Helmet Fit for Safety and Comfort
New 3D head measurement study helps define parameters for best fit

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Introduction

**Increasing number of users**

- Growing markets in job, leisure and sports
- From children to seniors
- Skiing: 16 million skiers in Germany
- Biking: 68 million bikes in Germany, not all bikers wear helmets
- Industry: 10 million workers in Germany with need for head protection
- Furthermore: Forest operation, fire department, police, military, inline skating, rock climbing, horse riding, motorcycling, canoeing and rafting …

- **Growing safety demands by awareness**
  both legal regulation and voluntary motivation
Introduction

The Facts / Findings

• Helmets avoid or reduce the risk of head injuries
• 2011: 79,000 notifiable accidents at work with head injuries were (according to German statutory accident insurance)
• Head injuries often lead to secondary damage like paralysis and/or speech disorder
• Economic benefit: Reduction of insurance expenses, patient care and rehabilitation
• Consumer acceptance is needed
  Only wearing a helmet can prevent from severe head injuries!
• Fit and wearing comfort optimized helmets are needed!
Introduction

The Challenge

• “SizeGERMANY” sizing survey showed remarkable variations in head shapes within the same head circumference
• Additional high-resolution anthropometric head data is needed, in particular shape information
• Market shares in head shape are needed for best market coverage
• Industry standards do not comply with the state of technology anymore, head shape information is missing totally
• Influence of hair on the size measurements and helmet fit is unclear

⇒ Important basic information for optimized helmet development is not available
**Visual comparison – male subject**

Identical head circumference of 58 cm

<table>
<thead>
<tr>
<th></th>
<th>male 1</th>
<th>male 2</th>
<th>delta</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Head Height</strong></td>
<td>22,3 cm</td>
<td>22,9 cm</td>
<td>0,6 cm</td>
</tr>
<tr>
<td><strong>Head Length</strong></td>
<td>18,8 cm</td>
<td>21,2 cm</td>
<td>-2,4 cm</td>
</tr>
<tr>
<td><strong>Head Width</strong></td>
<td>18,0 cm</td>
<td>15,0 cm</td>
<td>3,0 cm</td>
</tr>
</tbody>
</table>
Visual comparison – male subject (view from top)

Circumference 58 cm
**Visual comparison – female subject**

**Identical head circumference of 56 cm**

<table>
<thead>
<tr>
<th></th>
<th>female1</th>
<th>female2</th>
<th>delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Height</td>
<td>21.6 cm</td>
<td>23.1 cm</td>
<td>-1.5 cm</td>
</tr>
<tr>
<td>Head Length</td>
<td>19.4 cm</td>
<td>20.4 cm</td>
<td>-1.0 cm</td>
</tr>
<tr>
<td>Head Width</td>
<td>17.4 cm</td>
<td>14.8 cm</td>
<td>2.6 cm</td>
</tr>
</tbody>
</table>
Visual comparison – female subject (view from top)

Female 1

Female 2

Circumference 56 cm
Introduction

Additional Challenges

• Lack of up-to-date/recent anthropometric face data
• The current industry standards for personal protective equipment (PPE) should be adapted to the state-of-the-art anthropometric data in order to assure best face, ear, eye and respiratory protection
State of technology

**Worldwide head-sizing related activities:**

- CAESAR-project, 1997-2001 (NL/US)
- NIOSH Anthropometric Survey of Respirator Users, 2001-2004 (US)
- SizeChina (2006): Anthropometric head survey and digital database of Asian heads and faces for use by manufacturers (about 1600 Scans)
- 3D Facial Norms Database [https://www.facebase.org](https://www.facebase.org)
  3500 healthy Caucasian individuals age 5-40 (US)
- Various papers (US & CAN):
  - Head-and-face shape variations of U.S. civilian workers (2013)
  - A simple and standardized method for analyzing head and face morphology of a population sample (2010)
  - Sizing trials of a prototype aircrew helmet (2009)
  - Principles of Fit to Optimize Helmet Sizing (2006)
Aim of the Hohenstein study

The Aim is the improvement of head gear systems considering fitting plus comfort and function

Results:

• Up-to-date face and head measurements and head shapes of men, women and children in Germany
• German market share tables of sex, age and head shape types
• Head specific grading guidelines
• Virtual 3D-head shape models
• Guidelines and design characteristics for optimized development considering fit, ergonomic comfort, thermophysiological comfort and hygiene
Available 3D Scanner Systems
Step 1 of the Hohenstein study

- Detailed analysis of 3D-Scan-data of Hohenstein’s own database (17,000+ scans)

- Definition of measurements and methods according to established standards like (ISO 7250, SizeGERMANY etc. plus new additional head and face measurements)
Face Shapes: Landmark scheme
Head, Face and Neck/Chin Measurements

Head Circumference  Head Width  Head Length
Head, Face and Neck/Chin Measurements

- Head Height
- Eye Distance
- Eye-Chin-Distance
Head, Face and Neck/Chin Measurements

Morphological Face Length

Various Face Lengths

Diverse Ear Distances
Head, Face and Neck/Chin Measurements

Horizontal Face and Head Distances

Various Face Widths

Various Neck Measurements
Head, Face and Neck/Chin Measurements
Head, Face and Neck/Chin Measurements

Sagittal arc  Bitragion coronal arc
Step 2 of the Hohenstein study

• Analysis und statistical evaluation of 3D-scandata of men, women and children
• 3D-head shape analysis
• Definition of size ranges according to sex, age and head shape types based on percentage shares
Requirements for statistical evaluation

- Distinction between women, men, children
- Distinction between age groups
- Determination of minimum, average and maximum values and deduction of changes in value relating to the head sizes
- Deduction of measurement correlations, e.g. Head Width to Head Circumference as “head shape indicator”
Percental distribution of Head Circumferences

- **Women**
- **Men**

Percentage [%]

Head Circumference [cm]:
- 50, 52, 54, 56, 58, 60, 62, 64, 66, 68
Percental distribution of Head Circumferences

Girls:
- age range 6 to 10
- age range 11 to 13
- age range 14 to 17

Altersgruppe 6 bis 10 Jahre
Altersgruppe 11 bis 13 Jahre
Altersgruppe 14 bis 17 Jahre

Percentage [%]

Head Circumference [cm]
Changes of Head Width related to Head Circumference – Men

- there is a significant amount of intra-individual variation
Percentage of correlation coefficients
Head Width to Head Circumference – Men

Men:
- Head Circumference 56 cm
- Head Circumference 58 cm
- Head Circumference 60 cm

Percentage [%]

Head Circumference [cm]

Values:
- 0.26
- 0.27
- 0.28
- 0.29
- 0.3
- 0.31
- 0.32
- 0.33
Changes of Head Width related to Head Circumference – Boys

- there is a significant amount of intra-individual variation
Percentage of correlation coefficients
Head Width to Head Circumference – Boys

Boys:
- Head Circumference 54 cm
- Head Circumference 56 cm
- Head Circumference 58 cm

No. 28
Head shapes variations – Head Circumference 58 cm

- 0.26
- 0.27
- 0.28
- 0.29
- 0.30
- 0.31
Head Width variance – Head Circumference 58 cm

- Head Width variance 15,0 to 18,5 cm

Delta of 3,5 cm in width

Cannot be covered by only one helmet size!

Both shape and measurements are essential!
Percentage of potential German male customers related to the different head shapes

Men: Percentage of correlation coefficients
Head Width to Head Circumference 58 cm

- Ca. 7,0 Mio. (0,29)
- Ca. 5,4 Mio. (0,28)
- Ca. 3,6 Mio. (0,27)
- Ca. 1,2 Mio. (0,26)
- Ca. 1,2 Mio. (0,30)
- Ca. 12.500 (0,31)
- Ca. 50.000 (0,32)
- Ca. 150.000 (0,33)
Further Steps

- Ongoing statistical evaluation as well as 3D-head shape analysis
- Develop German market share tables
- Develop head shape specific grading rules
- Develop virtual 3D-head shape models representing realistic head shapes of German population for the first time
- Virtual 3D-analysis of fit and ergonomic comfort
3D-distance analysis „head to helmet inner face“

Probandin 1

Probandin 2
3D-distance analysis „head to helmet inner face“

- Analysis of distance variation between head geometry and real helmet inner face by using 3D-scanning technology
3D-distance analysis „head to helmet inner face“

- Analysis of distance variation between head geometry and real helmet inside by using 3D-scanning technology
Further Steps

- Evaluation of textile material requirements concerning fit and function
- Evaluation of infection prophylaxis by antimicrobial finishing and/or better temperature and moisture management
Thank you for your kind attention

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