The Combat Helmet as a System: Development of a Systems Model to Manage Complexity in Ergonomic Assessments

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Abstract. A systems approach was taken to identify the ergonomic attributes that affect the performance of a combat helmet system. The information was developed into a system model that comprehensively details the attributes, their influencing factors, and the outcome effects. Development of the model enabled the complexity of multi-disciplinary attributes to be managed and communicated. This model provides the basis for an assessment framework and provides a useful tool to inform design, development, and trade-off decisions.

Keywords. ergonomics assessment, systems model, soldier, combat helmet

1. Introduction

Ergonomics is a multi-disciplinary field with ergonomic practitioners coming from many different backgrounds (Chapanis, 1996). The multi-disciplinary nature of ergonomics is one of the strengths of the discipline (Dul et al., 2012) but as a consequence it can lead to complex problem spaces with many relationships and dependencies. One area where the issue of complicated problem spaces presents significant challenges is that of the ergonomic assessment of the Soldier Combat Ensemble (SCE). In recent years, military thinking has come to recognise not just the soldier as a system but the soldier as the most important system in the Army (Jones, 2006). The term 'SCE' refers to all the clothing and equipment that is worn and used by a soldier, with the soldier being central. One vital item of SCE is the dismounted combat helmet. This helmet is worn by dismounted combatants to provide protection against ballistic threats and blunt impact trauma as well as providing a platform for mounting head-borne equipment such as Night Fighting Equipment (NFE).

There are combat helmet requirements in terms of protection and platform capability, as well as a range of ergonomic requirements, including that the helmet can fit the soldier and is stable on the head while allowing the soldier to perform his/her mission-essential tasks. There are established standards and validated methods for evaluating the protection capabilities of a helmet but measures for evaluating the ergonomic aspects of a combat helmet are lacking. There are currently no frameworks or standards that provide consistent, validated outcome measures to guide the systematic collection and analysis of ergonomic data on combat helmet design.

This research program was established to address these issues with one aim being to develop a systems model of the combat helmet as a foundation for the resulting assessment framework. This systems model proved to be essential in enabling management of the large number of multi-disciplinary performance attributes, their associated influencing factors and effects, as well as other key information. The model also provided a method of visualising the system in its entirety to aid understanding and for use as a communication tool. This paper discusses the development of a systems model of a combat helmet and the utility of such a model in managing the complexity of the multi-disciplinary nature of ergonomics.

2. Methods and Results

2.1 The Combat Helmet as a System

The category of 'product system', as defined by Dul et al., (2012), appears the most relevant for describing the combat helmet: a product system with the dismounted combatant as the product user. The shell, retention system and suspension system are the components, which comprise the three parts of the basic helmet system (Blanchard & Fabrycky, 2011). These components work together to provide the dismounted combatant with ballistic and blunt impact protection as well as a platform for mounting ancillary equipment. The purpose of the combat helmet can also be termed the 'function'. Defining and understanding the function(s) is important to ensure that the system components are designed to enable the function(s) to be achieved (Blachanrd & Fabrycky, 2011). If one component of the system is not acceptable then it affects the whole system. So there are 'functional relationships' between the components of the helmet system, a requirement specified by Blanchard & Fabrycky (2011) e.g. an ill-fitting suspension system can cause instability of the whole helmet system, which may affect comfort and operational performance.

When attachment mechanisms and head-borne accessories such as NFE and torches are added to the basic helmet system, it becomes part of a larger system known as the combat helmet system, with the basic helmet system being considered as a 'sub-system' of this. The combat helmet system, when worn and used by a dismounted combatant, then interacts with and becomes part of the SCE. This building of sub-system blocks can be considered a System of Systems (SoS). Although the detail is outside the scope of this paper, to provide a wider picture the building of sub-systems continues with the individual soldier wearing the SCE then becoming part of a team of four soldiers (known as a 'fire-team'). This is another system which now includes communication and shared mental models. The fire team then becomes part of a section which comprises eight soldiers, then part of a platoon and so on.

2.2 Applying a Systems Approach

Dul et al., (2012) stated that the adoption of a systems approach is one of the three fundamental characteristics of human factors and ergonomics, the other two being that the discipline is design driven and focuses on two related outcomes: performance and well-being. As with the term 'system' there are different interpretations and applications of a 'systems approach', but two key themes run throughout the various definitions available. The first is that the approach adopted is broad and holistic (Dul et al., 2012). The second is that it considers the components to be interrelated (Karsh et al., 2014).

Blanchard & Fabrycky (2011) stated that there are three elements of a system; components, attributes, and functional relationships. The 'components' are the parts of the system and have been specified in the previous sub-section (2.1). The 'attributes' are the properties of the components and the properties of the whole system (Blanchard & Farbycky, 2011). To align with the first theme of a broad/holistic systems approach, research was conducted to identify all ergonomic attributes relating to the wearing and use of a combat helmet. This comprehensive attribute list was developed through an initial scoping literature review and completed by administering a modified Delphi survey using end users, i.e. dismounted soldiers (Davis et al., 2017). Both the literature review and the Delphi survey addressed the second theme of a systems approach, that all components are interrelated, by identifying factors that influence the attributes as well as the potential effects. This enabled better understanding of the functional relationships of the system which is the third element as defined by Blachard & Fabrycky (2011).

The literature review comprised a search of international literature related to helmet ergonomics with a focus on combat helmets, but with consideration also given to other types of military, sporting, and industrial helmets. The output of the review was a list of ergonomic attributes, influencing factors and potential effects. These could also be considered as the inputs and outputs of the sub-system which Sheridan (2014) also termed the 'cause-effect functions' with the effects able to be both positive and negative depending on the acceptability of the influencing factor(s). However, a conclusion of the literature review was that although many of the ergonomic studies had sought to obtain feedback from combat helmet users, no studies were found that sought to ask the users what they perceived to be the ergonomic attributes of the combat helmet system.

Based on this finding, a two-round Delphi survey was conducted with dismounted combatants to identify what they thought were the ergonomic attributes (Davis et al., 2017). The list from the Delphi survey closely aligned with that from the literature with the resulting list comprising fourteen multi-disciplinary attributes which were, in no particular order:

1. Fit
2. Ease of Use
3. Stability
4. Physical Comfort
5. Mass
6. Centre of Mass (COM)
7. Thermal Comfort
8. Visual Awareness
9. Mass Moments of Inertia (MMOI)
10. Audible Awareness
11. Speech Intelligibility
12. Equipment Compatibility/Integration
13. Operational Performance
14. User Acceptance

In addition, the Delphi survey was also used as a method of collecting importance ratings as a means of understanding important relationships and prioritising the attributes for future development and assessment (Davis et al., 2017). Participants were asked to rate each of the 14 attributes with the results showing that the attribute deemed to be the most critical to users was that the helmet does not interfere with operational performance. Other attributes with high weightings were: NFE compatibility/integration; stability/security on head; overall fit; visual awareness; and minimal interference with pack, weapon/sights and eyewear (Davis et al., 2017).

2.3 Building a Systems Model

Another finding from the literature search was that most ergonomic studies on helmets focused largely on only one or two attributes and did not treat the helmet, or the assessment of the helmet, as a system. Adoption of a systems approach led to the identification of fourteen attributes and subsequent influencing factors and effects which interact with each other to form a complicated series of pathways. The next logical step was to arrange these components and interactions in a systems model. Sheridan (2014) specified that commonality of the language of analysis and design is required in a systems model. The multi-disciplinary nature of ergonomics enables identification of system components and presentation of these in a consistent format which sets the foundation for commonality. The model not only provided a mechanism for commonality but also provided a vehicle for managing the complex feedback loops.

The initial step in developing a whole systems model was to model each attribute, the relevant influencing factors, and potential effects (see Figure *2*1). The Physical Comfort model in Figure 1 shows that, as well as other factors, attributes of Fit, Stability, Mass, CoM, and MMOI influenced the attribute of Physical Comfort. It also shows that Physical Comfort affects the attributes of Operational Performance and User Acceptance. This information formed the first layer of the overall combat helmet systems model and provided important information on the relationships between the component parts of the helmet as well as the ergonomic attributes.

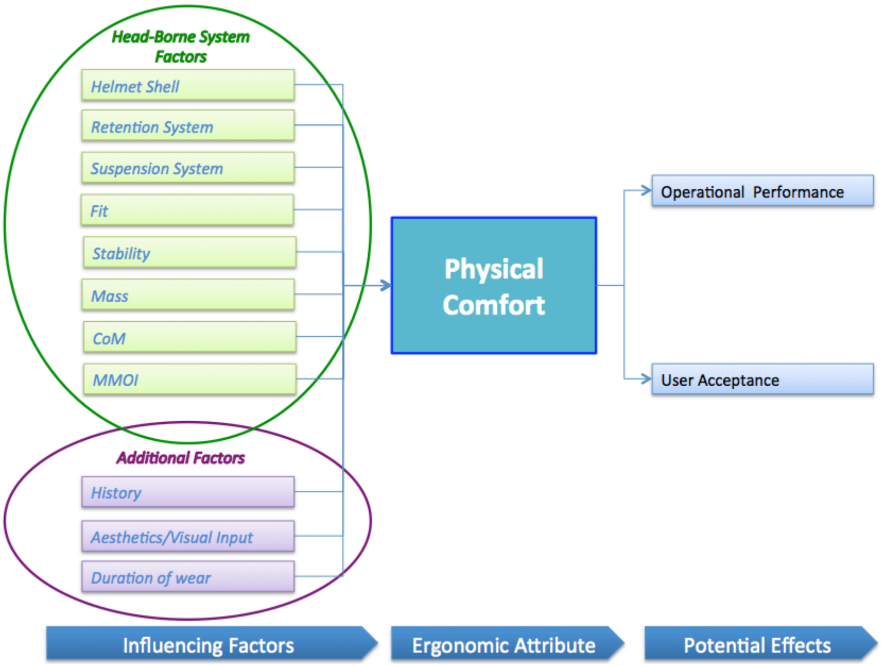

Figure 2: Physical Comfort Influencing Factor and Effects Model

The next step was to link all ergonomic attributes in one model which was achieved using TouchGraph Navigator©. Different colours were used to highlight the nodes with attributes in orange, influencing factors in red, and effects in purple[1]. The result of the work was a systems model that comprehensively details the ergonomic performance attributes of a combat helmet system, the influencing factors, and the effects (see Figure 2). Pathways in the model can be emphasised to clearly identify relationships in specific areas (see Figure 3) and to provide a useful tool for communicating information about the system.

[1] *Due to limitations of the software it was not possible to represent information on the importance of the attributes but the authors are continuing to explore software options.*

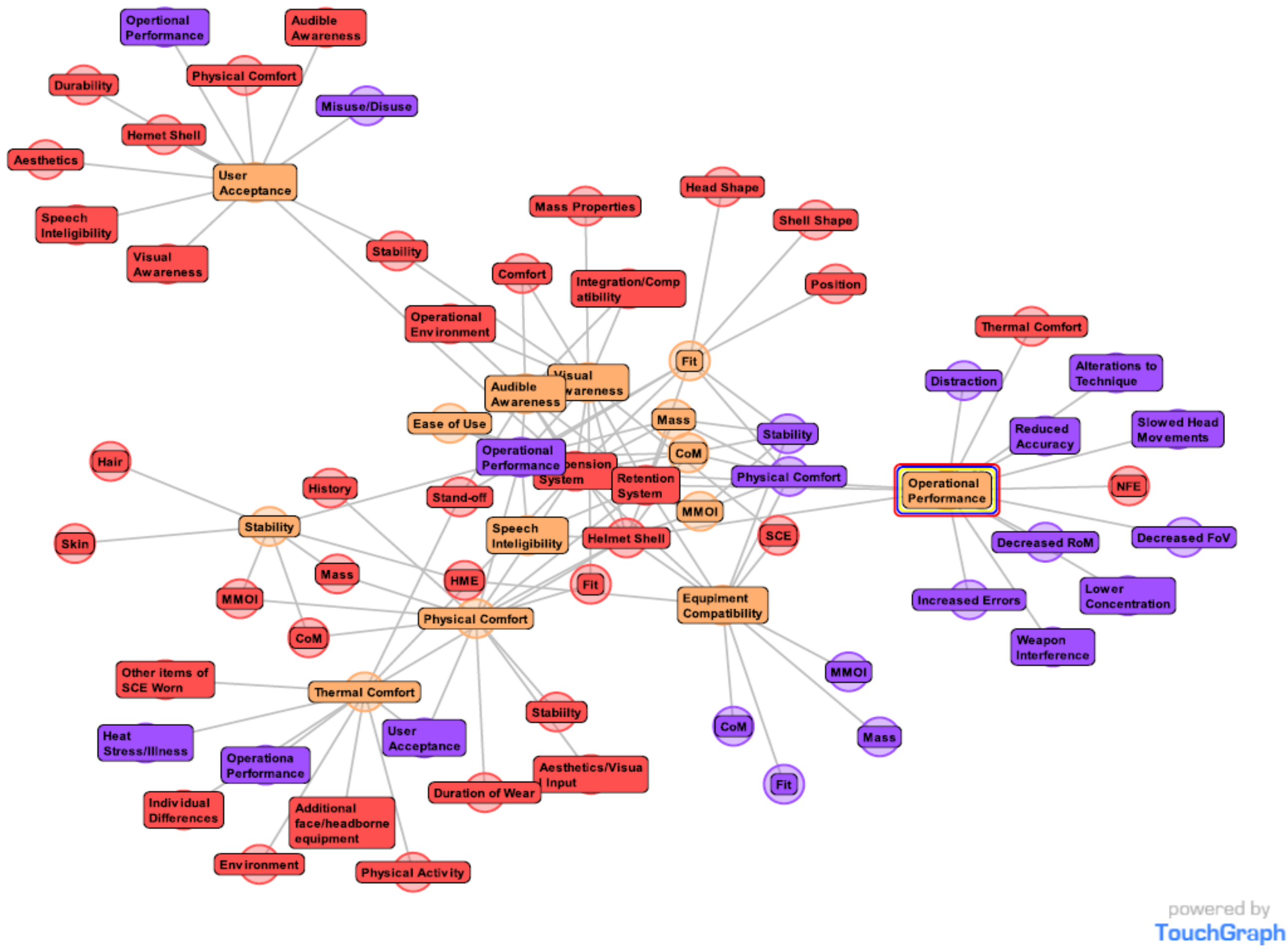

Figure 2: Combat Helmet Systems Model (Partial model presented due to display clarity in paper, full model can be requested from author)

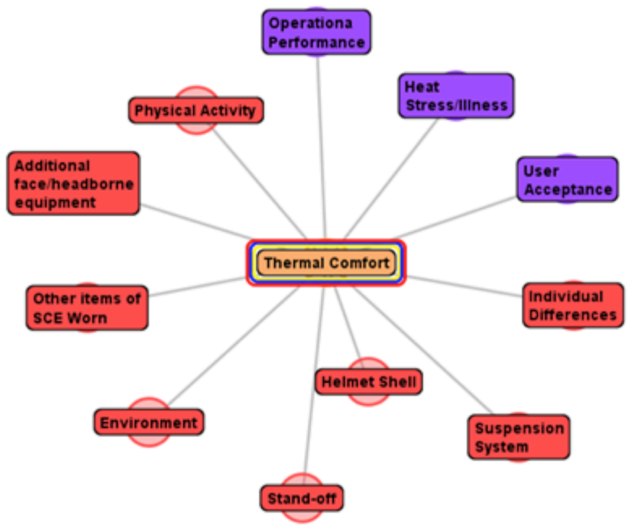

Figure3: Emphasised Pathway – Thermal Comfort

3. Discussion and Conclusion

As per the definition by Boardman & Sauser (2006), the combat helmet is a collection of entities, or components, and the relationship between these forms the whole helmet system which is greater than the sum of the component parts. A systems approach was taken to identify the ergonomic attributes and influencing factors of a combat helmet system. The information was developed into a systems model that comprehensively detailed the attributes, the influencing factors, and the effects. The importance ratings of the attributes were collected to enable prioritisation but are not currently included in the model due to limitations of the software. Building the model layer by layer enabled the complexity of multi-disciplinary attributes and multi-directional relationships to be managed and clearly articulated. This approach is recommended for modeling other items of the SCE to enable a clear understanding of the product system(s). The model also clearly highlights how complex an item as 'simple' as a helmet actually is.

When undertaking an ergonomic assessment of an item of SCE, such as a combat helmet, a soldier-centric system-based approach allows for a better understanding of the complexity of the relationship between helmet design and usability. The systems model provides a useful tool to aid design, development and assessment. It is important to note that although the model is designed to be used by persons with ergonomic/human factors knowledge and experience, it also provides transparent information and relationships for designers and researchers across different disciplines to use to enable a shared understanding and commonality as the basis for discussions and work.

In terms of design and development, it is important to understand design requirements and the implications of making design changes. A soldier-centred design enables user needs to be at the forefront of design trade-offs and decisions (Savage-Knepshield 2012). Every piece of SCE has been subject to competing demands and has resulted in trade-offs being made. The systems model provides a useful tool for informing trade-off decisions as it provides an understanding of the component parts and how they interact. The model not only presents information on design requirements in terms of the ergonomic attributes but also provides pathways for designers to understand the consequences of changes made to the helmet system. For example, if there is a proposed change to the retention system then 'retention system' can be selected and pathways in the model can be emphasised and followed to identify what components/attributes might be affected by the change, as well as the potential effects. Using this approach, if 'retention system' is selected then the model will indicate it is an influencing factor to the attributes of Fit, Ease of Use, Stability, Mass, CoM, MMOI, Physical Comfort, Audible Awareness, Speech Intelligibility, Visual Awareness, Integration/Compatibility, and User Acceptance. Fit has the potential to affect Stability and Comfort, and subsequently Operational Performance, as well as User Acceptance. Ease of Use has the potential to affect Operational Performance and User Acceptance, and so on. So the designer knows that if they were to change the retention system, consideration/assessment should be given to those 12 attributes and what the potential effects may be of the design change.

The model also provides comprehensive information on the areas that should be addressed during collection and analysis of ergonomic assessment data and can guide the activities and questions that should be administered during the assessment. When problems are identified in an assessment, then the information provided in the systems model can be used to identify the potential causes. For example, if heat stress is identified as a problem then a researcher can back-track through the pathways of the model to identify all the factors that influence the thermal properties of the helmet to start/guide their investigation and identify how improvements can be achieved.

The starting point of this research was the identification of 14 multi-disciplinary ergonomic attributes from a thorough search of the literature and input from users. Enabling these attributes to make sense would not have been possible without using a systems model. The model not only presented a mechanism to handle the complexity of the multi-disciplinary nature of ergonomics but also produced benefits of its own by providing a tool to aid the design, development, assessment, and trade-off decisions for a combat helmet system. It is a method that could be used for other items of the SCE and could be expanded to consider protection requirements to provide a larger systems view to inform design, development, assessments and trade-offs. It also has applications outside of the Defence domain.

Previous studies conducted on combat helmets have largely focused on one or two ergonomic attributes. This research, as far as the authors are aware, is the first approach to modeling the combat helmet as a system to enable understanding of all components, relationships and effects. In addition to the benefits discussed, the model will be taken forward as a basis for the development of a combat helmet systems ergonomic assessment framework. The next step will be to add a third dimension to the systems model in the form of outcome measures that comprise physiological, biomechanical and psycho-physical measures for all ergonomic attributes.

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