Simulation of hip joint location for occupant packaging design

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Abstract

DHM tools have been widely used to analyze and improve vehicle occupant packaging and interior design in the automotive industry. However, these tools still present some limitations for this application. Accurately characterizing seated posture is crucial for ergonomic and safety evaluations. Current human posture and motion predictions in DHM tools are not accurate enough for the precise nature of vehicle interior design, typically requiring manual adjustments from DHM users to get more accurate driving and passenger simulations. Manual adjustment processes can be time-consuming, tedious, and subjective, easily causing non-repeatable simulation results. These limitations create the need to validate the simulation results with real-world studies, which increases the cost and time in the vehicle development process. Working with multiple Swedish automotive companies, we have begun to identify and specify the limitations of DHM tools relating to driver and passenger posture predictions given predefined vehicle geometry points/coordinates and specific human body parts relationships. Two general issues frame the core limitations. First, human kinematic models used in DHM tools are based on biomechanics models that do not provide definitions of these models in relation to vehicle geometries. Second, vehicle designers follow standards and regulations to obtain key human reference points in seated occupant locations. However, these reference points can fail to capture the range of human variability. This paper describes the relationship between a seated reference point and a biomechanical hip joint for driving simulations. The lack of standardized connection between occupant packaging guidelines and the biomechanical knowledge of humans creates a limitation for ergonomics designers and DHM users. We assess previous studies addressing hip joint estimation from different fields to establish the key aspects that might affect the relationship between standard vehicle geometry points and the hip joint. Then we suggest a procedure for standardizing points in human models within DHM tools. A better understanding of this problem may contribute to achieving closer to reality driving posture simulations and facilitating communication of ergonomics requirements to the design team within the product development process.

Keywords: hip joint, H-point, seated reference point, simulation, digital human modelling

Introduction

Occupant packaging primarily aims to accommodate an intended range of drivers and passengers within the vehicle. However, this primary aim also constitutes one of the significant challenges, accommodating a maximal group of target users. Ideally, a vehicle will be designed to meet occupant needs while considering human diversity (Gkikas, 2016). Digital human modelling (DHM) tools have been widely used to analyze and improve vehicle occupant packaging and interior design in the automotive industry. However, these tools still present some limitations for this application. Current human posture and motion predictions in DHM tools are not accurate enough for the precise nature of vehicle interior design, hence typically requiring manual adjustments from DHM users to get more accurate driving and passenger simulations (Bhise, 2016; Brolin et al., 2020). Manual adjustment processes can be time-consuming, tedious, and subjective, easily causing non-repeatable simulation results. These limitations create the need to validate the simulation results with real-world studies, which increases the cost and time involved in the vehicle development process (Lämkull & Zdrodowski, 2020).

Working with multiple Swedish automotive companies, we have begun to identify and specify the limitations of DHM tools relating to driver and passenger posture predictions given predefined vehicle geometry points/coordinates and specific human body parts relationships. Two general issues frame the core limitations. First, human kinematic models used in DHM tools are based on biomechanics models that do not provide definitions of these models in relation to vehicle geometries. Second, vehicle designers follow standards and regulations to obtain key human reference points in seated occupant locations. However, these reference points can fail to capture the range of human variability. DHM tools aim to represent digital human models (manikins) within detailed CAD environments for analyzing and evaluating human interactions. Moreover, a lack of clear connections between occupant packaging guidelines and human biomechanical knowledge creates a limitation for ergonomics designers using DHM tools as they are not necessarily experts on all the nuances in both the guidelines and biomechanics. Perez Luque et al. (2022) reported that one of the main issues in vehicle development is the lack of accurate and reliable driving task simulation predictions. The lack of understanding and standardized procedures to make the manikin adopt the initial driving posture realistically means that ergonomics designers rely on their perception or expertise for quantifying driver seated positions and the consequential occupant packaging analyses.

This paper describes the relationship (or lack of it) between seated reference point in seat geometries and the hip joint for driving simulations, and presents an approach to sit manikins in a virtual environment considering geometric reference points and human body shape.

Problem description

Understanding and quantifying the initial seated posture is crucial for ergonomic and safety evaluations because the design and development of other ergonomic requirements such as seated posture comfort, operating controls, and interior and exterior visibility depend on it. Moreover, it is imperative to consider a diverse population with different body types and preferences to ensure a good fit for end-users (Gkikas, 2016). Successful vehicle interior design requires involvement insights from various fields, including biomechanics, ergonomics, engineering, and design. However, there is a lack of standardized methodologies connecting the different fields.

Ergonomics designers in automotive companies follow standards and legislation within occupant packaging and vehicle design. Standards, such as SAE and ISO, provide recommended tools and practices for defining key reference points, which specify the relative positions of the occupants with vehicle components. One of the essential reference points is the H-point (sometimes called the hip point). The H-point describes a theoretical intersection of a reference occupant’s torso and thigh lines (Gkikas, 2016). This means that the H-point simulates but does not precisely represent the human mid-hip joint location and its variability across people. The location of the H-point relative to a physical seat is commonly determined using the H-point machine (HPM-II) (Figure 1), which will be called HPM in this paper, and which can be physical or digital (Reed et al., 1999; Yang et al., 2014; ISO 20176, 2020). Vehicle manufacturers define a vehicle design-specific H-point, the seated reference point (SgRP), as a fundamental reference point for determining seating location for occupant packaging and vehicle dimensions (Bhise, 2016). The SgRP enables correlation between physical and virtual environments, and provides a consistent method for comparing vehicles. While fixed seats have only one H-point position (the H-point and SgRP is the same point), adjustable seats have more than one H-point location. All these H-point locations are mapped and described in the seat movement envelope, hence representing an area rather than a point. The representation of the H-point in the virtual environment can be used as a reference point to position manikins since it does not say how they sit, but rather where they sit. However, using such standards does not ensure the consideration of human diversity and variability sufficiently.

An alternative to starting with design standards is to investigate human body angles in driving situations to determine expected human driving postures. Over the years, many authors have followed this approach from the biomechanical and ergonomic design fields, mainly focusing on values of subjective comfort, human structure and functions in driving situations (Schmidt et al., 2014). However, the results of these works are typically not specified in terms of actual vehicle reference points, making it difficult or impossible to apply the results in current design contexts without significant effort. Moreover, authors often consider and observe variability in posture among different factors, including gender, anthropometric measurements, age, symmetry, seat design, vehicle model, and driving venue (Reed et al., 2002; Schmidt et al., 2014; Park et al., 2016a). While these studies focus on human driving posture and body joint angles, they rarely define the relation of those angles to the driver seat geometries, limiting their current influence on DHM tools and design processes in general.

Figure 1. Physical HPM-II model (ISO 20176, 2020)

Park et al. (2016) have developed a data-based prediction model for passengers considering body dimensions, age, and gender from humans with reference to vehicle layout measurements. This model follows a “cascade” approach, in which the most relevant variables are predicted first, followed by less important variables. One component of this model is a regression model, which predicts the mid-hip location to the H-points of the automotive seat. The main limitations of this study include the fixed position of the backrest angle, the use of a non-naturalistic laboratory setting and the limitation to participants in the USA. Reed et al. (2019) expanded this model for pelvis position and rotation in the automotive seat by including data from highly reclined postures in automotive seats. They concluded that the spine and pelvis posture changes as the torso reclines in an automotive seat.

While existing human posture studies have been used to develop data-driven and optimization methods, some additional considerations complicate predicting hip joint locations related to vehicle geometries. The appearance of the manikins in DHM tools can lead to different and/or inaccurate predictions when it is tied to collision volumes determining the boundaries of the manikin relative to the seat geometry (Lämkull et al., 2007; Lämkull & Zdrodowski, 2020). Thus, even with possibly accurate predictions of where the mid-hip should be placed, ergonomics designers may modify the manikin's position and posture until the manikin body shape looks appropriately aligned to the automotive seat and realistically represents a human-vehicle interaction. Brolin et al. (2020) introduced DHM functionality which uses the mid-hip to H-point relationship from Park et al. (2016) together with constraints and adjustment ranges of vehicle components to statistically predict seated driving postures. Even though the results were promising, initial comparisons of such predictions with data from user tests showed some differences, which indicates that further research is needed.

In this paper, we compare the regression models from Park et al. (2016) with an approach to seat manikins in driving environments using more realistic human body meshes with a wide range of body mass index (BMI).

Approaches for initial seated driving posture

Several DHM tools are currently used for occupant packaging and automotive design like Ramsis, Santos, Jack Siemens, and IPS IMMA. While these tools are based on different modelling and prediction methods for defining the seated driving posture, they all mostly follow the same procedure for adopting the initial seated driving posture. A *DHM standard procedure*, identified in discussions with companies, consists of the following steps: First, DHM users make the manikin or manikin family assume the driving posture, which is generally defined by the DHM software following specifying angles according to a particular study. Second, constraints are set to fulfil basic requirements and get an initial seated driving posture consistent across manikins and simulations. These constraints or requirements are typically defined in the feet (e.g. heels should take up support, right foot on the accelerator pedal), grip points on the steering wheel, eye or mid-eye vector to define the head direction, and top of the head to ensure the manikin stays within a particular space. Finally, manual adjustments are often made. Typically, the mid-hip, torso or the automotive seat position are manually adjusted and constrained to get postures visibly fitting the seat geometry, following the ergonomics designer criteria. Notably, this DHM procedure has a limitation of not having any clear and direct relationship relating the mid-hip point and the H-point and the adjustment range of the seat. So, even if the manikin has "optimal angles", we would not know how or where to place it in the automotive seat.

As an attempt to fill this gap, in this paper, an approach is presented as an alternative to the previous ones to be able to sit manikins realistically and consistently while considering the standards and legal requirements for occupant packaging, a wide range of BMI, and the mid-hip and H-points relationship in driving environments. This approach was compared to the *Statistical Prediction* approach proposed by Park et al. (2016), which showed some issues for particular cases as mentioned in the literature.

Method

Figure 2 summarises the main steps of the *Body Shape Alignment*, the proposed approach in this paper. The first step consists of loading a virtual template of the HPM in the digital environment and positioning it in the vehicle direction. Next, the H-point of the HPM template should be aligned to the SgRP of the driver seat as well as the HPM template surfaces to the driver seat surfaces. Once the HPM template is correctly aligned to the seat, the manikin should be aligned to the HPM template surfaces. As the last step, the coordinates of the SgRP, H-point and mid-hip point could be extracted from DHM software to analyze the relationship or offset between these different variables further.

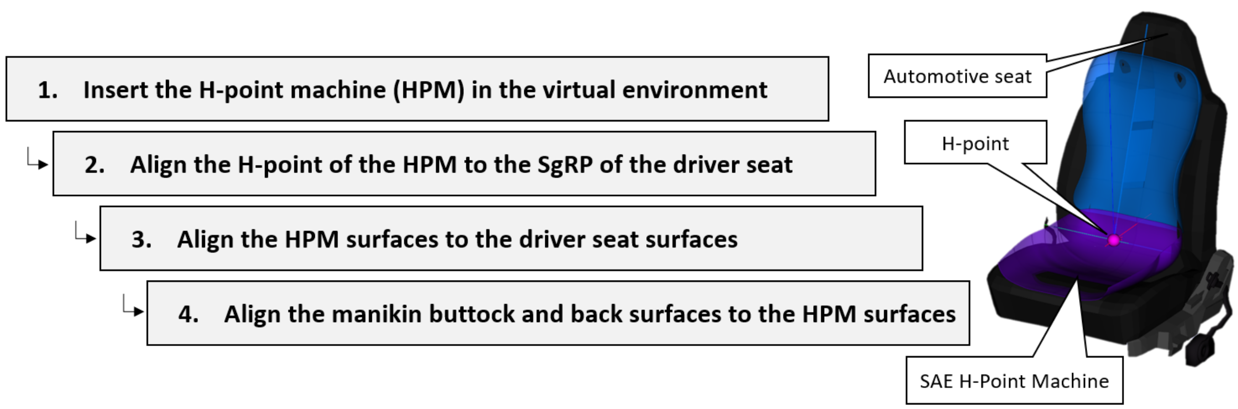

Figure 2. Body Shape Alignment approach.

Comparison procedure

The Statistical Prediction and Body Shape Alignment approaches were used to sit manikins in virtual driving environments using a wide range of BMI human body meshes. The automotive vehicle model was a Volkswagen Beetle from the training repository of Siemens Jack (Siemens, 2017). The human body meshes were obtained from the BioHuman website (*UMTRI BioHuman*, 2022) which provides 3D manikin meshes based on statistical analyses of high-resolution laser scans. The human body meshes were used for the comparison of seated driving approaches due to their closer to reality appearance. A manikin family of 7 females and 7 males was considered in the simulations. The anthropometric measurements of the manikin family were generated from two three-dimensional boundary ellipsoids, with a confidence level of 90% (Brolin et al., 2012). One ellipsoid for each sex, based on stature, body weight, and sitting height. The anthropometric data was taken from the CAESAR data set (Robinette et al., 2002). In addition to an average manikin case for each sex, six manikin cases were defined at the ends of the three axes of each of the two ellipsoids. US population was selected on the BioHuman website to generate the meshes since the regressions models of the Statistical Prediction from Park et al. (2016) are done considering the US population. 40 years was the defined age for all the manikins. Table 1 describes the anthropometric measurements of the manikin family. It should be noted that the generated test manikins span a more extensive range of BMI values compared to the sample from Park et al. (2016), which might affect the results. However, the measurement combinations of the generated test manikins are realistic and could be found within the CAESAR data set, which motivates the use of these more extreme test manikins.

Table 1. Anthropometric measurements of the manikin family cases.

Manikins	Body weight (kg)	Stature (mm)	Sitting height (mm)	BMI (kg/m^2)	Manikins	Body weight (kg)	Stature (mm)	Sitting height (mm)	BMI (kg/m^2)
Case F1	65	1639	865	24	**Case M1**	83	1775	926	26
Case F2	95	1814	949	29	**Case M2**	124	1974	1018	32
Case F3	50	1475	785	23	**Case M3**	61	1604	836	24
Case F4	47	1678	893	17	**Case M4**	62	1818	959	19
Case F5	115	1600	837	45	**Case M5**	122	1734	892	40
Case F6	64	1695	838	22	**Case M6**	82	1834	899	24
Case F7	66	1584	891	26	**Case M7**	85	1719	953	29

Results

Figure 3 shows the human mid-hip to the H-point of the automotive seat locations using the Statistical Prediction and Body Shape Alignment approaches. Figure 4 shows the initial driving posture of the human body meshes by using the Statistical Prediction and the Body Shape Alignment. It can be seen how the meshes in the former are more spread on the x-axis compared to the second approach (Figure 4).

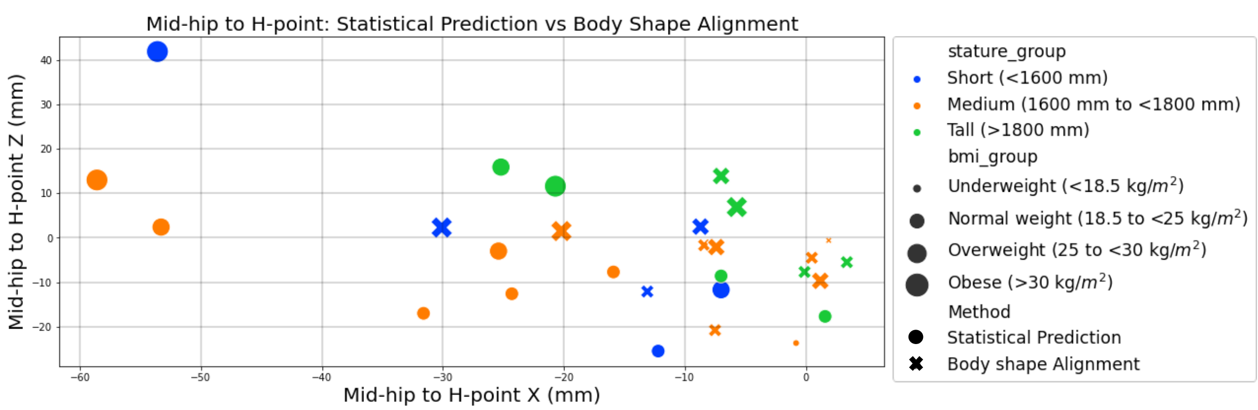

Figure 3. Mid-hip to H-point: Statistical Prediction vs Body Shape Alignment.

The most evident differences in the mid-hip to the H-point location were observed concerning the BMI. Figures 3 and 4 show how manikins with higher BMI move forward in the x-axis with the Statistical

Prediction approach. This might not be seen as a problem at first. However, the gap between the manikin with higher BMI and the seat is significantly evident when observing the human body meshes in such a position. That would lead to manual adjustments, making the statistical prediction not accurate. On the other hand, it can be seen how the spread in the x and z-axis is not as wide with the Body Shape Alignment as with the Statistical Prediction.

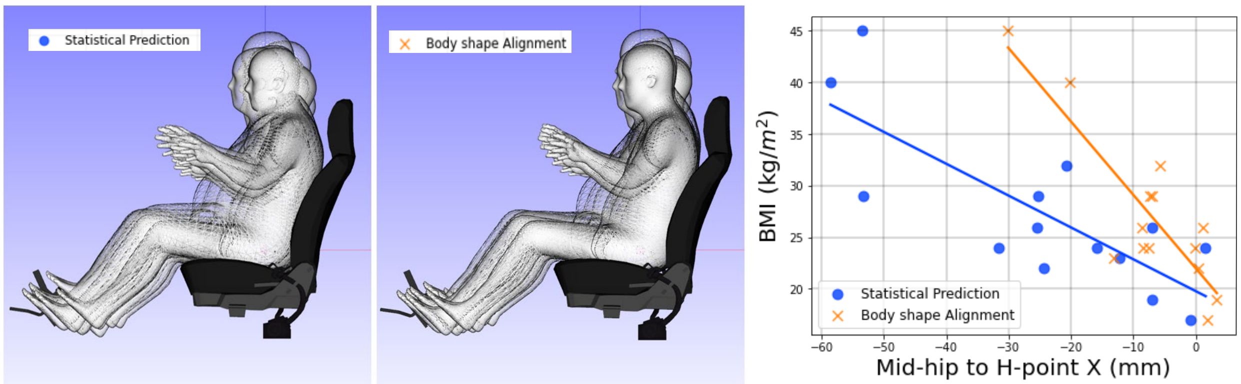

Figure 4. Initial seated driving posture: Statistical Prediction (left) and Body Shape Alignment (right).

Discussion and Conclusion

The presented Body Shape Alignment is an procedure for seated driving posture. Although the results show that obtaining the initial seated driving posture is possible, it needs further development. In its current state, it predicts the mid-hip to the H-point location of the automotive seat in a standardised way considering standards and legal requirements and human body shape variability. However, this initial procedure might involve subjectivity in the alignments. This can be fixed by further defining appropriate constraints between the automotive seat, HPM, and the manikins or body shapes meshes in the virtual environment. In this way, if you move the seat, the H-point's location and the mid-hip point's prediction will also move. The human body meshes used in the comparison were calculated with sex, stature, BMI, SH/S, and age from the BioHuman framework. However, people with the exact anthropometric measurements could also have different body shapes. Fit people could have BMI rates of overweight people due to the larger muscle mass. That is not reflected in the presented study. In addition, changing the body joint angles of the meshes was not possible since it is defined in the 3D mesh generation from the BioHuman framework. Going further, the use of the body shape alignment approach for getting a proper initial driving posture relies on, and therefore requires, accurate human body meshes within DHM software. The accuracy of the body shape alignment approach could be further advanced by implementing models regarding seat foam and human buttock deformation (Wang et al., 2021). The mid-hip location prediction on the human body shapes could also be further advanced, e.g. by considering the study from Brynskog et al. (2021), in which detailed pelvis geometry is predicted with overall anthropometric variables. While the presented approach seems to have consistent results across different anthropometries, more research is needed to know, for example, if this approach applies to non-US populations and other types of vehicles.

Figure 4 shows that the more considerable differences between mid-hip to H-location with different approaches come as the BMI increases. One reason could be the limited representation of people with higher BMI values in the developed regression models compared to the manikin family used in this study. In addition, measurement errors could occur since the mid-hip is a problematic and challenging point to identify. At the same time, the differences could have been due to the estimations of the mid-hip point in the human body meshes used in this study. While previous studies have found mid-hip locations typically forward of the H-point (Reed et al., 2002; Park et al., 2016a, 2016b), it can be seen in this study that various mid-hip locations are slightly rearward of seat H-point, as shown in Reed et al. (2019). Delving deeper into these mid-hip to H-point differences, we should consider the postural diversity within a population. Then, what can be viewed as a postural variety and an error? What can be considered an accurate initial driving posture? The Statistical Prediction approach includes root mean square error (RMSE) that could be used to represent human diversity. However, while statistical predictions can be beneficial, we should also consider that such values are determined for the specific conditions and population of that study and might be limited to use in other conditions, vehicle types, and different populations. The driving posture was different in the past and will be different in the future, especially considering the introduction of autonomous vehicles and new concepts of transportation (Yang et al., 2019). Simulation and evaluation of different sitting postures and non-driving related activities are becoming critical for developing future vehicles in regards to ergonomics and safety. When modelling human-product interactions, the main challenge comes with the need to be able to predict any possible interaction (in existing and future vehicles) accurately and realistically. Further research is required to identify and define suitable interaction models for engineering design covering a universal valid approach.

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