck at the neck collar around pivots R1. These springs act in parallel, such that the desired torque can be delivered using compact springs. Two torsion springs 'K_2' were mounted around R2.

The lower torsion springs, K_1, mounted at R1 are commercially available springs from Gutekunst Federn, type T19125 (Left and right). According to manufacturer specifications one spring delivers 0.825 Nm over a range of 34.8 degrees. So parallel mounted springs deliver a total maximum torque of 1.65 Nm. The total stiffness of pivot R2 will be 0.047 Nm/deg.

Torsion springs, K_2, mounted around R2 were also obtained from Gutekunst Federn. Two parallel acting springs mounted at R2 deliver a maximum torque of 0.86 Nm over a range of 27 degrees. Total rotational stiffness around R2 is 0.031 Nm/deg.

Body Support

The body support consists of a neck collar fitting the neck just above the shoulders. The neck collar has a stiff 5 mm thick stainless steel shell to which the lower pivot points are mounted. It has a soft 15 mm rubber inlay. The inlay is moulded around a steal plate providing stiffness and pre-shaping of the rubber inlay. A curved lever is attached to the back of the shell guiding torsion spring reaction torques towards straps around the hips.

Figure 11: Rendering of Solidworks CAD drawing

Technical Evaluation

Functionality - range of motion

To test the range of motion and the position of rotation points R1 and R2 of the head support it was tested on five healthy people. All showed to be able to bend the head forward in a for them natural way over the head support's full range of motion. Because the head support has two pivot points it is also possible to translate the head forwards and bend the neck at the same time.

Observing the upper pivot while the healthy person rotated the head back and forth, while it had to look at a diner plate from a sitting position, it was measured that this pivot rotated approximately five degrees. For the same healthy person the R2 rotation was blocked temporarily while doing the same job, this felt less comfortable and natural but 20 degrees rotation around R1 could be maintained.

Head weight support

Figure 12 shows the results of the torque-rotation measurements done with the designed prototype in which the chosen torsion springs were assembled. It shows the desired torque obtained from numerical analysis (thick solid red and blue lines), predicted torque-rotation based on manufacturer specifications (dashed blue and red lines) and measured torque-rotation characteristics (blue and red asterisks).

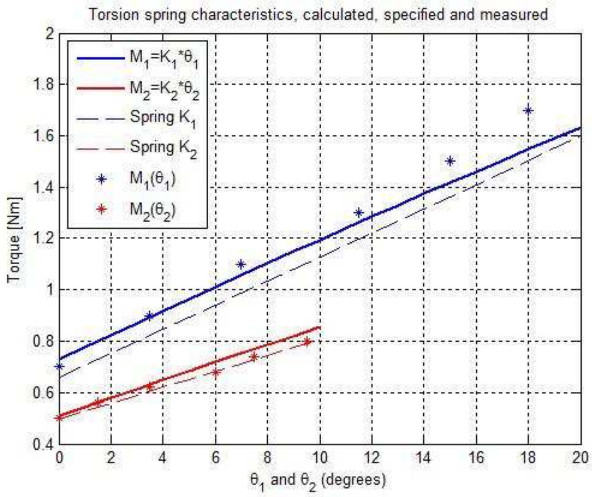


Figure 12: Calculated torque-rotation characteristics of $M_1 = K_1 \cdot \theta_1$ and $M_2 = K_2 \cdot \theta_2$ indicated with solid thick blue and red lines. Torque-rotation characteristics (Spring K_1 and Spring K_2) according to torsion spring manufacturer specifications indicated by dashed blue and red lines. Measured torque-rotation characteristics $M_1(\theta_1)$ are indicated with blue and red asterisks.

Measurement results were obtained for pre-tensioned torsion springs K_1 and K_2. Pre-tensioning angles α_1 and α_2 for K_1 and K_2 were respectively 14 and 16 degrees. Springs K_1 at each side of the neck collar can be set with separate set screws. Springs K_2 can be pre-tensioned together with one set screw. The constructions for pre-tensioning are illustrated by figure 13.

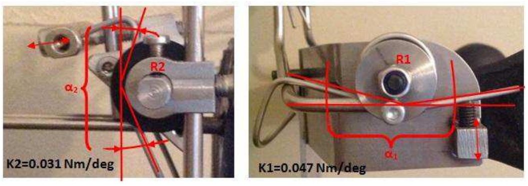


Figure 13: Left: Pre-tensioning construction for spring K_2 at an angle α_2. Right: Single spring pre-tensioning of spring K_1 at angle α_1 with a set screw. The same construction is on the other side of the neck collar.

Body Reaction Forces

When the head bends forward, the torsion springs balancing torques are transmitted to the forehead through the forehead pad. Forehead pad contact area is 2300 mm^2. Resulting skin pressure varies between 1.3 kPa and 9.1 kPa. Not compressive load but shear stress is known to cause discomfort to the patient. Shear stress increases rapidly with decreasing skin thickness [9]. Forehead skin is relatively thin. Therefore there is a potential risk for skin damage and/or discomfort for the patient using the forehead pads. The work of Bennet [9] contains some case studies of different skin load methods. Relations for shear stress of each of these load methods were derived. Loading of the forehead skin by the forehead pad (curved plastic sheet with neoprene foam layer) is comparable with one of the case studies. This case study describes the loading of skin tissue with a dull chisel pressing on a thin sheet of plywood which is is contact with the skin. Load method and shear stress as a function of horizontal distance are show in figure14. According to the results of this study, the forehead pad as designed can reduce shear stress up to a factor ten compared to a dull chiles poking the skin directly. Forehead pad stress level can be five times less compared to shear stress levels of a rigid block pressing the skin. Resulting shear stress levels of were considered relatively low and acceptable.

The resulting reaction force F_4, shown in figure15 at the back is minimal when the head is in upright position meaning: $M_1(\theta_1 = 20) = 0$ Nm. This results in a force $F_4 \approx 3N$. It is maximal when $M_1(\theta_1 = 20) = 1.7Nm$, resulting $F_4 \approx 21N$.

Reaction force F_3 at the hips result from applied torque at the neck collar by the torsion spring K_1 (0.7-1.7 Nm) and the distance (0.5 m) of the straps with respect to the lower pivot. Calculation of torque equilibrium yields reaction force at the hips. This force varies between 2 and 3.5 N. The total mass of the head support is 0.85 kg. This weight is supported at the neck on which the neck collar is resting. So, the reaction force at the neck collar is approximately 8 N. The weight is divided over two sides of the neck collars. Reaction forces R_w from the body support design are shown in figure 15.

Patient Experiments

The prototype was tested on two female patients. This added additional qualitative knowledge about the designed head support. Patient one suffered from Spinal Muscular Atrophy type 2 (SMA II).

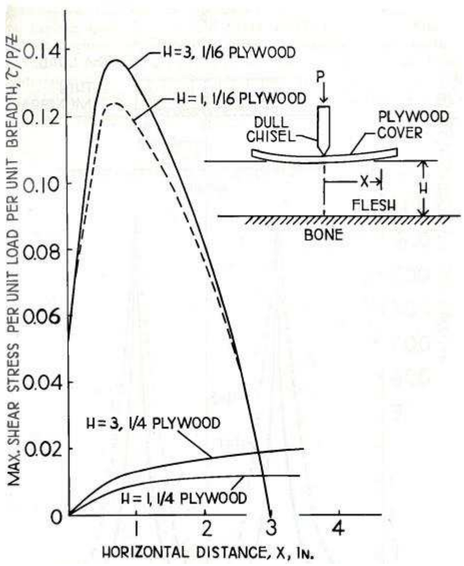


Figure 14: Load case comparable to forehead loading with forehead pad. A dull chisel (point load) is pressing a thin sheet of plywood which is in contact with the flesh. The graph shows a relation between shear stress and horizontal distance from the point loading applied with the chisel.

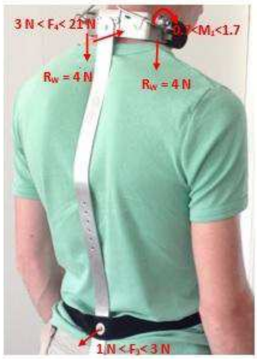


Figure 15: Torque M_1 is applied to the neck collar this causes indicated reaction forces at the hips and upper back. Total head support weight 0.8 kg is carried by the shoulders.

Patient two suffered from Amyothrophic Lateral Sclerosis (ALS). The SMA patient is able to keep her head upright herself but bound to a wheelchair. The other patient was still able to walk and use her arms, but her head was hanging skew forward. This type of patient was out of scope compared to the intended user. However her fairly good mobility made her an interesting case study for the body supported aspect of the head support.

Important learnings are listed below:

- Patient 1 could move the gripper around point R2 for the full 10 degrees.
- During movement around R2 the gripper maintained it's position on the head.
- Patient 1 experienced the body support to be too heavy.
- Patient 1 found the neck collar and attached lever comfortable.
- The head support could be fitted without problems to patient 1.
- The head of patient 2 could be kept in neutral position by the head support
- The balancing mechanism was too weak for head and neck bending of patient 2, with some manually applied force to the gripper the patient was able to move around R1.
- Patient 2 could wear the head support sitting in a chair and while walking, without noticing difference in comfort of the Body Interface.
- Vertical reaction force of the neck collar on the shoulders, due to the weight of head support, were uncomfortable for patient 2.
- Reaction forces from the hip strap were experienced to be low and comfortable.
- Aesthetics were acceptable for both patients.

4 Discussion

This section discusses the results and compare it to design requirements.

Range of motion

The requirement of ten degrees head rotation and twenty degrees of neck rotation were met within the design of the prototype. A healthy person could rotate head and neck without any restriction. It was also noticed that the upper pivot only had a minor contribution in total head rotation. It slightly compromises the feeling of natural head rotation. Due to some flexibility of gripper the head it is also possible to look a little bit left and right.

Support Mechanism

Based on a simple model for head and neck rotation force analysis was done and torque around the head and neck joint were predicted. Based on this (suboptimal) commercial torsion springs were selected to come as close as possible to the desired calculated torque-rotation characteristics. Whether the calculated are comparable with real patient head- and neck movement must be verified

Comparing torque-rotation measurements with calculated torque-rotation characteristics from figure 12 it can be concluded that an error is made for both the lower and upper pivot. The calculated characteristic and measured characteristic for spring K_1 differ the most. This error is made according to the author, because of friction between torsion spring K_1 and the stainless steel neck collar as the Mechanical Link rotates. It should be possible to reduce friction by redesigning pivot R1 and its pre-tensioning construction, for instance by applying a low-friction bushing between the spring and neck collar.

The sensitivity of patients to this friction is unknown and should be measured for future designs . From knowledge of arm supports it is known that patients are quite sensitive to friction in balancing mechanisms, so it is strongly recommended to address this item in future head support designs.

Except balancing error and regarding that the prototype design only served as a first proof of principle, results indicate that the idea of using compact linear torsion springs for partial head weight compensation can be promising. It is suggested to use custom designed torsion springs for future designs if more patient data is collected. It is envisioned that the Mechanical Link part(includign springs) of the head support, will be one fully compliant mechanism [10]. This will allow slimmer design and fully patient-centred and customizable head support designs.

Finally, current prototype design is based on a simplified model of the head and neck. This model is not validated for patients with a neuromuscular disease, since scientific data does not exist. Further research will be needed in order to determine remaining muscle force, joint stiffness, joint location and joint range of motion at neuromuscular diseased patients being in different phases of their disease. A more advanced prototype design with sensors included together with the theoretical model proposed in this study could be used as measurement device and validation method of head and neck models to learn about patients with different neuro-muscular diseases. This research step will require close collaboration between companies such as Armon Products facilitating technical support and development, doctors, ergo-therapists, physical therapists and insurance companies.

Head- and Body Interface

Reaction forces on the forehead vary between 3-21 N. The applied skin pressure is in the order of magnitude 1 and 9 kPa. Compared to acceptable skin pressures [11, 12] at lower limb prosthetics which are around 200 kPa, it is expected that forehead skin pressure is acceptable. Extensive patient testing will help to improve the ergonomic shape of this contact interface, and achieve even lower skin contact pressures.

Reaction forces guided to the body at the neck collar and hips turn out to be low and acceptable for patients. The long moment arm from lower pivot to hip strap turned out to be a comfortable, concealable and low force body attachment. According to patients the total mass of the head support is too large. Total mass of future designs can be decreased by using more lightweight materials like plastics or carbon fibres. This will improve patient comfort significantly.

Aesthetic Design

The aesthetics of the quite technical looking prototype could already count on appreciation of several patients, at a conference presentation. It is slim and hidable if wanted. The head interface can be hidden with a cap, the body interface can worn underneath clothing. This is possible because it is close to and predominantly behind the user. Therefore it is not in the user's face or field of view and looks inconspicuous compared to existing solutions, and the patient will look as normal as possible. From this mainly technical design, aesthetics can be certainly improved and changed to specific wishes of the patients.

5 Conclusion

Due to decreasing muscle force around the head and neck, balancing head weight becomes harder for patients. Rather than fixing the head it was proposed to support part of the head weight over 10 degrees head rotation and 20 degrees neck rotation.

Using an analytical approach by using a simple biomechanical model of the head and neck and force analysis a balancing strategy and head and neck balancing requirements were determined.

Measurement results deviated from the calculated torsion spring characteristics. The most likely cause for this error is internal friction within the prototype. The biggest error was measured for the lower rotation point (R2) of the prototype.

Numerical analysis and measurement results of the proposed conceptual design presented provide a basis for future (compliant) designs of the support mechanism.

The head interface with a back- and forehead padding together with two side supports has a good grip on the head. While bending the head low reaction forces between 3 and 20 N are applied to the head.

Balancing torque at the lower pivot is guided through a neck collar and ergonomically curved lever towards the hips yielding low reaction forces. Fixating the head support at the hips and neck collar to the body provides a solid base for support mechanism and head interface. Because of the slim design, the body supported headrest can be used within any chair, even while standing upright.

References

[1] Prinses Beatrix Spier Fonds. www.prinsesbeatrixfonds.nl, 2013.

[2] Hoehn K. Marieb, E.N. *Human Anatomy & Physiology.* Pearson, 2007.

[3] de Jager. Mathematical modelling of the human cervical spine, a survey of the literature. In *Mathematical Modelling of the Human Cervical Spine, A Survey of the Literature*, 1993.

[4] van der Horst. *Human Head Neck Response in Frontal, Lateral and Rear end Impact Loading.* PhD thesis, Eindhoven University of Technology, 2002.

[5] Goldsmith W. Deng, Y.C. Response of a human head-neck-upper torso replica to dynamic loading 2: analytical and numerical model. *Journal of Biomechanics*, 20:487–497, 1987.

[6] Yoganandan. Finite element model of the human head. *Med.&Biol. Eng. & Comput.*, 34:375–381, 1996.

[7] C.H. Spenny J. Wismans. Head-neck response in frontal flexion. *SAE*, 1984.

[8] J.C. Cool. *Werktuigkundige Systemen.* Delft University Press, 2003.

[9] L. Bennet. *Transfer Load to Flesh.* Bulletin of prosthetics research, 1973.

[10] Howell. *Compliant Mechanisms.* John Wiley and Sons, 2001.

[11] F.T. Mak. State of the art research in lower limb prosthetic biomechanics-socket interface. *Journal of Rehabilitation Research and Development*, 38:–, 2001.

[12] T.L. Beil. Interface pressures during ambulation using suction and vacuum-assisted prosthetic sockets. *Journal of Rehabilitation Research and Development*, 39:693–700, 2002.

Appendix A: Conceptual Designs

Rik Steenbergen

June 25, 2012

Contents

1 Introduction

Appendix A will show different conceptual designs for a body supported head rest. Concepts for three main parts will be discussed here: the head interface, balancing mechanism and the body interface. This study proposes to do the design of these parts separately. So for each part design requirements are set up based on interviews with patients and problem analysis. The head and body interface can both be looked on from a force perspective. The head interface applies forces to the head in order to balance it. How and where these forces can be applied to the head are analysed with a simple model. This force analysis will show different possibilities to balance a head. These balancing forces cause reaction forces that need to be guided towards the body interface. How to guide these forces to the body contains the design of the body interface. The body and head interface are coupled by a balancing mechanism providing the balancing forces at the head support and applying forces to the body interface.

2 Problem analysis

This section explains how we look at the problem of head balancing at people suffering from a neuro-muscular disease. First it is important to explain what we mean by 'a neuro-muscular disease'. This is important because different diseases affecting muscles have different effects on remaining functions. We concentrate on head balancing, in which we can distinguish two groups:

1. Group 1: This group has reduced to no muscle strength, and no remaining muscle control.
2. Group 2: This group has reduced to no muscle strength, but they still have (reduced) control over their muscles.

For the first group the result is that the neck muscles are not capable of lifting the dead weight of the head and controlling movement of head and neck. As a result the head will hang down and skew when no head support is applied. Later on we will discuss what kind of head rests are available for this situation. To give a complete picture, these people are mostly sitting in a wheelchair because they cannot walk and use their arms any more. Communication and breathing is also difficult because these muscle groups are also affected.

The main difference between group 1 and 2 is muscle control. Where group 1 has no muscle strength and control left, the second group does have sufficient but reduced control. This study presumes that if the neck muscles are assisted in lifting (part of) the dead weight of the head, head movement can be possible. People from group 2 will eventually end up in a wheelchair because distal body parts like arms and legs are affected early on in these progressive diseases. At fairly early stages of the disease people are still mobile. This means not bound to the wheelchair whole day, and able to walk short distances. Because the muscle disease progresses from distal to medial parts of the body, the second group needs to cope with weakened neck muscles for a prolonged time. The situation sketched for the second group will be the type of people for which this body supported head rest is designed. The first group is unfortunately too weak to aim for restored head and neck movement.

The first group however determines, according to the authors opinion, the main focus for many companies selling head supports. Why we think this is the case and what current solutions exist, is discussed in the next section.

3 Current solutions

Before getting started with the design of the body supported head rest, it is good to look at and analyse current head rest available on the market.
Visiting one of Europe's largest conference (Support 2012) with all kinds of assistive devices for disabled persons, it is remarkable to see that people that definitely need a head support do not use one. Making use of a fixed head support at the back and tilting the wheelchair backwards is a way that can be observed clearly. Many disabled solve head instability this way.

Together with information from patient interviews we think disuse has two reasons: one, disabled people want to look as normal as possible. They avoid constructions like head supportive devices that make them look disabled. Second, most of the available solutions offer little freedom of movement of the head. So in other words they offer too much support and give the user the feeling to be too restricted.

The first reason mentioned has to do with cosmetics. This effect is also mentioned in the design method by Plettenburg *. Therefore, aesthetics should not be underestimated in designing assistive devices. The second reason has to with what was mentioned at the end of the previous section: the focus of many companies is on fixating the head instead of assisting head movement. Another item is that most head supports can only be used when seated in a wheelchair. Remember that group 2 is still mobile and is not likely to offer mobility for head support and be bound to the wheelchair.

Next a classification of current head rests is given. This classification also explains why this study proposes a body supported head rest instead of a wheel chair supported head rest.

Current available solutions show differences in how the head supporting device guides reaction forces, to the wheelchair or the body. And a distinction between head fixating and moveable devices was observed. It shows that a combination of a wearable and moveable solution does not exist yet.

This latter option seems interesting because people from group 2 are still mobile and want to use the head support in their wheelchair, on a normal chair and in a car seat for instance. Devices as shown in the left column (wheelchair supported) often need to be customized for one particular type of (wheel)chair. As the connection between head rest and (wheel)chair is permanent the user if forced to sit in exactly the same position on the chair every time. This is impossible for a longer timespan and very uncomfortable according to many patients.

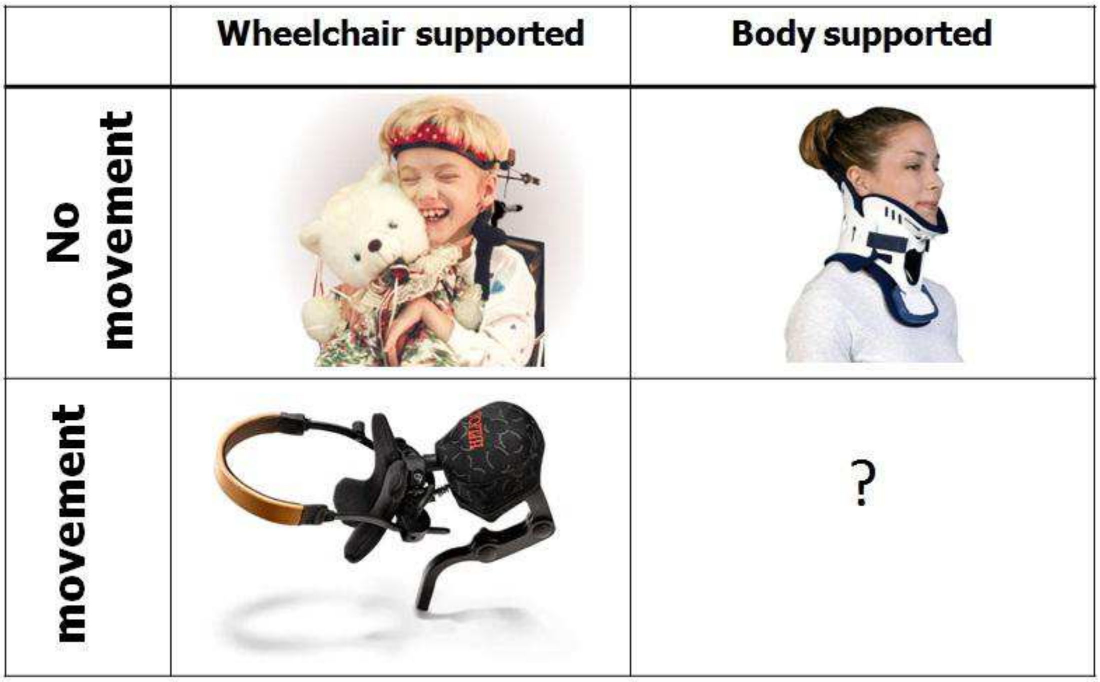


Figure 1: Classification of current available head rests. Top left: Focal head rest, fixates the head (no movement) and needs to mounted on a wheelchair. Top right: Neck collar, Fixes the head, body supported. Bottom left: Head movement is possible with the Helios device, mounted on wheelchair. The fourth category body supported and supporting head movement does not exist yet.

To use a neck collar could be an option. But it has the drawback of fixing the head and therefore takes away remaining head movement/function. This implies that looking around and up and down is not possible. While those functions in daily living activities (ADL) are essential for them. People are also critical about neck collar aesthetics and do not like to use them. A wheelchair-independent solution seems to be a preferred option.
To summarize, it might carefully concluded that existing three categories of head supports do not cover the whole spectrum of expectations of head support users.

The fourth category might therefore be interesting to investigate. This category allows(supported) head movement and can be worn on the body which covers the desire to be unbound to a wheelchair and fixed sitting position. Potentially a body worn solution can be made such that it is easy to hide underneath clothing, which will have an aesthetic advantage opposed to the massive and mechanical-looking headrests currently available.
It does have drawbacks and challenges too. For instance, body posture of people with a muscle disease differs completely form healthy posture. Scoliosis is one of the most complicating items. Scoliosis results in odd spine orientation. Therefore head and trunk are often uniquely positioned relatively to each other. Fixing a head interface to the patient's body could be challenging. Apart from

the fact that applying forces to a weakened body of a patient can already be uncomfortable.
Despite the drawbacks, the author thinks that this fourth option of a body supported head rest that assists in head movement, can be an alternative to solve some of the existing problems with current headrests. Also from an user acceptance point of view (aesthetics,) this type of solution could be interesting.

Next, design requirements and concepts for the three main components of the body supported head rest are presented.

4 Head interface

4.1 Design requirements

The following list presents the design requirements of the first main part: the head interface. The function description of this module is: Apply counter-forces to the head at suitable locations at the head. The requirements are split into different categories according to Pahl&Beitz*:

The head interface has the following geometric requirements:

Geometry

- Head breadth: 56 ± 10 mm
- Head circumference: 552 ± 20 mm
- Head length: 182 ± 15 mm
- Head interface should be able to follow head contours according to sizes above, within 10 mm

The geometry of the head interface is based on NASA's online Volume I anthropometric database related to design considerations *ref!!

The average (50^{th} percentile) dimensions of a 40 year old American women are taken as a first approximation of the head interface's dimensions

Force requirements

- Forces can only be applied to places where eyes, ears and mouth are not hindered.
- Shear forces should be omitted as much as possible
- Head weight at center of mass is approx. 50 N
- External force disturbances at center of mass are approx. 15N

Kinematic requirements

- No slip/relative movement between head skin, hair and head interface

Assembly requirements

- Head interface should be lightweight $\leq$ 100 grams
- Head interface should have inconspicuous or good looking appearance

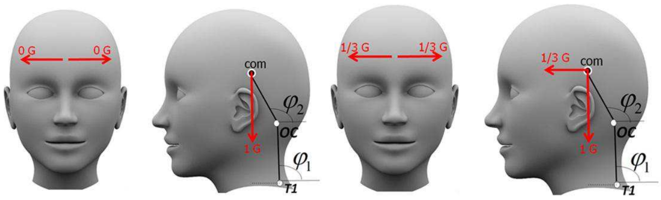
4.2 Conceptual Designs

This section shows ideas for possible head interfaces. Two routes have been been chosen for designing the head interface. It was thought that the head interface (in fact the whole head support) should be inconspicuous or should look as nice as a piece of jewellery or fashionable item. Both ways are thought to improve user acceptance and give the user self confidence wearing the head interface/support.
Some examples of commonly accepted fashionable items worn on the head are shown in figure 2.

Figure 2: Some examples of head interfaces that are fashionable and potentially hideable. Top left: Porsche design glasses. Top right: Senheiser design earphones. Bottom left: hideable bicycle helmet. Bottom right: slim designed neck collar.

Part of the design is force analysis together with a simplified model of the head and neck proposed by Wismans, 1984 *. This kinematic model and forces acting on the system help to design the head interface. The model at figure 3a shows the static case where the head weight needs to be compensated. Figure 3b shows an additional acceleration forces coming form external disturbances. These disturbances can for instance be the braking of a bus or car and the head becomes accelerated forwards are sidewards. 1/3G was measured to be the maximal acceleration of the head's center of mass(com) in both forward and sidewards direction.

These two different load cases need to kept in mind, when designing the head interface. Next three conceptual designs are proposed for the head interface.



(a) (b)

Figure 3: (a) 1G of force is acting vertically on the head's center of mass (com). (b) At the com 1G of head weight is acting, 1/3G external disturbance force horizontally and 1/3G force in left and right direction.

Glasses

Glasses are fashionable well accepted items worn on the head. The concept in figure 4 shows how it is thought to be included in a head support. Pro's and con's are listed below the figure.

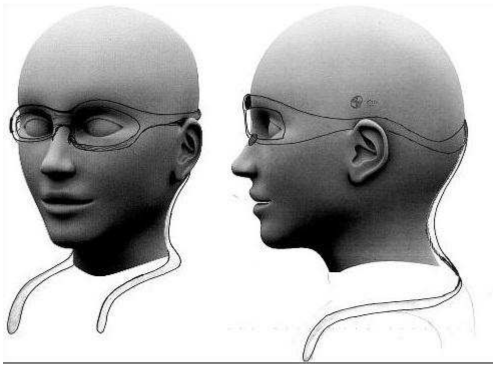


Figure 4: Glasses as a head interface being part of the body supported headrest

Pro's	**Con's**
Aesthetically accepted	Not every user needs glasses
Design can be slim and within head contours	Forces applied near eyes
Sidewards forces countered at the sides of the head	
Head circumference is enclosed preventing the head from falling out	

Chin support
Putting a hand under our chin is a natural way also for healthy people, to support head weight. A chin support as a head interface is the next concept. Figure 5 shows the chin support and counter forces applied to the forehead and chin.

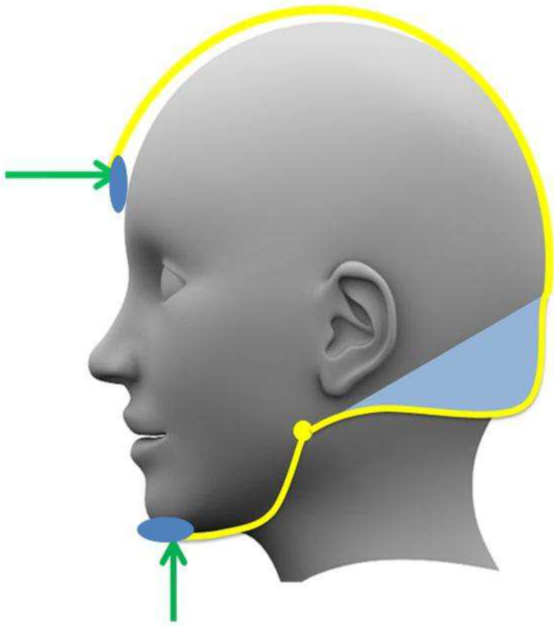


Figure 5: Applying forces to chin and forehead in order to balance the head.

Pro's	**Con's**
Forces at chin and forehead natural and acceptable	lower yaw movement hindered
Design is slim, within head contours	extra pivot for lower yaw movement
Sidewards forces countered at back sides of the head (blue)	
Head enclosed preventing the head falling out	

Three fingers

The idea behind the previous two concepts is that the weight and external forces acting on the head's com are counterbalanced by straight forward applying forces at suitable spots (chin and forehead) on the head.

The next idea is more advanced and can be explained better when looking at a particular way of balancing the head. This balancing concept uses the simple double inverted pendulum model of Wismans* shown in figure 3a and 3b. This joint torque balancing is discussed in the next section. For this concept we focus on the upper joint, the occipital joint or shortly, OC-joint.

It was observed that many patients have their chin on the chest when the head tips/hangs over. This position can only be reached when the head rotates around the occipital joint. Therefore, this idea for balancing proposes to balance joint torque M_{OC} separately from the joint torque at the lower pivot M_{T1}. So what we propose is to apply a *force couple* $F \cdot d$ to the head such that we can achieve a joint torque M_{OC} at OC. This force couple is applied to soft pads at the front and back of the head. More specific, the back pad is at the occipital part of the skull. There is a nod where the back padding can 'grip' under. By placing it at this location, the finger from back to front is thought to have less chance to slide up causing grip loss and possibly causing the head to fall out. Many fixed head rests are also supporting this part of the head, so it is expected reasonable force is tolerated here. Figure 6 shows the concept's working principle.

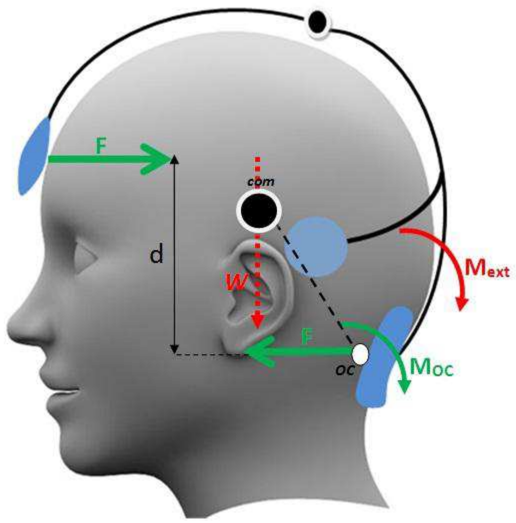


Figure 6

The external moment M_{ext} comes from the balancing mechanism for which concepts are shown in the following section. M_{ext} is transmitted to the head as a force couple indicated with the green arrows. This causes joint torque M_{OC} counteracting the head's weight torque.

The next section discusses ideas for balancing the head.

5 Balancing Concept

5.1 Design requirements

Geometry

- Dimensions of balancing mechanism desired to be within 10 mm of neck contours.

Forces

- Balanced head weight equal to 50 N
- External disturbances forward equal to 15 N
- External disturbances sidewards equal to 15 N

Kinematic

- Balancing mechanism should have 2 rotational Degrees of Freedom (DOF)
- Rotation axis should be as close as possible to the first thoracic vertebra(T1)and the occipital joint(OC).

Conceptual designs

Two ideas for head balancing will be presented next: 1. full head weight balancing and 2.balancing joint torques. With the first idea it is assumed that the head is a dead mass free floating in space of which the weight has to be fully compensated against gravity just for the bending of the head. The second idea focusses on joint torque compensation. The torque caused by the head's weight is counterbalanced. The balancing mechanism is connected to the head interface which is the part applying forces to the head. We will start with full head weight balancing or, static balancing.

Static balancing
The idea of statically balancing head weight comes was inspired by the balancing of arms of disabled persons *referenties!!. By relieving the dead weight of the arm or in this case the head from the muscles it is expected (in case of arms, proved) that head motion becomes possible. Remaining muscle function can be used in order to move the instead of carrying the weight of the head.
Gravity equilibrating mechanisms are treated in *referenties!!. Depending on the model used for head and neck we can choose to balance the mass for 1 DOF or 2 DOF. The most simple model for head and neck bending would be a single DOF inverted pendulum as shown in figure **??** at the left. At the right a possible balancing concept with a counterbalancing weight. Of course the distance between counterweight and pivot together with the counterweight itself can be varied.

The full weight of the head is compensated. An adjustable counterweight mechanism could be a very simple though effective concept. But from a force perspective this option is not desired. It can be easily seen that the weight of the head and the counterweight cause a vertical reaction force at pivot T1 of $2W$. Remember that we like to design a *body supported* head rest, meaning that

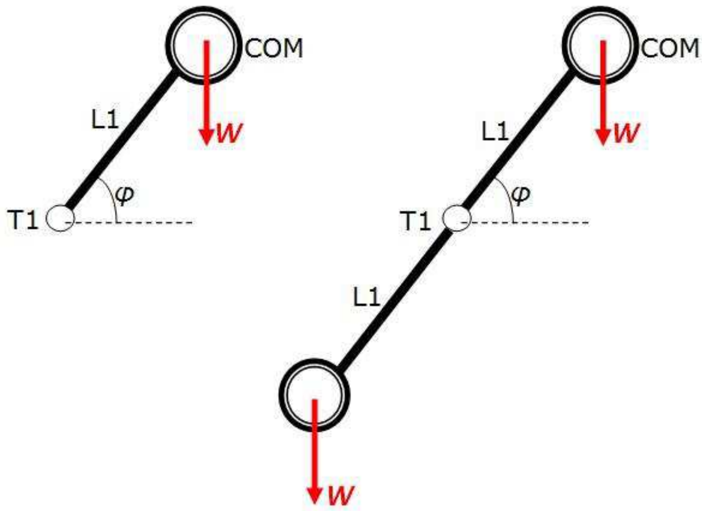


Figure 7: Head and neck flexion/extension modelled as a singel DOF inverted pendulum at the left. Possible balancing concept with a counterweight.

this vertical reaction force is applied to the body of the user. With a head mass of 5 kg, the concept is regarded as uncomfortable for the user.

The simple basic gravity equilibrator from *referenties!!, reduces the force applied to the user's body. Figure 8 is adopted from *referenties!!. The weight of the head can be compensated by a zero-free-length spring instead of a counterweight.

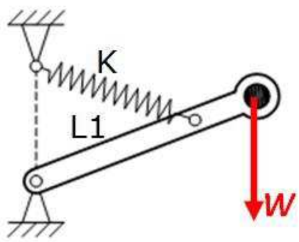


Figure 8: Basic spring gravity equilibrator adopted from *referenties!!. The weight of the head 'W' can be compensated by a zero-free-length spring.

So, a relatively simple spring mechanism could be an option for head balancing, if head flexion and bending is modelled as a single DOF inverted pendulum. This single DOF approximation could be assumed based on the graph in figure . Wismans *referenties!! measured head trajectory during high impact measurements. The assumption of a circular trajectory of the head's com based on the figure seems to be acceptable for these experiments. But it is questionable whether this trajectory would be the same when head bending is slow and initiated by humans themselves. No data of slow head motion trajectories was found in literature.

In the author's opinion the head and neck can better be approached by a double inverted pendulum with rotation axis near T1 and OC as already proposed in the concept of the three fingers grabbing the head.
For this case two other concepts for 2 DOF balancing are shown in figure 9 and 12.

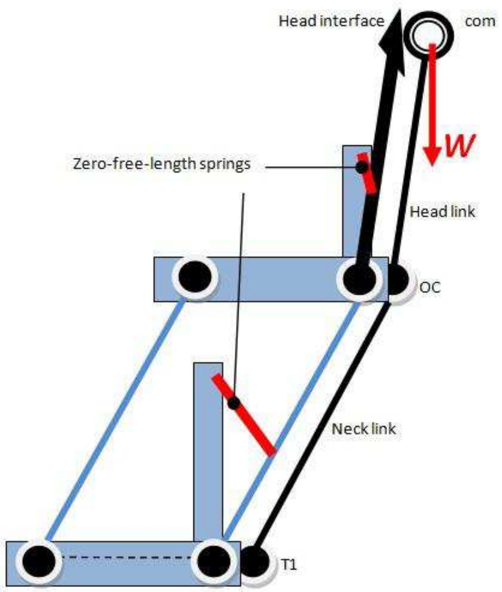


Figure 9: 2 DOF gravity equilibrator. This concept is adopted from *referenties!! This balancing mechanism has rotation axis near T1 and OC. The balancing mechanism is the result of stacking two 1 DOF basic equilibrators.

Figure 9 shows the combination of two stacked 1 DOF basic equilibrators (blue), parallel to the double inverted pendulum representing the neck and head from a side view (black). The rotation axis of the mechanism are near T1 and OC. The upper link is aligned with the head's com. Two zero-free-length springs(red) statically balance the weight. This mechanism, especially the parallelogram, could be symmetrically placed at each side of the neck to make it as compact as possible around the neck. Attaching the head by means of the head interface would result in 2 DOF statically balanced head flexion. The lower two pivots of the parallelogram construction are attached to the body interface, transmitting reaction forces/torques towards the body.

The concept was tested in Working Model 2005 with realistic parameters. The model is shown in figure 1 This helped to investigate the reaction forces at the base or body interface part of the parallelogram.

The reaction forces can be plotted for the lower two pivots attached to the body support in order to estimate that is applied. The force at the body support measured over time is 50 N horizontally to the left and 200 N downwards. These

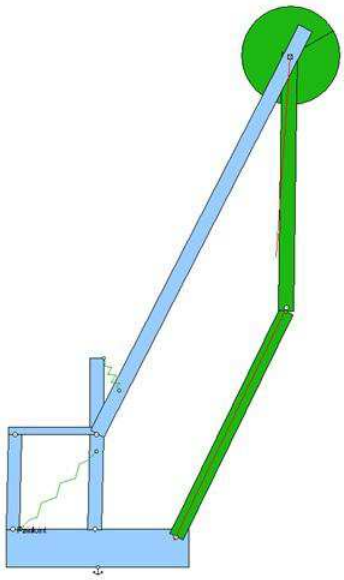


Figure 10: Working Model model of the 2 DOF equilibrator. Lower part of the balancer has dimensions 50x50 mm. Lower spring stiffness is equal to 0.154 N/mm, and th upper spring 14.2 N/mm. Stiffness of lower pivot of the double pendulum is 1.25 Nm/deg. Head mass is equal to 5 kg and head and neck link are both 0.125 m. Note that the upper link is aligned with the head's com.

reaction forces are quite high because the full weight of the head is carried with the balancing mechanism.
The next concept focusses on balancing joint torques.

Joint torque balancing
Opposed to the previous static balancing where the full weight of the head was supported this solution only supports a part of the weight of the head. Generally nothing is wrong with the cervical spine of the patients. The structure is strong enough to carry the part of the head weight normal to it. These means that the weight component perpendicular to the head link should be compensated. This component demands torques around OC and T1 as shown in figure 1. Again the head and neck are modelled as a double inverted pendulum as proposed by Wismans *referenties!!.

The joint torques are thought to be hard to deliver for the patients, and it is hypothesized that when we assist in delivering these torques by balancing weight component R, the head can be hold upright. Remaining muscle strength could be used to control head movement. This model resulted in the idea to apply a force couple to the head as explained in the section of the head interface above to balance M_{OC}. Figure 6 shows this external torque to be delivered by the balancing mechanism. An additional counter torque at T1 is needed. Calculations of joint torques M_{T1} and M_{OC} as a function of joint angles φ_1 and φ_2 in appendix B, show this relation is linear. This appendix also discusses what torsion springs are to be used. So linear torsion springs could be used to deliver the joint torques needed. Off course normal springs with adjustable levers

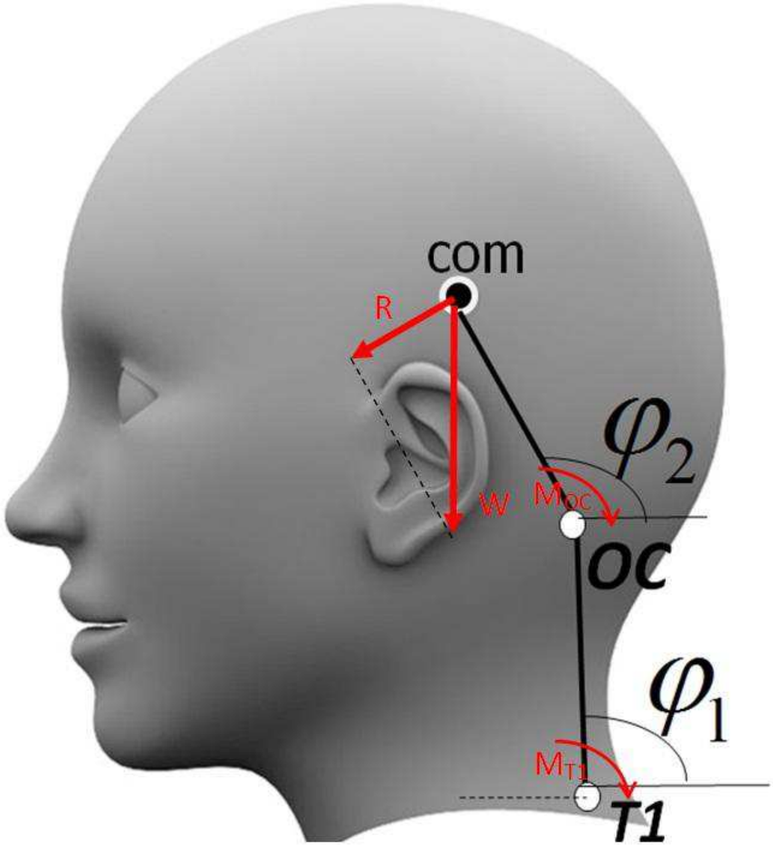


Figure 11

could be used to in order to exert the torques. Torsion springs are thought to be more compact which is beneficial for the aesthetics. Linear torsion springs in combination with a link connecting head interface and body interface with revolute joints for 2 DOF movement, could be a relatively simple solution for the balancing mechanism. It is schematically presented in figure3.

Test model To test if the concept of applying a force couple to the head would work, a planar 2 DOF wooden mock up model of the head and neck was made (figure **??**. A mock up of the head interface was also constructed. This was base one the finger-concept.

The head interface is a two finger spring tensioned gripper that grips the head at the front and near the nod at the back of the head. The head interface as a bolt fixed to it. To this bolt the external torque can be applied with a wrench. This external torque is than transmitted to the two contact points applying a force couple to the head.

Important remarks about the experiment:

- High friction at contact points is essential to get sufficient grip with grip-

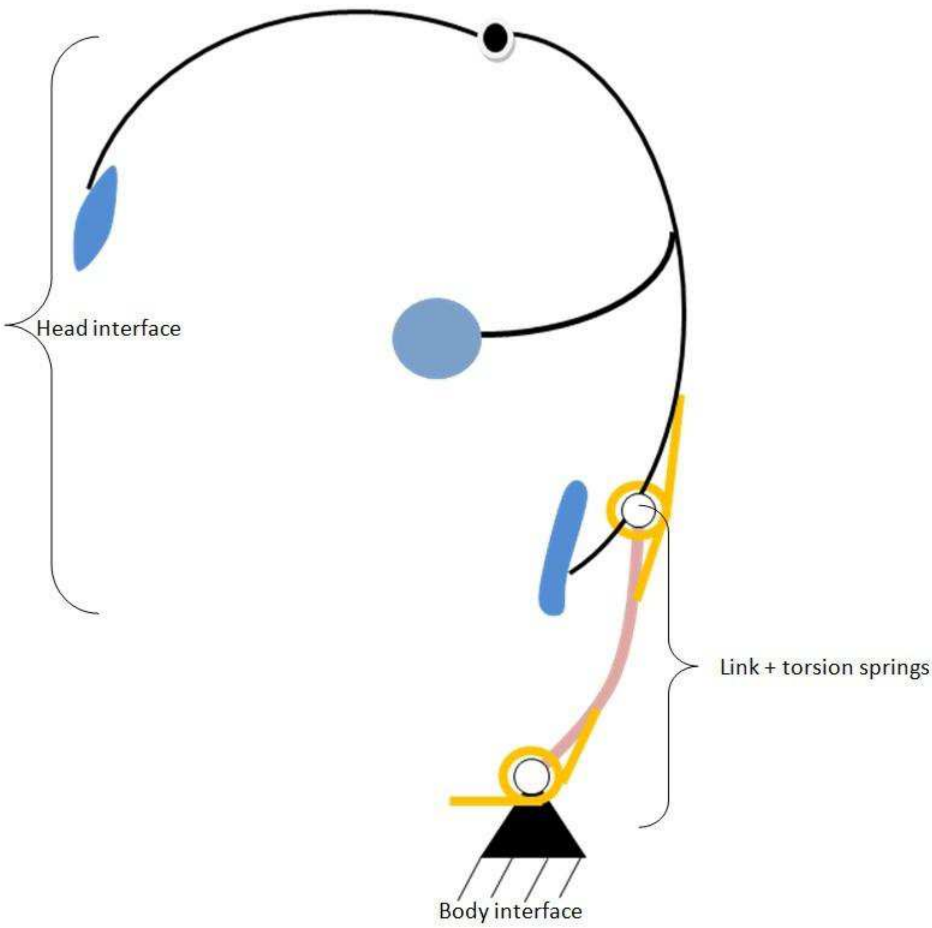


Figure 12: Joint torque balancing mechanism: an ergonomically shaped neck link (red), revolute joints for 2 DOF movement controlled by linear torsion springs (orange). It connects the head interface and body interface. The rotation axis' are aligned with T1 and OC.

per.

- Location of the contact point at the back should be at the nod just underneath the occipital bone. This nod prevents the 'head gripper' to slip.
- Relatively low torque is needed to balance the head.

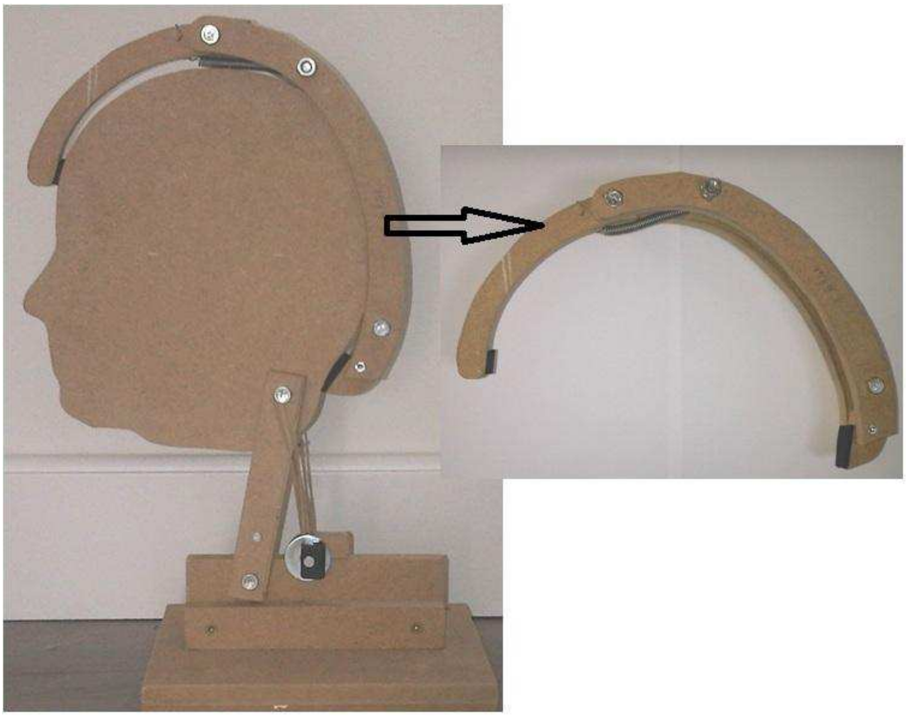


Figure 13: Mock up of the head and neck. An external torque is applied at a bolt with a wrench in order to balance the head. The head is gripped with a two-finger gripper touching the head at the front and at the nod near the occiput at the back of the head.

6 Body Interface

6.1 Design requirements

Geometry

- Wearable underneath clothes
- Within 10 mm of body contours
- Adaptable to different body sizes
- No interference with arm function
- No interference with respiration equipment

Forces

- No shear forces
- Reaction forces as low as possible

Material

- Anti allergic and breathable materials

6.2 Concepts

Examples of body supports In daily life and also in a bit more advanced situations body interfaces are used to carry and transmit loads on and to the body. Figure shows some of them. For the head support we need a body support that is fixed to the body and forms a solid base to attach one of the balancing mechanisms. In other words, it should be constrained to the body (no slipping and turning) and guide reaction forces and torques towards the body in a comfortable way.

Figure 14: From left to right: body supported camera, rigid spine harnesses, backpacks and a shoulder harness to attach a prostheses to the body.

With *referenties!! (Gemperle et.al dynamic wearability, examples as in figure 14 and patient interviews several potential spots on the body can be pin pointed to guide reaction forces to. These locations are shown in figure 15.

Magnitude and directions of these reaction forces and torques depend on the kind of balancer. With the 2 DOF equilibrator, the base to which the parallelogram is mounted is loaded differently than if the base was mounted to the torsion spring balancing mechanism. For the design of the body support we do not look at balancers already designed. In fact, most ideas for the body support were developed before the design of the balancers started.
For the design of the body support a single link inverted pendulum thinking model of the head and neck was used. Instead of one DOF, this model allows three head rotations at the base: head rotation (φ_z), flexion/extension (φ_y) and lateral bending (φ_x). This is illustrated in figure 18. So three reaction forces and three reaction torques acting on the base of the pendulum, which represents the body support in our case.
Shoulder braces One of the concepts already tried in a previous assignment on the body supported head rest are shoulder braces. The shoulders are a straightforward choice when trying to guide reaction forces to the body. The shoulders are close to the head which enables a compact construction for the whole head support. When braces are put over both shoulders with contact points at the chest and back, rotation of the body support φ_y and translation

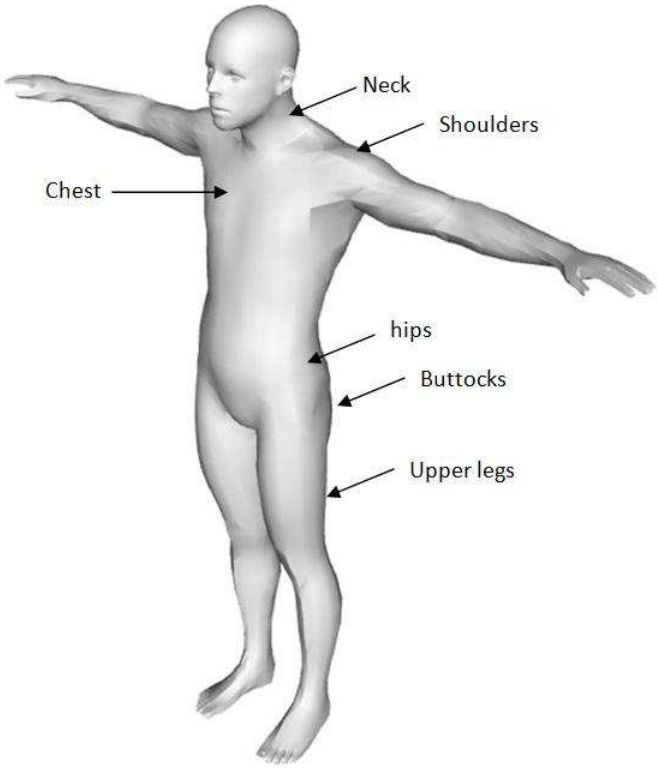


Figure 15: Potential body locations to guide reaction forces: Neck, shoulders, chest, hips, buttocks and upper legs.

in x-direction are constrained. It needs additional straps that loop from back to front ends of the braces at the armpits to constrain the other degrees of freedom. Figure **??** shows the Apoyo a previous prototype designed by Rik Steenbergen and Jos Lassooij, using the shoulder braces.

The shoulder braces as shown, were found not convenient in adjusting to the patient as body posture and shoulder positions are very odd for muscle diseased people. The contact points are relatively close to the base, such that moment arms are very short causing relatively high and uncomfortable contact forces occured. This concept could be further developed or reviewed, but as the results were disappointing at the start of this project other concepts needed to be developed. Those will be discussed next.

Neck collar + Harness + Hip belt

Shoulder prostheses below and above elbow, are attached to the stump and the upper body by using a stiff, neatly fitting prosthesis and a body harness *referenties!! Plettenburg. This concept takes the same approach by having a stiff neck collar serving as a solid base for mounting the balancing mechanism, and an adjustable body harness.

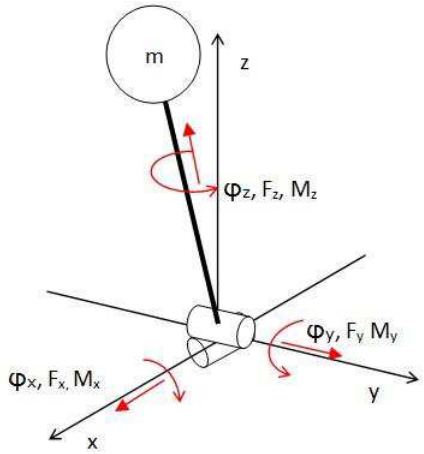


Figure 16: Simple model representing the head (m) as a one link three DOF inverted pendulum. In general it can be stated that the body support is loaded with three forces F_x, F_y, F_z and three torques M_x, M_y, M_z. All possible motion of the body support should be constrained as much as possible to form a solid basis for the balancer and head interface.

The idea is to have a neck collar of thermoplastic material with soft inlay deformable to patient specific neck diameter and body posture irregularities. The neck collar is curved along the back of the neck, so translations in y-direction (model)are constrained. The straps of the harness are attached as shown in figure **??** at both sides of the collar. The straps are attached at the front and back of the collar. These straps join approximately at the armpit level underneath the upper arm. Then they are attached by a strap (at both sides of the trunk) to the sides of the hip belt.
Forces and torques applied to the collar are transferred into tensioning of the straps pulling the hip belt When tightly fitted to the neck and body, the other degrees of freedom of the neck collar are constrained.

Advantages and disadvantages are listed below:

Pro's	**Con's**
Hideable underneath clothes	hip belt can creep up
Easy access at the sides of the upper body	weight of head support at neck
Adjustable to different body sizes	

Neck collar, Lever and straps This concept is partly based on the possible use of the balancer that uses torsion springs. The balancer is mounted on the neck collar such that the rotation axis of the balancer coincides with the T1 rotation axis of the user. The neck collar will be exposed to this joint torque and will tend to rotate forwards together with the head of the user. This is the main load of the neck collar. The lower the neck collar is attached to the body the lower the reaction forces will be, because the moment arm increases. So by attaching a lever to the neck collar and fixing this lever with straps around the chest and hip reaction forces guided to the body should be very low. The soft

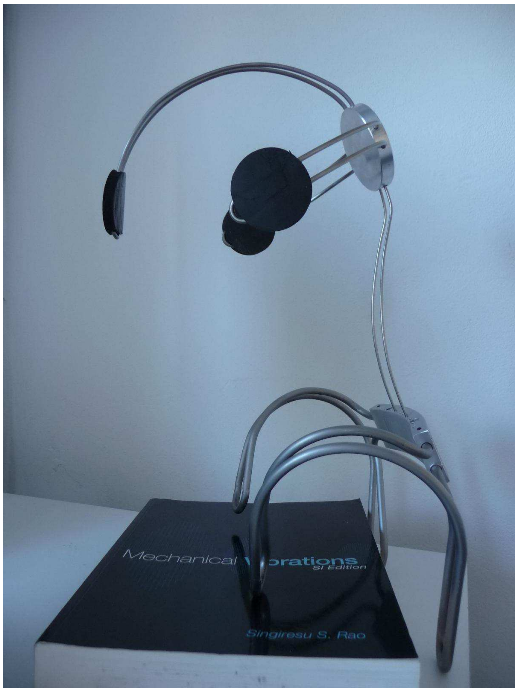


Figure 17: Photo of previous protoype Apoyo. Shoulder braces were used as body support in order to wear the headrest

padded lever is curved along the contours of the back such that it does not poke in the back when sitting in a (wheel)chair. An advantage of this concept is that it is more simple compared to the previous one. Figure19 shows a schematic representation of the concept.

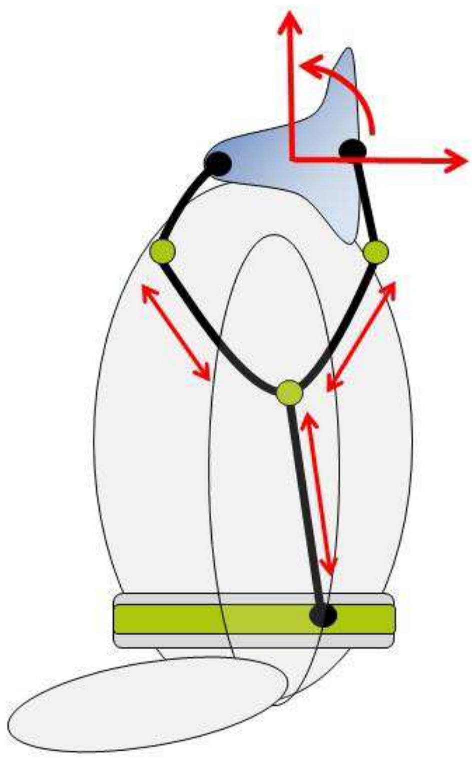


Figure 18: Schematic drawing of the Neck collar + harness + hip belt concept (green). Forces and torques applied to the custom made neck collar (blue) are transferred to the hip belt. The neck collar will not move making it a firm basis for the balancing mechanism. The straps are attached at the front and back at both sides of the collar. They join at the armpit and run down to the hip belt.

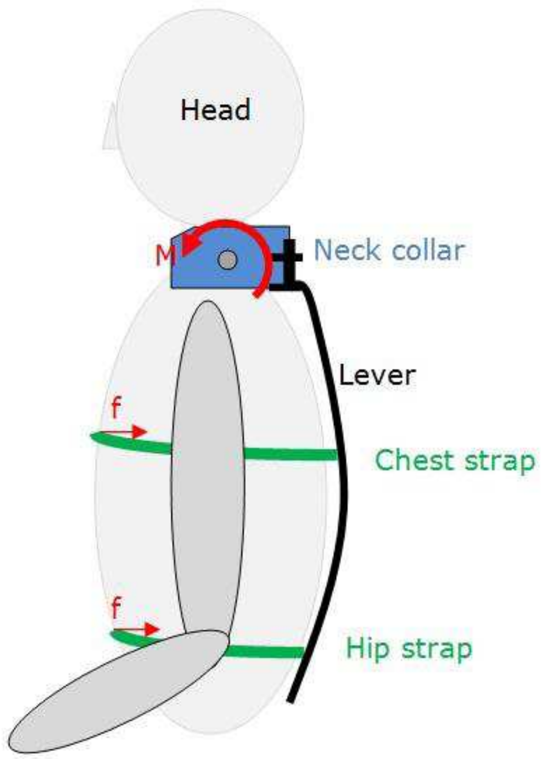


Figure 19: Schematic drawing of the Neck collar + lever + straps concept. Torque applied to the neck collar is transferred by the lever to low reaction forces 'f' at the body by attaching it with a chest and hip strap to the body.

Appendix B: Technical Drawings

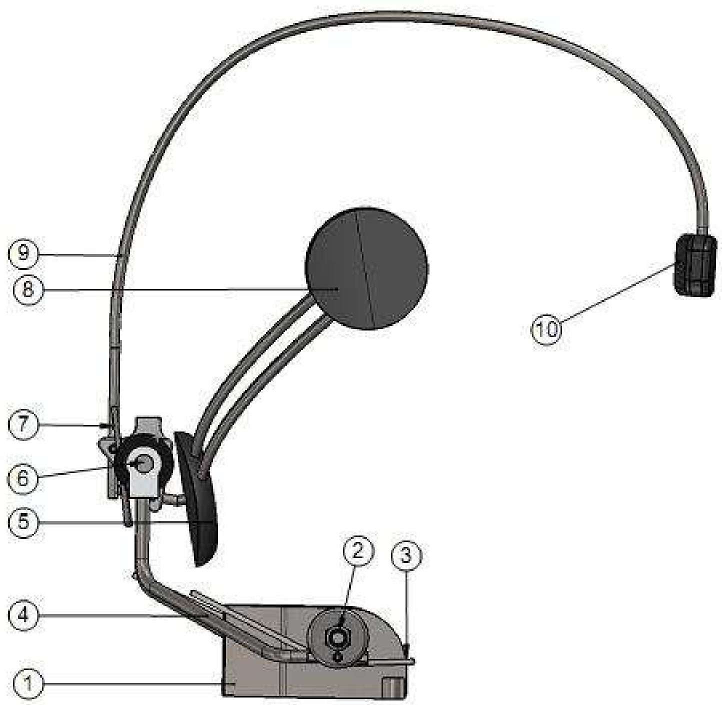
Rik Steenbergen

July 27, 2014

Contents

1 Parts

1.1 Main Parts



ITEM	DESCRIPTION
1	Neck Collar
2	T1 pivot
3	Lower torsion spring
4	Neck link
5	OC Pad
6	OC pivot
7	Upper torsion spring
8	Side supports
9	Finger
10	Front head pad

benaming Assembly main parts

maateenheid mm

formaat A4

tekeningnummer 1

TU Delft
Industrial Design Engineering

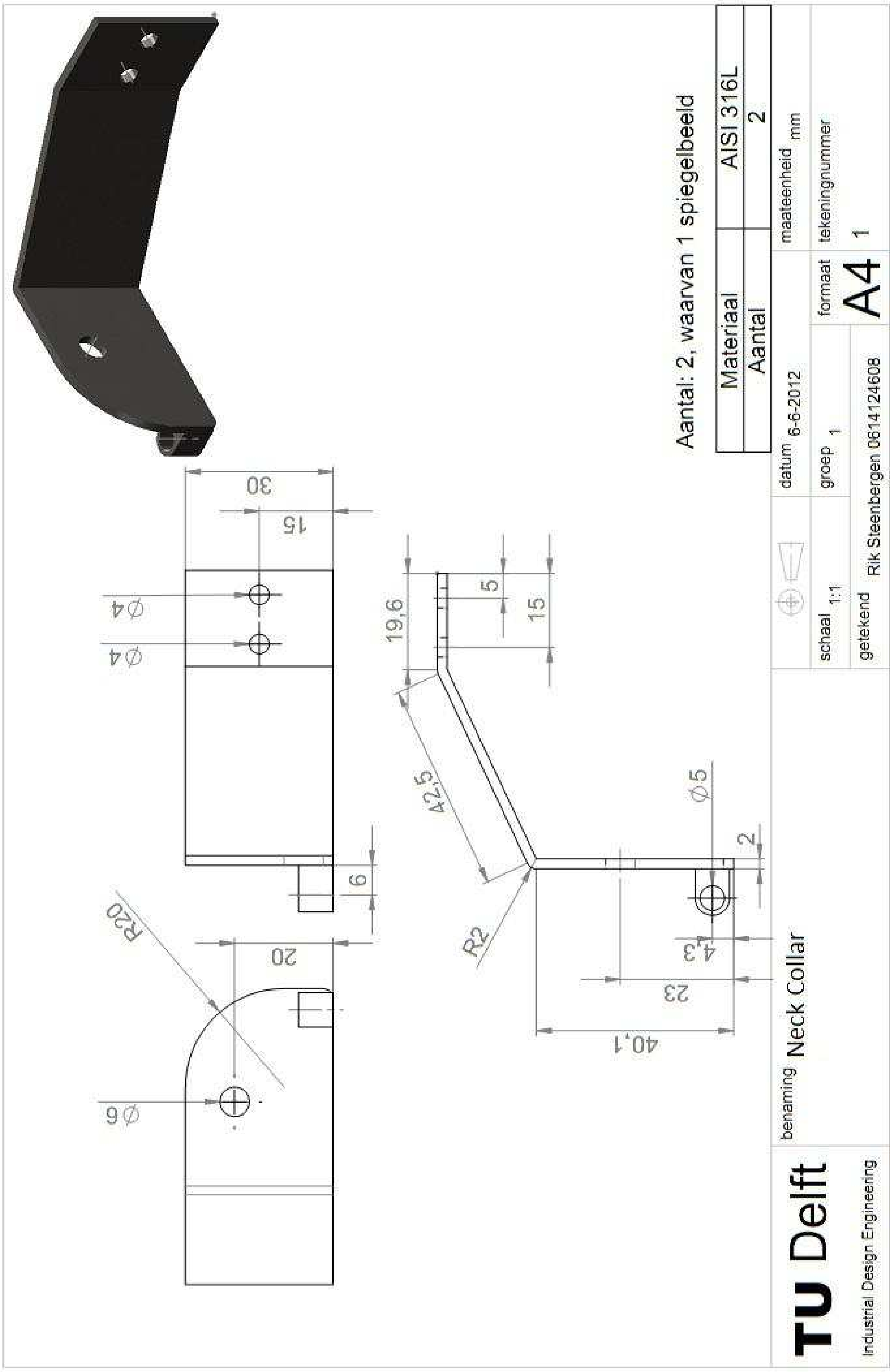
schaal 1:1

datum 7-6-2012

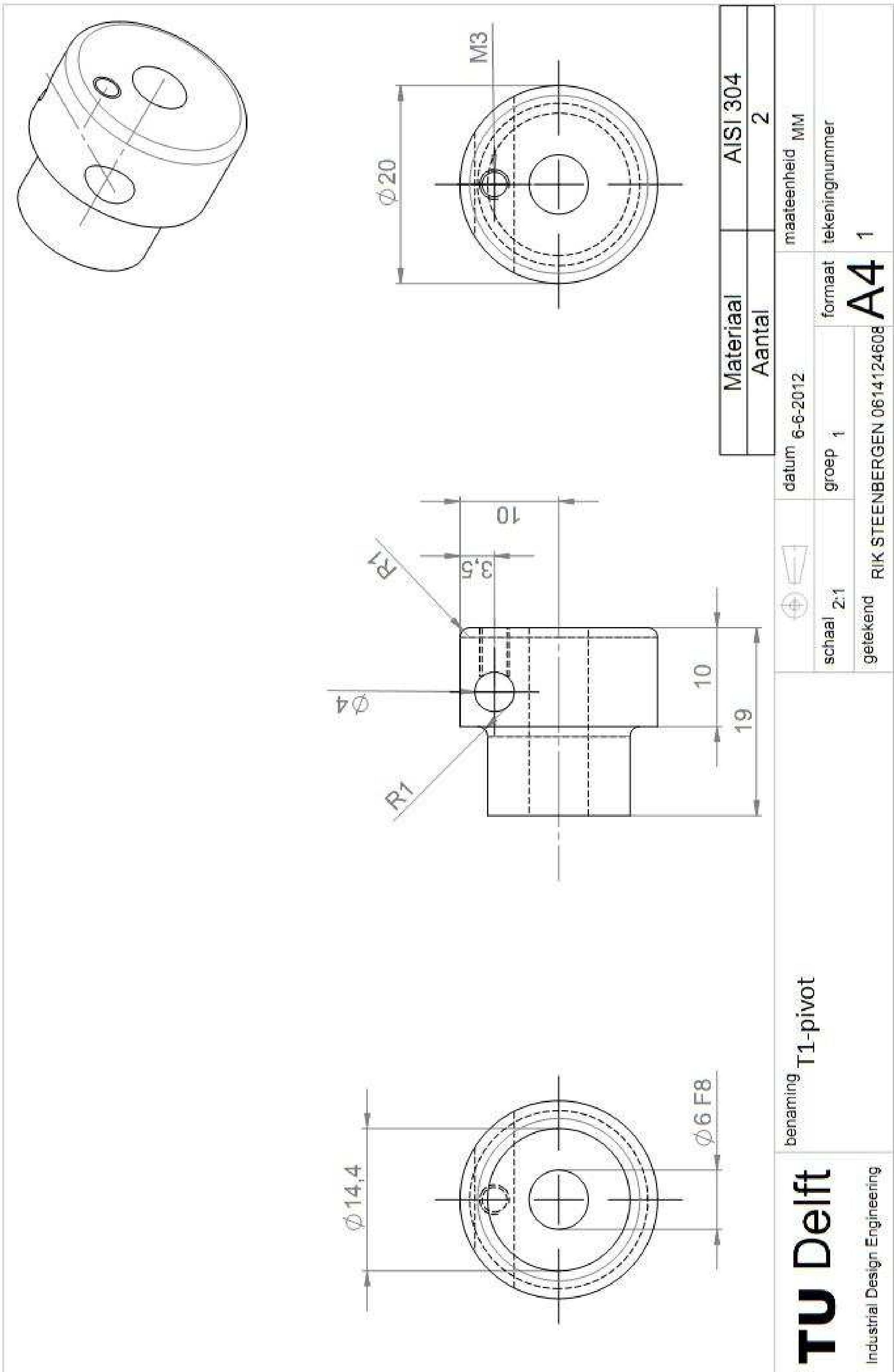
getekend Rik Steenbergen

groep 1

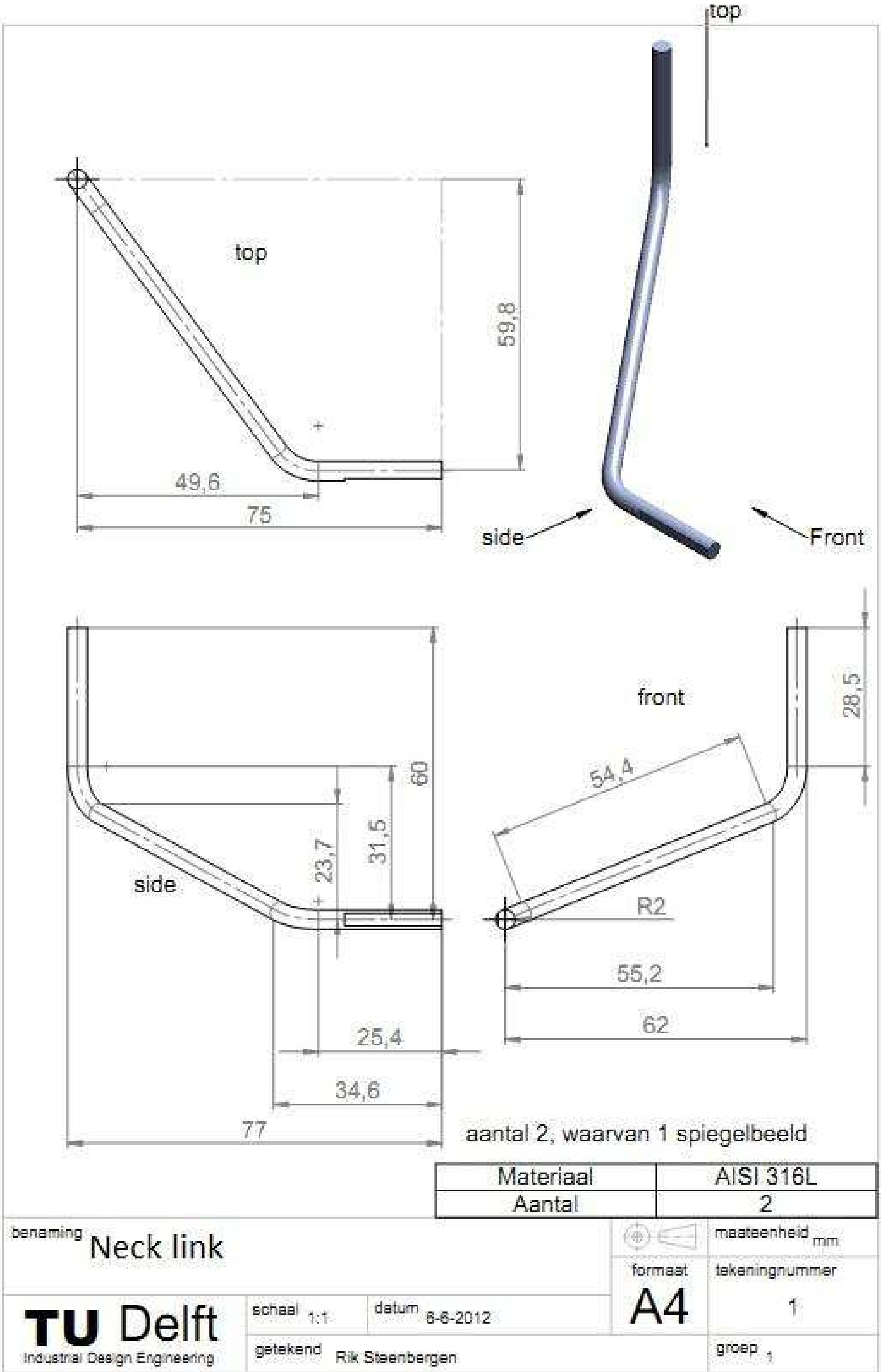
1.2 Neck Collar



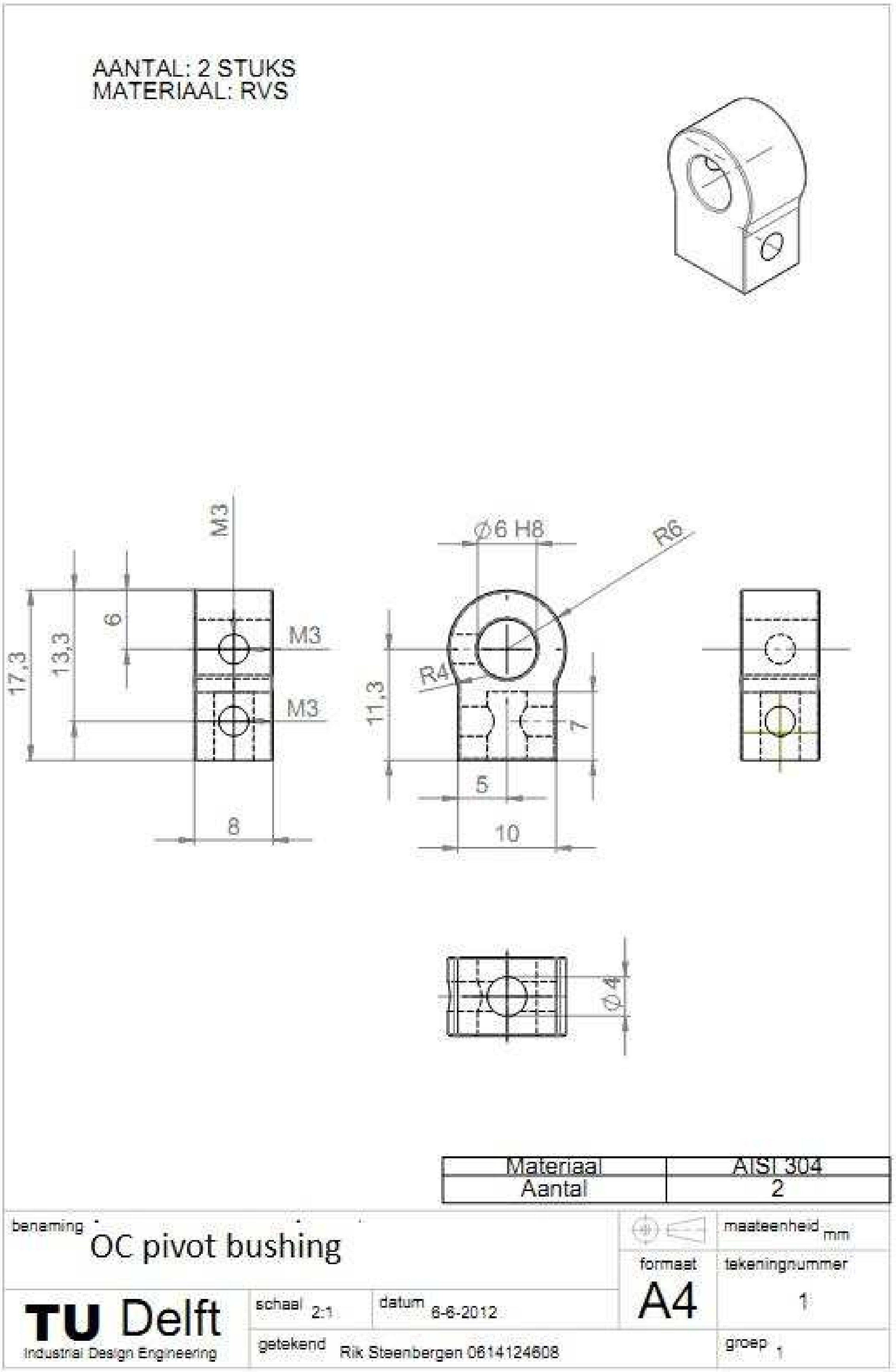
1.3 T1-pivot


M3
Ø20
AISI 304
2
Materiaal
Aantal
maateenheid MM
tekeningnummer 1
formaat A4
datum 6-6-2012
groep 1
RIK STEENBERGEN 0614124608
schaal 2:1
getekend
10
3,5
R1
Ø4
10
19
R1
benaming T1-pivot
Ø14,4
Ø6 F8
TU Delft
Industrial Design Engineering

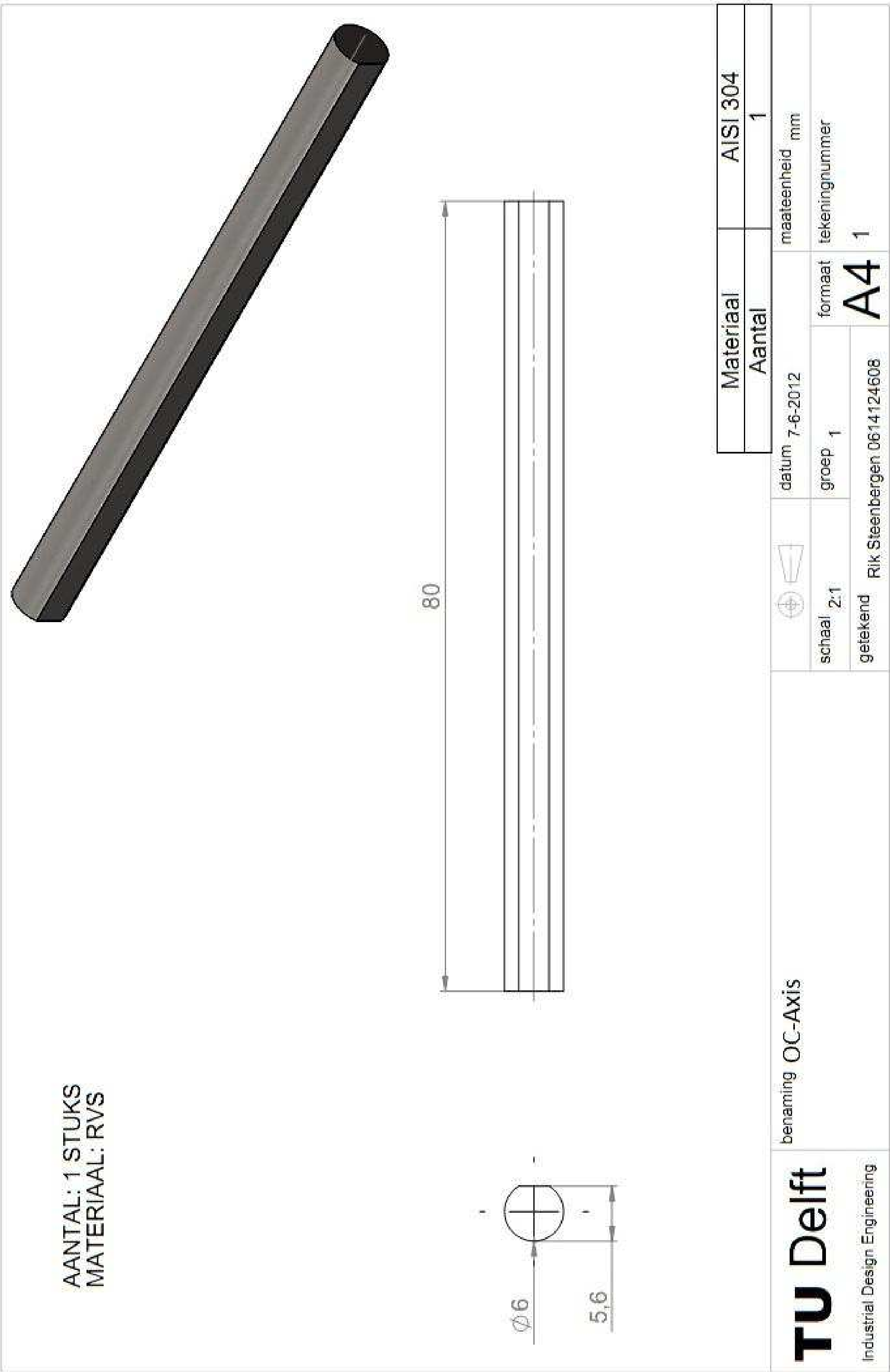
1.4 Neck Link


top
top
59,8
49,6
75
side
Front
front
60
31,5
23,7
side
54,4
28,5
R2
55,2
62
25,4
34,6
77
aantal 2, waarvan 1 spiegelbeeld
Materiaal
AISI 316L
Aantal
2
benaming
Neck link
maateenheid mm
formaat
A4
tekeningnummer
1
TU Delft
Industrial Design Engineering
schaal 1:1
datum 6-6-2012
getekend Rik Steenbergen
groep 1

1.5 OC-pivot bushing

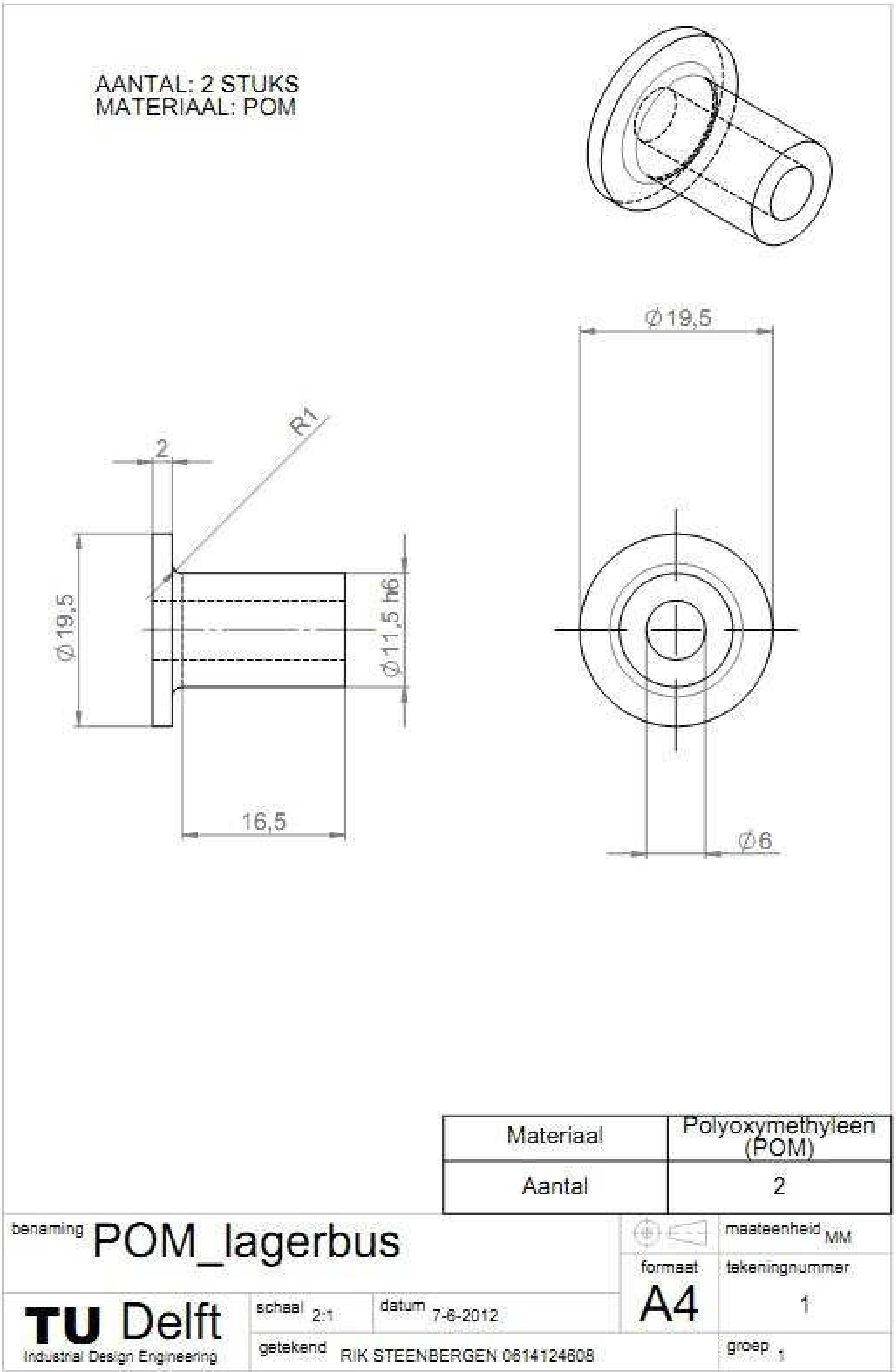


1.6 OC-axis

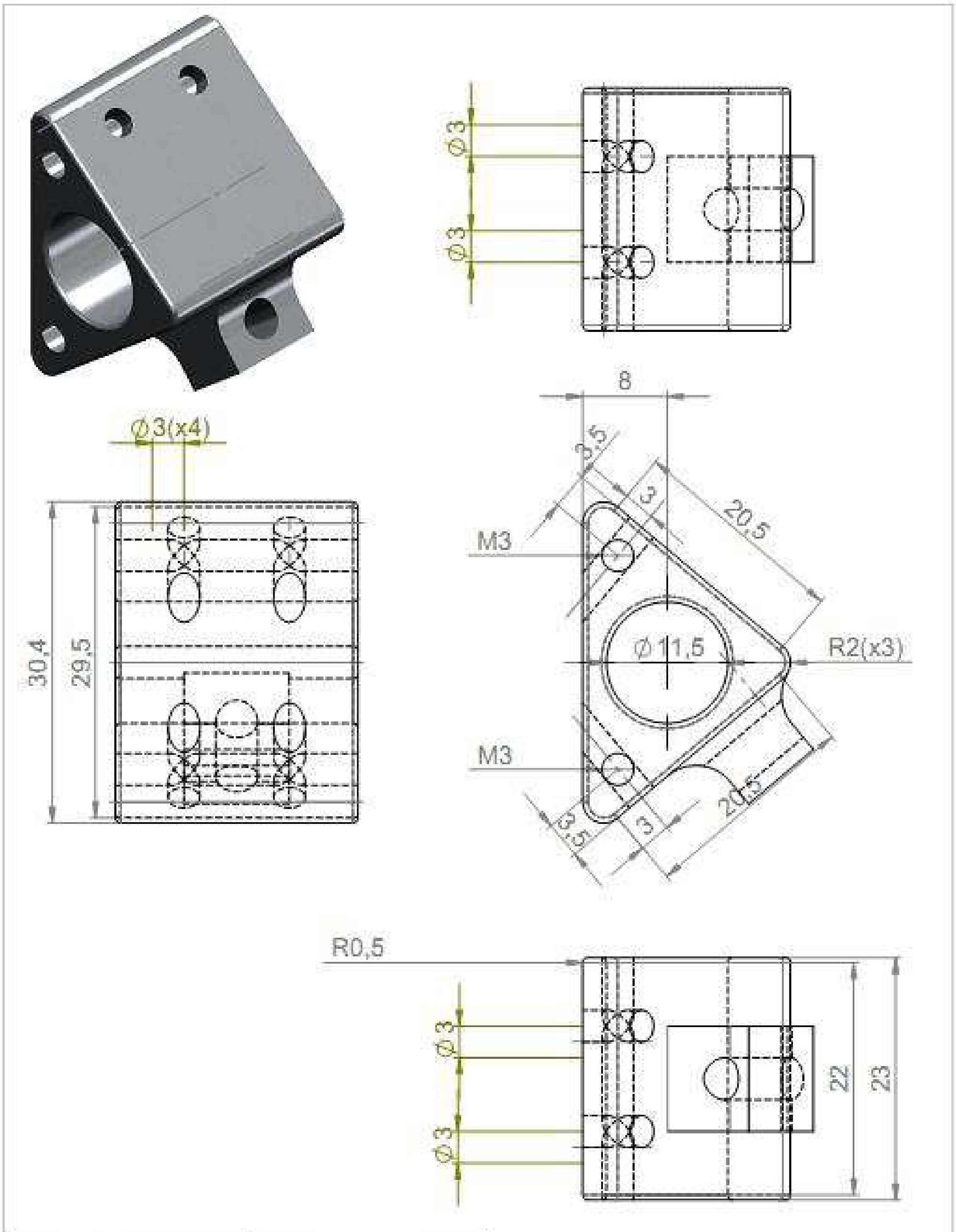


AANTAL: 1 STUKS
MATERIAAL: RVS
Ø6
5,6
80
Materiaal
AISI 304
Aantal
1
datum 7-6-2012
maateenheid mm
schaal 2:1
groep 1
formaat
A4
tekeningnummer 1
getekend Rik Steenbergen 0614124608
benaming OC-Axis
TU Delft
Industrial Design Engineering

1.7 POM bushing



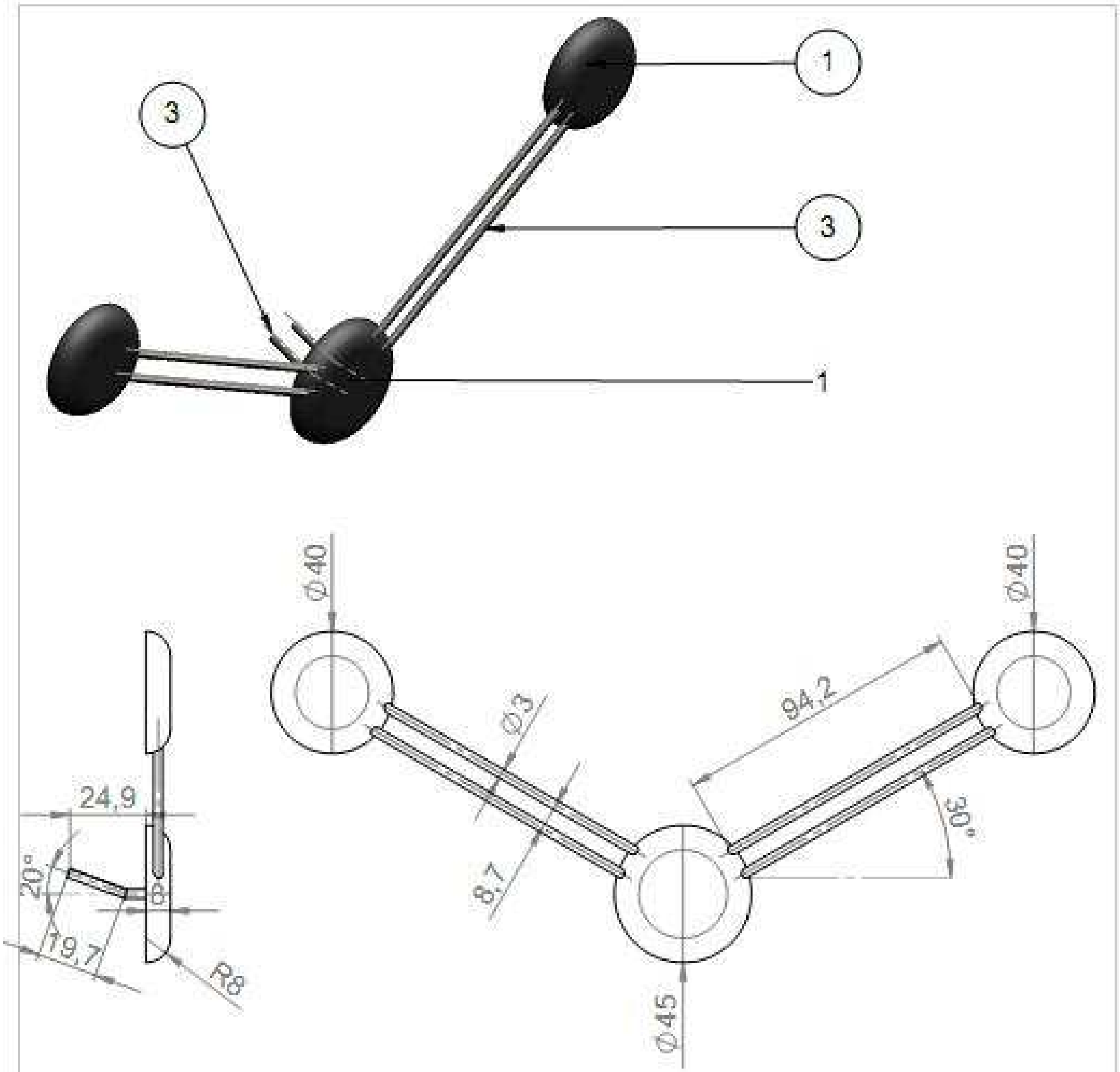
1.8 OC Pivot



Materiaal	Alu 1060
aantal	1

benaming OC-pivot				maateenheid mm
			formaat A4	tekeningnummer 2
TU Delft Industrial Design Engineering	schaal 2:1	datum 7-6-2012		
	getekend Rik Steenbergen 0614124608			groep 1

1.9 Side support + OC Pad



Item	materriaal
1	PU rubber
2	PU rubber
3	AISI 316L

benaming **Side support + OC pad**

maateenheid mm

formaat A4

tekeningnummer 1

TU Delft
Industrial Design Engineering

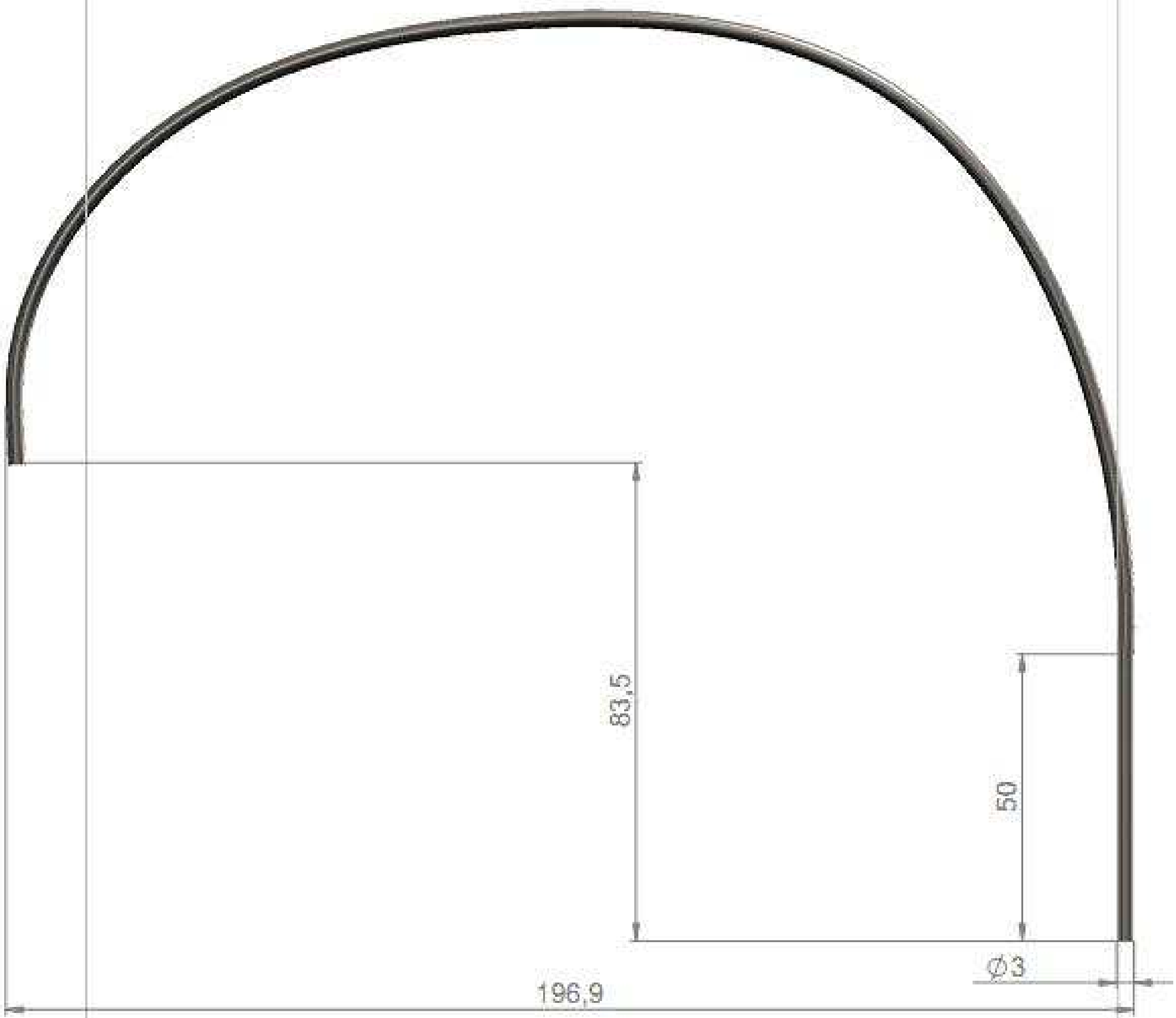
schaal 1:2

datum 7-6-2012

getekend Rik Steenbergen

groep <<groep>>

1.10 Finger

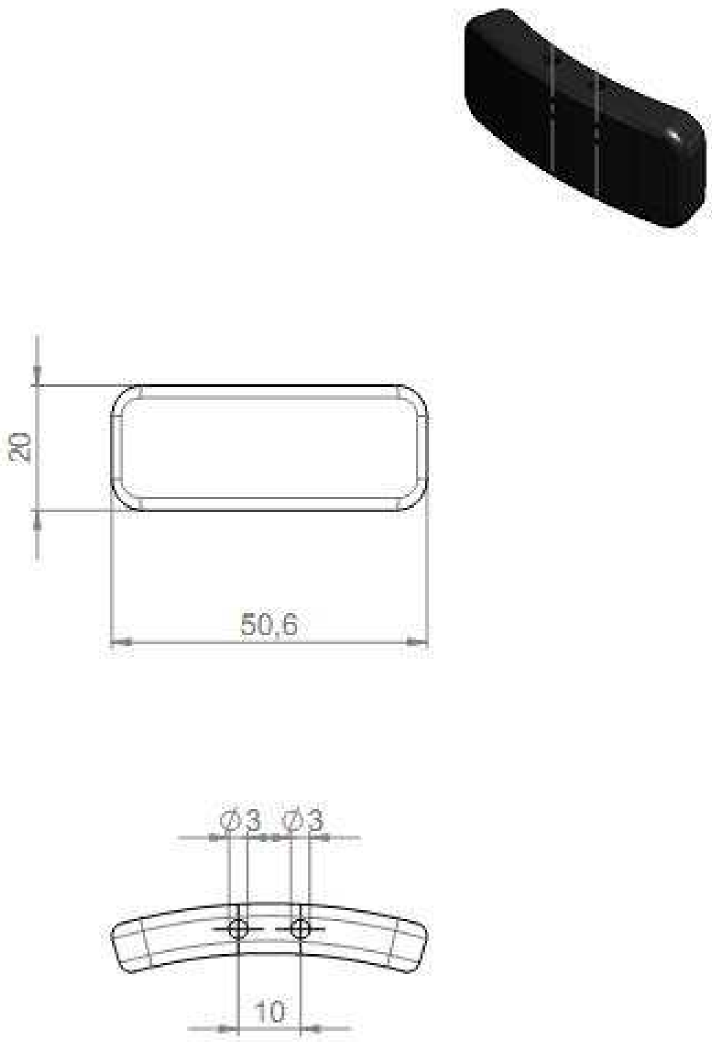


Buigen langs deze contour!

Materiaal	AISI 316L
Aantal	2

benaming Finger			maateenheid mm
		formaat A4	tekeningnummer 1
TU Delft Industrial Design Engineering	schaal 1:1	datum 7-6-2012	
	getekend Rik Steenbergen		groep 1

1.11 Front head pad



Materiaal	PU-Rubber
Aantal	1

benaming Front head pad				maateenheid mm
			formaat A4	tekeningnummer 1
TU Delft Industrial Design Engineering	schaal 1:1	datum 7-6-2012		
	getekend Rik Steenbergen			groep 1

2 Assemblies

2.1 T1-pivot assembly

The exploded view in figure1 shows the way to assemble the lower pivot T1.

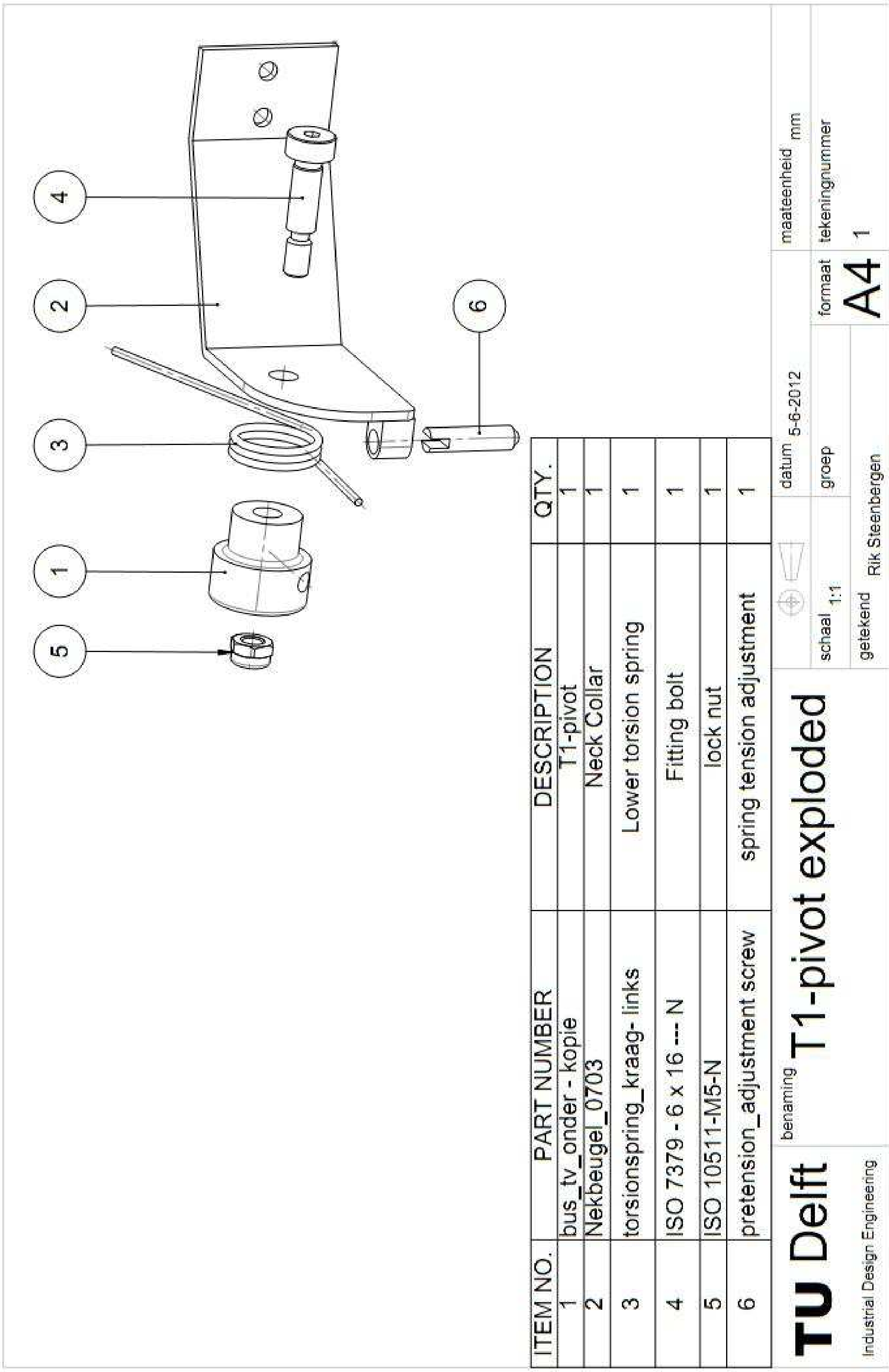


Figure 1: Exploded view of the lower pivot; T1. It has six components: neck collar, M6x16 fitting bolt (rotation axis), slotted pretension M5 screw,lower torsion spring, T1-pivot and a M6 locking nut.

2.2 OC-pivot assembly

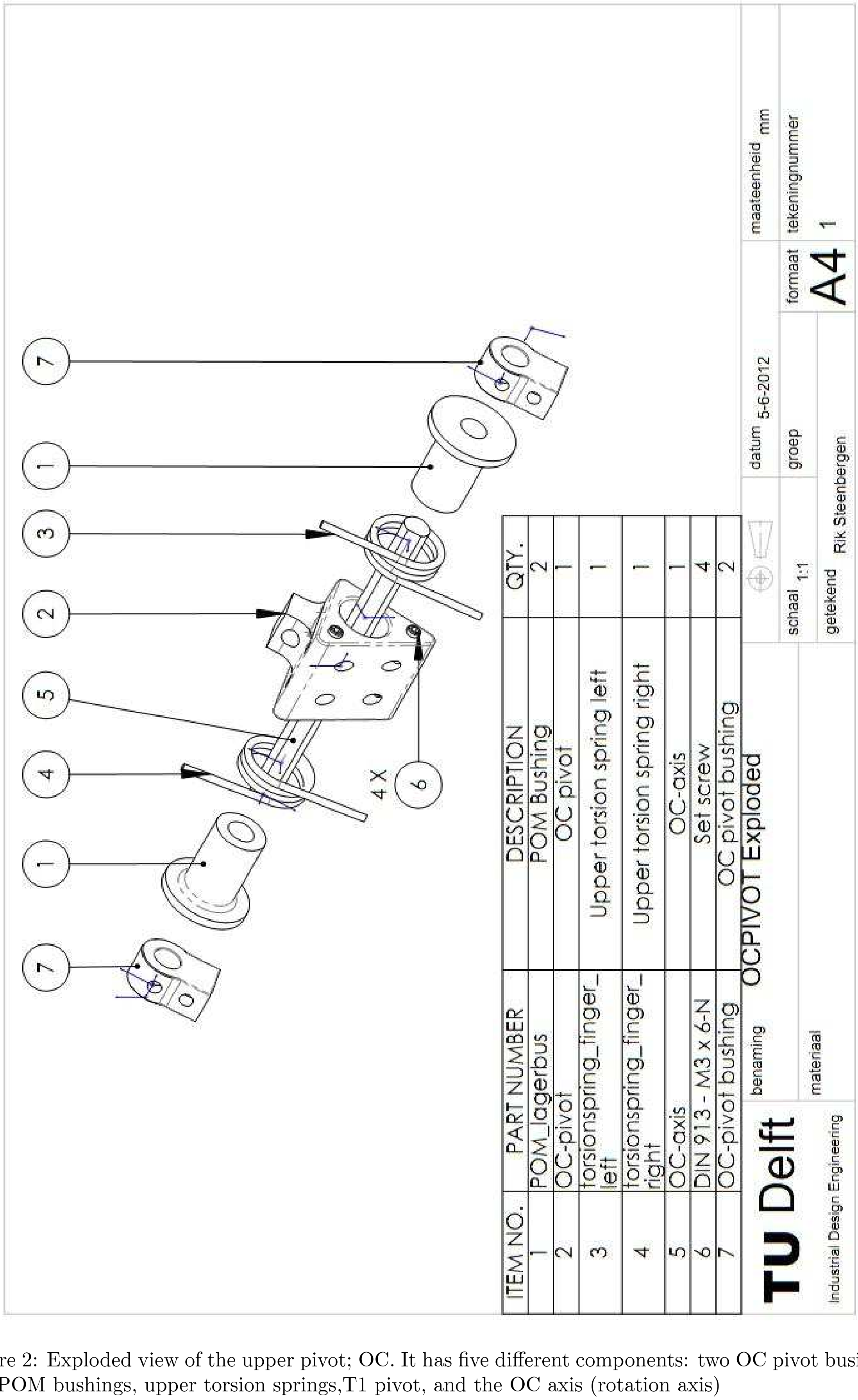


Figure 2: Exploded view of the upper pivot; OC. It has five different components: two OC pivot busings, two POM bushings, upper torsion springs,T1 pivot, and the OC axis (rotation axis)

.

Appendix C: Production Process

Rik Steenbergen

July 27, 2014

Contents

1 Introduction

From the technical drawings in Appendix C, the prototype was manufactured. Two companies were involved in producing the parts. During production three important changes were made to improve and/or simplify the production the prototype. Firstly the adjustment of spring tension for both joints. Secondly, the adjustment to variable neck diameters of the neck collar (body interface). Thirdly, the vertical adjustment of the head interface. This process and the reason for changes are described in this Appendix D. At the end of this appendix the list of manufacturers and suppliers address', email and phone numbers can be found.

2 Production process

Three parties were involved during production, Microgravity Products, Job Knepper ontwerp en realisatie and TU Delft. The first two, both produced parts for the prototype. job Knepper ontwerp en realisatie was hired by Micrograviity Products (MGP) to manufacture the parts that needed milling and turning. This collaboration between companies was initiated by the author. The parts that needed a more 'practical approach' in order to get things fitted around the neck and head, were manufactured at MGP in close collaboration with the author. So, it was decided that some parts should not be worked out in detail in CAD drawings but could be fabricated from a rough hand sketch and the function description of the part.

With practical approach is meant that some tweaking and tuning was needed to get the prototype working. Another reason for leaving things open until the last moment is the small budget to work with. As a small company MGP is not able to invest large amounts of money into experimental prototypes as in this case. So relatively expensive parts due to (CNC) milling and turning are omitted as much as possible. But this was compensated by creatively looking for alternatives for certain parts, such that functioning of the prototype was not compromised but parts could be easily made. The company did a great job, and during this process some initial improvements were done. This practical experience showed that some things could be simplified and function properly.

2.1 Adjusting and mounting torsion springs

The adjustment of bot upper en lower torsion springs is an example of a function that was solved during manufacturing of the prototype. Off course, a dedicated and better design is needed for this eventually, but to test the underlying working principle of the head support it was not considered relevant to design complicated and costly adjustment mechanisms. The location and directions of the spring actions were determined beforehand. The adjustment, more specific the parts that hold the pokes of the springs in position was determined as the assembly process developed. 1 show a practical solution for pre-tensioning the upper springs. Appendix C shows the assembly of the neck collar, T1 rotation axis, lower torsion spring and adjustment bolt.

Figure 1: Pretension system of the upper spring. The torsion springs pokes run through a tube of which the position can be determined by adjusting the screw in the upper pivot.

The upper torsion springs act in parallel and can be adjusted at the same time with the same amount of pretension by turning the bolt. The thread in the OC pivot part was designed beforehand. The lower torsion springs are to be adjusted seperately. The slotted bolts hold de pokes of the springs in place. The other pokes of these springs are bent around the neck links, to make sure they do not slip when the springs are tensioned during head bending.
To make sure the head does not fall backwards little back stops are applied at the neck collar. This is something that was solved during assembling. The back stops are shown in figure 3 Again, those are not final solutions but sufficient for the purposes of this prototype.

2.2 Neck collar

The first idea for the neck collar was to have neck collar consisting of a left and a right part as shown in figure2. These parts can be connected by a slotted plate and four bolts. This way the neck collar can be adjusted to different neck diameters. This is important because neck diameter will vary. Additional to this rigid neck collar this first idea needed a customized thermoplastic shell inside it. The idea was that this padded shell would give optimal fitting and comfort, and that the rigid parts as in figure2 would be adjusted to the shell's diameter.

The upper rotation axis (OC-axis) was therefore designed to be longer such that the neck links can slide further apart.
An employer of MGP suggested to do it in more simple way: a stiff stainless steel (4 mm thick) rigid neck collar with a fixed diameter of 130 mm. This corresponds to a average size neck diameter. (As the subjects had very thin necks this diameter would do for testing.) Inside this very stiff and rigid neck

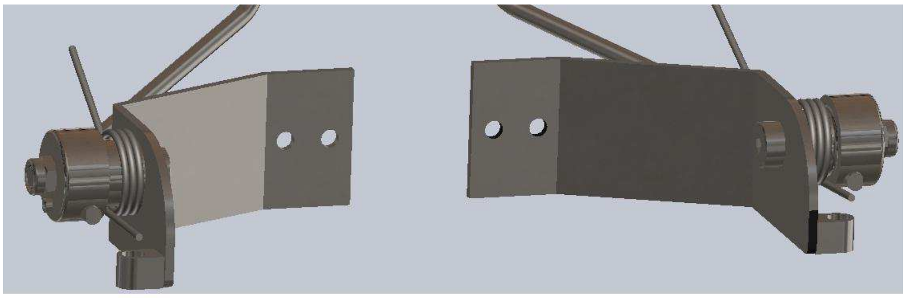


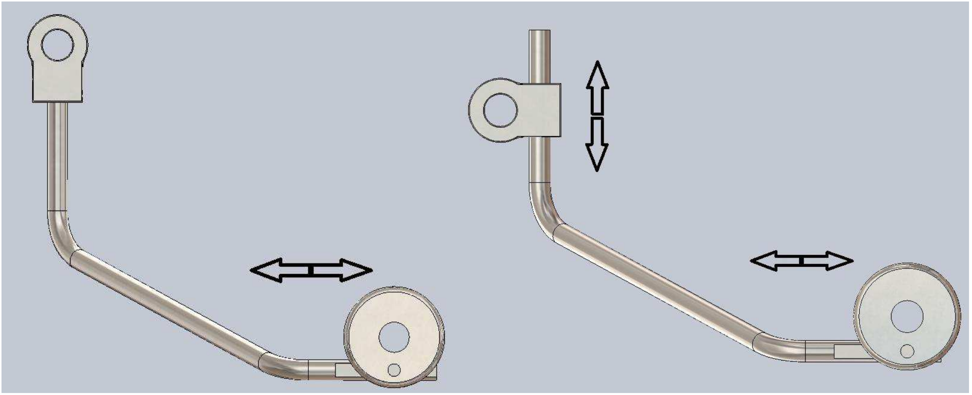
Figure 2: Two separate parts adjustable to different neck diameters.

collar an inlay of steel reinforced anti-allergic PU-rubber was mounted with two bolts at the back of the neck collar. This soft inlay is 10 mm thick and has extra thick (15 mm) and wide (25 mm) paddings at the sides. Now, this soft inlay can be bent to the right neck diameter. The thick paddings at the sides are soft and compressible offering comfortable wearing. The paddings hardly slip along the skin off a large contact area and high friction coefficient.
This suggestion yielded a much simpler concept for the neck collar, which is adjustable to different neck diameters and offers quite good comfort. The balancing mechanism profits form this too, because the T1-pivot's rotation axis' can hardly become unaligned because of the very stiff stainless steel outer construction of the neck collar. The current idea is that with three sizes for the outer rigid stainless steel part of the neck collar, all neck diameters can be covered. Figure 3 shows a photo of the neck collar with important features numbered.

Figure 3: Photo of the final neck collar after changes during production. 1. backstops for necklinks, 2.rigid c-shaped neck collar (stainless steel), 3. T1-rotation axis, 4. lower torsion spring and 5. PU-rubber steel reinforced adjustable neck collar inlay.

2.3 Height adjustable head interface

The original design did not compensate for shorter or longer necks. There was no vertical adjustment for the head interface, as the Neck links are designed to



(a) (b)

Figure 4: Side view of T1-pivot busing, Neck link and OC-pivot bushing. Figure 4a shows the original position of the OC pivot bushing, with only horizontal adjustment of the head interface . Figure 4b shows the changed position of the OC-pivot bushing at the Neck link. The head interface can be adjusted both vertically and horizontally.

have fixed a fixed height. In the original design the head interface could only be adjusted at the T1-pivot bushings horizontally.
The vertical adjustment of the head interface was again suggested by a employer of MGP. This required slight adaptation of the OC-pivot bushings, as shown in figures 4a and 4b. By making these bushings sliding along the upper part of the Neck links the whole head interface is adjustable to different neck lengths. Once the suitable height of the interface is determined for the user, the bushings can be fixed on the Neck links.
Due to this minor and simple but clever adaptation, the head interface is adjustable in vertical direction. This makes it easier to fit the head support to the user.

The total production process took about four weeks, until the first prototype could be tested.

3 Manufacturers and suppliers

Microgravity Products
Kiotoweg 739
3047 BG Rotterdam
The Netherlands
www.armonproducts.com

P: 0031 10 4714187
E: peter@armonproducts.com
W: www.armonproducts.com

Job Kneppers Ontwerp en Realisatie B.V.
Handboogstraat 33
2613 PZ Delft
The Netherlands

P: 0031 15 2148977
E: info@jobkneppers.nl
W: www.jobkneppers.nl

Gutekunst Federn
Carl-Zeiss-StraÃe 15
D-72555 Metzingen
Germany

P: 0049 7123 960-0
E: order@gutekunst-co.com
W: www.federnshop.com

Jeveka B.V.
Keienbergweg 8
1101 GB Amsterdam Z.O.
The Netherlands

P: 0031 20 342 0 342
E: purchase@jeveka.com
W: www.jeveka.comm

Appendix D Experiments

Rik Steenbergen

July 27, 2014

Contents

Introduction

This Appendix contains the reports written directly after the subject experiments performed with two persons having different neuromuscular diseases. These reports tell findings about fitting the head support to the subjects. Difficulties, different insights and of course feedback of the subjects and their relatives about the tested device are reported.
For each subject a brief description of their clinical picture is sketched. This gives insight about their situation and personal problems they experience with head stability. How head instability affects their lives. Then, detailed findings from these tests are reported. Some recommendations are done for future experiments.

1 Experiment, subject 1

Experiment data

Date, time: May 10 2012, 13:00
Experiment type,number:conference visit, fitting 2
Subject Gender: female
Persons present: Peter Mastenbroek,Ralph Mastenbroek, S.Fazeli, Rik Steenbergen
Prior head rest experience: Foam neck collar, fixed head rest wheelchair.
Additional remarks: This subject was tested at the "Support Beurs 2012". This subject is actively involved in testing new products for Micro Gravity Products.

Profile subject 1

Subject 1 has Spinal Muscular Atrophy type 2 (SMA II), it was diagnosed at an age of nine months. The subject is bound to a wheelchair not able to walk. She uses a Armon Ayura arm support providing sufficient arm function.
The head is marginally stable. The head can be kept upright independently but it is energy demanding. Only a slight disturbance is needed to make the head tip over. She uses here arm support to support the head from time to time with her hand.
Keeping the head up when driving bumpy pavements, a taxi is turning and during writing behind the computer are activities when head instability problems are experienced.
Mainly because of aesthetic considerations currently available head rests are not used by this subject.

First fitting The second fitting with a redesigned head interface was cancelled because the conference was too busy. The previous fitting showed that the head interface was too small and that it should be redesigned. This first fitting also showed that the head is kept up right but the springs are too stiff for this subject to move the head. The subject has to work against the springs, something she does not have the muscle strength for. The head interface could be disguised with the hair of the subject without really noticing it is there. The finger from back to front of the head interface as a too short horizontal distance such that

the head did not fit in.
The whole head support was found too heavy by the subject. Aesthetics acceptable for prototype but should be improved for final product. The neck collar was a bit uncomfortable, but fitted the neck correctly.

2 Experiment subject 2

Experiment data

Date, time: May 7 2012, 14:45
Experiment type,number:home visit, fitting 1
Subject Gender: female
Persons present: Husband subject, S.Fazeli, Rik Steenbergen
Prior head rest experience: Foam neck collar, experimental harness and head band provided by the company Livit Orthopedie. **Additional remarks:** Contact with this subject was initiated by ergo-and physical therapist of Sophia Revalidatie Den Haag, treating the subject. Searching for a solution to keep the head up, Micro Gravity Products was contacted. This way the author was invited for a first meeting at March 27, 2012.

Subject's name, address and phone number can be requested at Rik Steenbergen (riksteenbergen@gmail.com). To protect subject's privacy, the subject will be contacted first for approving additional experiments other than performed by aforementioned and employees of Micro Gravity Products.

Profile subject 2

The subject was diagnosed with PLS(Primary Lateral Sclerosis)in May 2010 ,and with ALS (Amyotrophic Lateral Sclerosis in June 2011. A very specific and rare progress of the disease was established with this subject. The disease started to affect superior muscles first. Muscles for head movement/stability (neck muscles), speech and swallowing are affected severely. Muscles of arms and legs are affected but not as severe as the superior muscles. As a result the subject can walk independently and has weak but functional arm function. The disease affects the subject's muscles in a top-down manner.
The subject cannot talk and swallow saliva. Communication takes place via typing on an I-Pad. Excess slime in the throat needs to be sucked out several times a day.
As a result of the affected neck muscles the head hangs down. The neck is curved such that it is oriented almost horizontally. The head also hangs skew to the left.
As a first (temporary) solution a foam neck collar was used to support the head. After a few weeks this foam collar was not used any more, because it offers no support to the head at all. Only for the weakly visit to the acupuncturist by car the collar is used.
A body supported head rest as proposed here, is seen by the subject and her therapist as a valuable solution to keep her head up and stable. Since the subject is mobile she could use the head supported during walking and when sitting in a chair.

Result: first fitting

At this first fitting, four attempts were done to fit the head support to subject 2. These attempts fatigued the subject, also because of previous activities that day (acupuncture, visit family doctor). So after these attempts it was decided to stop.
From the total of four attempts, two were done sitting on the couch and two in a standing position. In one sitting attempt the head support could be fitted reasonably well. The other attempts failed to fit the head support. The following list shows points of improvements
Miss-fitting can be contributed to:

- Extreme position of the neck: The neck is curved into a horizontal position. This means that there is a horizontal distance to bridge between the back and occipital joint. This distance cannot be bridged by the prototype nor was it possible, because of pain, to push the head further up in order to get it into the head interface. The body interface (wide aluminium flat pre-shaped to the back, attached to the hip and chest) was not flexible enough to position the neck collar in a correct position.

- Not fitting head interface: The head interface was dimensioned based on average head sizes, a mock-up model and healthy persons. The head interface appears to have too few options to adapt to different head sizes. Especially the sidewards supports could not be fitted in a correct position such that sidewards support could be provided.

- The finger of the head interface running from back to front appeared to be too flexible. Because the head of subject 2 hangs forward in a skew manner and the sidewards support did not function properly too much force was put on the front-head pad, in a "wrong" direction (sidewards).

- Limited stroke of the head support around T1-axis: The extreme horizontal neck position cannot be reached by the head support's rotation at the T1-rotation axis.

- Limited spring force: The springs at pivot T1, was not capable of providing the torque needed to pull the head up from the extreme head position. Due to pain when the head was pushed up it can not be concluded that the springs are too weak in general. If the head of this subject can get in a more upright position the springs might be able to keep the head upright.

The overall impression was that the concept of the designed prototype could work. The design was also found appealing. And the subject had confidence that when the head support is adapted to her specific posture (custom made) it could help her.
After this first fitting it cannot be concluded whether the head support failed to support the head for subject 2. More customized dimensions of the head- and body interfaces can make a huge difference, and only when this fits correctly to the subject conclusions can be drawn about the balancing spring force. Another

important mark to make is that the head support was initially designed for people who had a marginally stable head position. This means that there is sufficient muscle force in which the head supports helps to support the weight in a range of 30 degrees of head flexion. From this perspective this case might be too extreme, and the prototype designed as such might not be suited for it. The author has the impression that a fixed (not moveable) body supported head rest could be a better option than a moveable head support as the tested prototype. The presumption exists that subject 2 has too weak neck muscles to be able to move the head with the aid of this prototype.