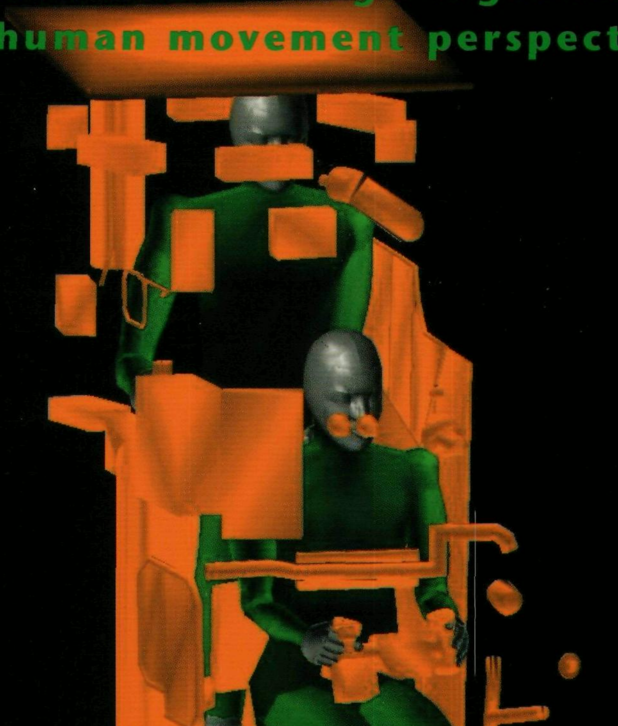
ABOUT AGENTS AND AVATARS

Simulation-based design ergonomics from a human movement perspective



Prof. dr. Nico J. Delleman

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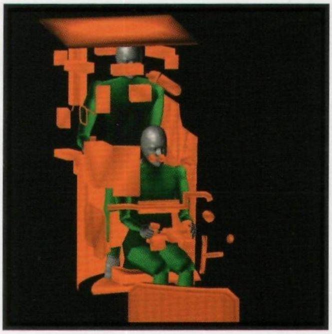

Inaugural address

by Dr. Nico J. Delleman

Professor of Simulation-Based Design Ergonomics

Université René Descartes – Paris 5

Delivered on October 29, 2004, at UFR Biomédicale, UPRES Ergonomie, Laboratoire d'Anthropologie Appliquée, 45 rue des Saints-Pères, Paris, France

Université René Descartes – Paris 5

TNO

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Cover: Digital human models in a CAD environment (Leopard 2 Tank)
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Monsieur le Président,
Professeurs, Collègues,
Mesdames, Mesdemoiselles, Messieurs,

Simulation-based design ergonomics is the science of adapting tangible products and processes to human capabilities during the design process by using numerical simulation to improve the task performance (speed, accuracy), the physical fitness/comfort, the health and/or the safety of future users.

Major decisions are often taken early in the design process, before it has moved beyond the Computer-Aided Design (CAD) phase. To incorporate ergonomic considerations in this purely digital phase, a designer will need digital representations of the future users, which are known, logically enough, as digital human models. If you look at the screen (cover of this booklet), you'll see an illustration of this. We see two digital human models in a CAD version of a military vehicle. In this case, the model is simply being used to see whether people of various sizes fit the workstations, but there are many more things that can be simulated, as I hope to make clear in my presentation. The main purpose of simulations is to evaluate design options as much as possible and as early as possible. And the reason for this is that it is much easier to change a digital design than a mock-up or a prototype, thereby reducing time-to-market or time-to-operation, not to mention costs.

Digital human models have been around since the 1960s. In its report on a 1985 workshop in the USA, the National Research

Council (1988) distinguished three major classes of models: "*anthropometric*, representations of static body geometry such as body dimensions, reach, position of the body and/or its parts, posture; *biomechanical*, representations of physical activities of the body in motion, using anthropometric data as inputs; and *interface*, specific combinations of anthropometric and biomechanical models for representations of human-machine interactions". The report expressed a desire to work towards an integrated ergonomic model that would have the following characteristics: it should be dynamic, use a common notation system, incorporate or simulate the real world, have a three-dimensional structure, be predictive, be capable of being validated, be user-friendly, be time- and cost-effective, permit on-line documentation, be written in a standard language for transportability (use on different systems), have standardized segment and whole-body co-ordinate systems and have graphical capability. The interface models - which most resemble our current digital human models - are typically the products of universities, government organisations and individual companies. They include SAMMIE, COMBIMAN, CREW CHIEF and BOEMAN, and were intended mainly for in-house use. These days, however, we see models like SAFEWORK, JACK and RAMSIS, which are dedicated commercial products with a world-wide user base and which are mostly used in conjunction with leading CAD software (Chaffin 2004). Researchers, model developers and users have all gathered at the successful annual Digital Human Modeling Conferences organised since 1998 by the Society of Automotive Engineers (SAE). Special recognition should go to Dr. Michael

Biferno of the Boeing Company, who took the initiative and guided the conferences for many years.

In this presentation I hope to give an overall idea of what simulation-based design ergonomics is all about: the background research, the tools and the applications and the possible shape of things to come. I will follow the general characteristics of a digital human model (figure 1), by beginning with skeleton and enfleshment research, where the key issue is how to make models that have realistic body segment lengths, joint ranges of motion and body outer shapes. But the main part of the presentation will be on motor behaviour research, which is where agents and avatars enter the picture. The key issue here is how to let the model beha-

Figure 1. General characteristics of a digital human model.

1. Body
   - skeleton (segments, joints)
   - enfleshment (geometry)
2. Interaction with the environment
   - physical interfacing (positioning of model)
   - motor behaviour (posturing of model)
3. Task execution
   - speed, accuracy
   - physical fitness/comfort, health, and safety effects

ve naturally with respect to posture and movement. I will then describe our research program, which will hopefully deal with the nature of the task execution characteristics. In this case, the issues are, first, how to let the model perform realistically for the speed and accuracy of executing a task (see Drury and Paquet 2004), second, how to let the model express physical fitness/comfort and, third, how to predict health and safety effects. The anthropometric models distinguished by the National Research Council (1988) fall under item 1 (skeleton and enfleshment), while the biomechanical models fall under item 3 (physical fitness/comfort and health). In a report on a 1998 SAE survey of practising designers Chaffin (2004) proposed that the following human attributes should be included in future digital human models: anthropometrics of a variety of population groups, maximum volitional reach capabilities and sight lines, realistic human motions, motion movement times and complex reaction times, population strengths and endurance capabilities. All these attributes can be found in the general characteristics of a digital human model (see figure 1), with the first two in item 1, the third in item 2, and the latter two in item 3.

Rather than give an exhaustive report of research results, I have selected some studies that either support my main statements or illustrate the research program. You will notice that the terms posture and movement/motion are used interchangeably, as they both refer to orientations of body segments. Digital human models should be easy to use provided this is not at the expense of validity. Validity relates to all the characteristics described (see figure 1). This presentation will mostly discuss research on validity, meaning the quality of prediction, as this is *the* basic issue for any model. Ease of use for designers will only be discussed briefly.

Skeleton and enfleshment

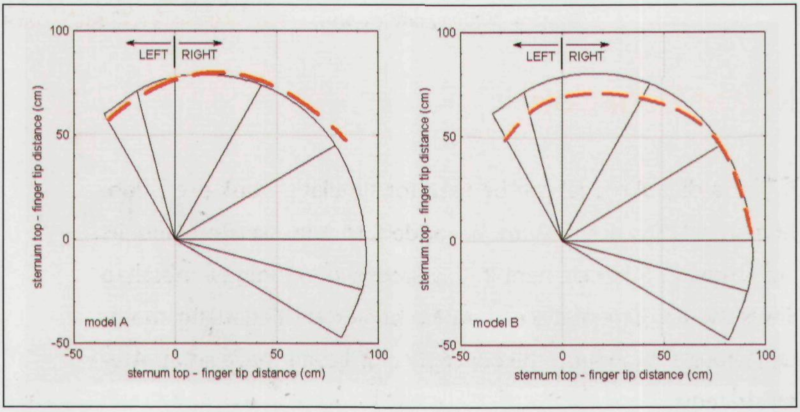
A digital human model consists of various segments linked at joints to form the skeleton. At TNO Human Factors, the validity of the skeletons of two models was tested for the dimensions of the segments and the range of motion of the joints. In an experimental workstation, the maximum reach of the test subjects was measured for left/right directions -30° and -15° (leftward), 0° (straight forward), 30°, 60°, 90°, 105°, and 120° (rightward), combined with various up/down directions (figure 2). Here, data will be presented for reaching in the horizontal plane. For each subject, an individual model was created based on traditional anthropometric distance measures such as stature and upper extremity dimensions, as required by the software. The maximum reach of the individual model was compared to the subject's maximum reach in the workstation, i.e., the distance between the top of the sternum and the tip of the right index finger. Model A provided maximum reach data for left/right directions of -30°, -15°, 0°, 30° and 60°, while model B also provided output for 90°. It turned out that model A underestimates the maximum reach of the subjects when reaching more to the left, and overestimates it when reaching more to the right (figure 3, left). The shape of the maximum reach curve for the model resembles the shape of the maximum reach curve of the subjects. A mutual shift of 6 cm sideward was calculated. Four segments contribute to maximum reach. These are the shoulder girdle, the upper arm, the forearm and the hand. The lengths of the latter three contribute when reaching to the right and when reaching to the left, while the length of the shoulder girdle segment mainly contributes when reaching to the right. The fact that model A overestimates to the right and underestimates to the left to about the same extent, suggests that the length of the shoulder girdle segment in the model needs to be reduced. Model B estimates the maximum reach of the subjects reasonably well when reaching to the right (figure 3, right). We can conclude that the lengths of the four upper extremity segments seem to be modelled correctly. *However, the model does underestimate when reaching* more to the left (up to about 20 % when reaching 30° leftward). This is most likely caused by incorrect data on the range of motion of the shoulder girdle (with respect to the chest/trunk) or on the range of motion of the upper arm (with respect to the shoulder girdle) or both. In itself that is not strange, as no range-of-motion data of the subjects had to be fed into the model. Furthermore, group data on ranges of motion in traditional anthropometric databases is not as plentiful as distance data. This makes it unlikely that model developers will be able to make a good choice of data to use in their models, and equally unlikely that relationships between distance measures and range-of-motion measures could be determined for prediction purposes.

Regarding the validity of the enfleshment (geometry) of the models, it is a great step forward that three-dimensional data are becoming available now through the use of scanning equipment (figure 4), as foreseen by the National Research Council (1988). The first major study using whole-body scanners - CAESAR (Civilian American and European Surface Anthropometry Resource), conducted between 1998 and 2001 - collected data on 2400 North American (US, CA) and 2000 European (NL, I) subjects. Robinette et al. (2004) described the rapid evolution of

Figure 2. Subject sitting at the experimental workstation for testing the validity of the skeleton of digital human models through maximum reach measurements.

techniques for processing scanning data and its potential applications. It is of crucial importance to the enfleshment of digital human models that scans can be converted to a model, and Brodeur and Reynolds (2004) seem to have been the first that have done this. Segment lengths and joint centre positions are calculated from comparable landmarks in their ERL model and in CAESAR scans. Allen et al. (2002) showed how the geometry of the body in any posture can be estimated from scans of the body and body segments in various postures using common parameterisation and interpolation techniques. Finally, regarding the validity of the skeleton and the enfleshment of digital human models, I am very pleased to see that international co-operation in anthropometry will be continued and enlarged in WEAR (World Engineering Anthropometry Resource) - a consortium of partners from North America, South America, Europe, Africa, Australia and

Figure 3. Model maximum reach (bold red broken line curve) vs. subject maximum reach (thin black solid line curve) for left/right reach directions in the horizontal plane for two models (average group data).



Asia. In this section, I have shown that range-of-motion data is important for predicting maximum reach; in the next section, I will show the importance of range-of-motion for predicting postures and movements. We also know that postures near the end of a range of motion are uncomfortable. I therefore propose that future studies include scans of body segments in extreme joint positions so that range-of-motion data can be deduced.

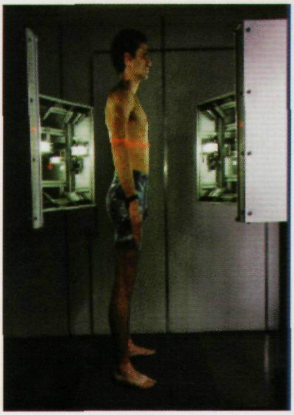


Figure 4. Whole-body scanner.

Motor behaviour

Before a digital model can be used for simulating task execution, human intelligence has to be added to the skeleton and its enfleshment. A key element in this process of bringing a model to life is the implementation of motor behaviour. Regarding motor behaviour, I distinguish the concepts of postural space and postural strategy.

Postural space

A postural space is defined as all postures that can be adopted voluntarily and momentarily, given a set of physical limitations. Basically, each space is determined by the ranges of motion of body joints and eyes. A range of motion may be reduced by personal protective equipment such as glasses or clothing. Furthermore, the capability of the eyes in terms of visual acuity may affect the space by limiting the range of viewing distances. The dimensions, spatial position and orientation of a workstation and a worker may affect the postural space simply by mutual physical interference. Worker dimensions also include personal protective equipment such as shoes, clothing or a helmet. The operation to be performed may pose demands on vision, hand/foot control and/or stability. That is, all three types of demand can be characterised by interfaces with the workstation that affect the postural space. For instance, vision requires an unobstructed line of sight and a minimum angle between the line of sight (gaze direction) and the surface of a visual target. Control may require a certain type and orientation of grip/contact. Stability, in terms of a balanced posture of the whole body, always requires a base of one or more points/areas of support at the workstation, while stability, in terms a fixed posture of a body segment, may require additional support.

Postural strategy

Within the postural space, human beings have redundant options for getting the gaze or the hand onto target. A hand position, for example, may be achieved by many combinations of orientation of the forearm, the upper arm, the shoulder girdle and the trunk. Most likely, a worker will prefer a selection of these, guided by an underlying principle (see Bernstein 1967; for analogous considerations concerning external force exertion, see Haslegrave 1994, 2004). A postural strategy is a distinct posture or movement selected to execute a task. The simplest hypothesis on postural strategy says that a body segment will only be moved if a target cannot be reached by movement of the segments located more distally (i.e., closer to hand, Korein 1985). Hsiao and Keyserling (1991) hypothesised that a proximal segment (i.e. one closer to the buttock) would show a greater tendency to stay within its neutral range than a distal segment whenever movement of segments was necessary to view or reach a target. A neutral range was defined as the part of the maximum range of motion that involves minimal discomfort. Jung et al. (1995) proposed basing postural behaviour on the penalties associated with the deviations of the segments from the centres of their ranges of motion. In both cases, no anatomical, biomechanical or physiological rationale was provided for the cost function mentioned ("discomfort", "penalty"). In other words, what is the criterion involved? Is it work against gravity, muscle fatigue, joint positions loading passive structures like ligaments? Or something else entirely? According to Soechting et al. (1995), final arm postures can be predicted from the strategy of aiming to minimise the work done to move the hand to the final position. Rosenbaum et al. (1995) postulated that reaching behaviour is guided by knowledge gained by a person about postures adopted earlier at final hand positions ("stored postures"). This would involve spatial accuracy costs (the extent to which stored postures miss the current target) and travel costs (how much effort it will take to move to the stored postures from the starting posture). The travel costs were quantified by Fischer et al. (1997) based on the weight of the body segments moved by a rotation at the hip, by a rotation at the shoulder and by a rotation at the elbow (all rotations are in the sagittal plane, which separates the left and right sides of the body). Only one of the predictions from the model was supported by their experimental data, namely the prediction that the smallest rotation would be found at the joint moving the most weight, i.e. the hip. The same was observed by Radau et al. (1994) for gazing. In general, it can be said that we lack data supporting any of the hypothetical strategies presented in the literature. It seems that the postural behaviour of the trunk is driven by an external (world-related) control parameter, namely minimising work against gravity. Recently, several studies were performed that also offered insight into the role of internal (body-related) control parameters. These will be presented shortly.

Agents

I distinguish two different types of digital human models - agents and avatars. I will first speak about agents, then about avatars. An agent is a digital human model driven by human intelligence that is fed into the software through principles or rules. I will show two examples of research into postural strategies which aimed to make agents more intelligent as far as human motor behaviour is concerned.

Monnier (2004) of the INRETS research laboratory (supervised by Dr. Xuguang Wang and Dr. Jean-Pierre Verriest) studied the strategies used for reaching for a car seatbelt. Besides various substrategies, he uncovered three main strategies: right hand, left hand up and left hand down (figure 5). The right hand (RH) strategy is used most for the fore/aft belt positions tested but this gradually moved towards a greater use of the left hand down (LHD) strategy when the belt was positioned further back. The left hand up (LHU) strategy is preferred by some short test subjects. All motor behaviour found in the experiment was determined by subjects reaching the ends of their joint ranges of motion. For the upper arm, that refers to adduction for RH, internal axial rotation for LHD, and external axial rotation for LHU. The belt positions tested seemed to require movements at the edge of the postural space. It looks as if the subjects had only uncomfortable move-

Figure 5. Three different strategies for reaching for a seatbelt: right hand, left hand up, and left hand down (from left to right) (Monnier 2004).

ments available and sought the least uncomfortable. In such a situation differences in body dimensions and joint ranges of motion among individuals seem to lead easily to different "most comfortable" motor behaviour, as shown by the considerable variety of strategies and sub-strategies found.

Delleman et al. (2003) studied generic reach behaviour well within the postural space. Test subjects were asked to touch various spatial targets with the tip the right index finger (figure 6).

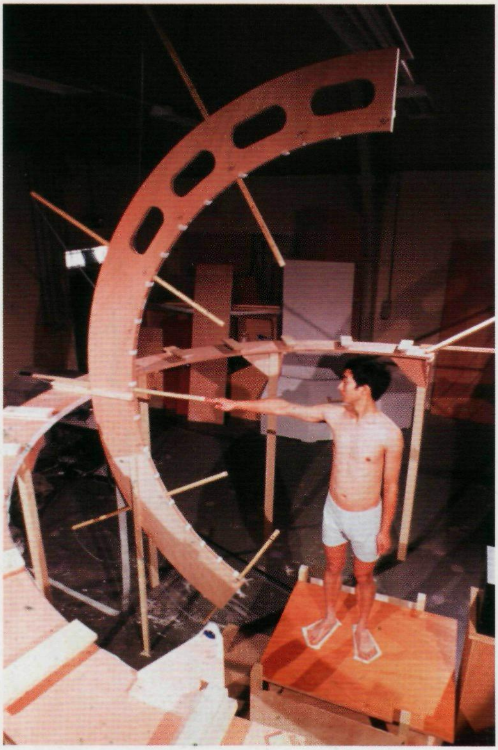
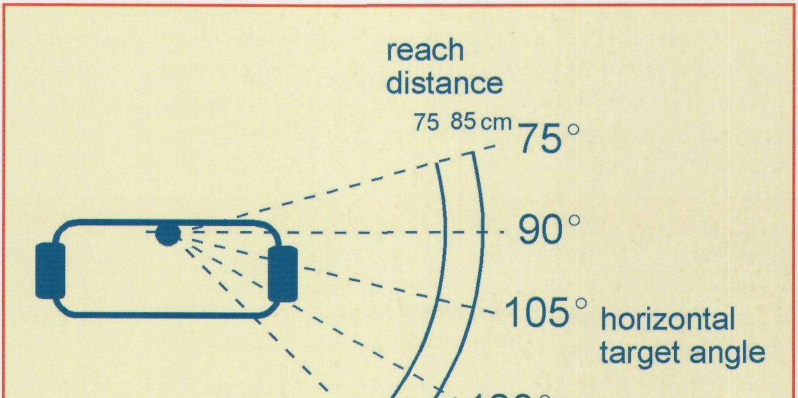


Figure 6. Test subject standing at the experimental workstation for studying generic reach behaviour.

Ten targets were positioned on concentric circles in the horizontal plane with the centre at the top of the sternum (figure 7). The reach directions were 75°, 90°, 105°, 120° and 135° to the right in the horizontal plane (where 0° = straight forward and 180° = straight backward). The reach distances were 75 cm and 85 cm, i.e. within full arm reach sidewards for all subjects. Skin-mounted sensors were positioned on the tip of the right index finger, at the top of the sternum, and on the sacrum to study the role of the arm, chest, and pelvis. While standing, these segments each contribute at a particular rate to getting the index finger onto a target (table 1). These rates are reasonably similar to the average

Figure 7. Top view of the five directions and two distances used for studying generic reach behaviour. The trunk (open rectangular shape), sternum (blue dot), and shoulders (small blue rectangular shapes) are shown.



contributions of the arm (58%), chest (12%) and pelvis (30%) to the total range of motion of the arm, chest and pelvis. I call this the proportionality principle, which was also found in static gazing (Delleman and Hin 2000, Delleman et al. 2001). It suggests that the arm, chest, and pelvis share the musculoskeletal load equally while reaching sidewards. When the range of motion of the pelvis was excluded by performing the reaches in a sitting posture, the motor behaviour of the remaining active segments (arm and chest) was adapted to maintain the proportionality principle (table 1). The same phenomenon was found in sideward gazing when the pelvis and chest ranges of motion were restricted by, respectively, sitting and fixed hand positions (Delleman et al. 2001). It is amazing to see that the contributions instantaneously change according to environmentally-imposed range-of-motion restrictions.

Table 1. The average contributions of the arm, chest and pelvis to getting the index finger onto a target while standing and sitting (refer to 'Motor behaviour' at reach distances 75 cm and 85 cm) and the average contributions of the arm, chest, and pelvis to the total range of motion of the arm, chest and pelvis (refer to 'Range of motion').

		Contribution		
Standing	Reach distance	Arm	Chest	Pelvis
Motor behaviour	75 cm	0.50	0.15	0.35
Motor behaviour	85 cm	0.55	0.13	0.32
Range of motion		0.58	0.12	0.30
Sitting				
Motor behaviour	75 cm	0.75	0.25	---
Motor behaviour	85 cm	0.75	0.25	---
Range of motion		0.78	0.22	---

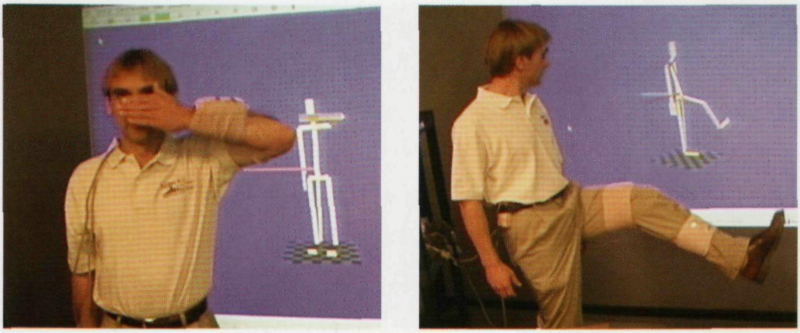
On the basis of a pilot study, it was expected that the trunk would be involved only when reaching more than 75° sidewards. However, it turned out that the trunk is involved earlier. On the basis of the results (linear regression equations, $0.61 < R < 0.77$), it was estimated that at the 75 cm reach distance the pelvis started to move at 50°, while the chest (with respect to the pelvis) started to move at 62°. At the 85 cm reach distance, the values were 39° and 50°, respectively. Now the question is what causes the chest and pelvis to get involved at these reach directions? I assume that would be a job for experts in shoulder girdle modelling, possibly involving an analysis of the role of other segments, such as the trunk. A discussion and a joint effort to find an answer would be very welcome.

Avatars

Although the study of strategies in human motor behaviour is very interesting from a scientific viewpoint and worthwhile from a practical viewpoint, it also requires a lot of effort. A great deal of work has been put in over many years to get an understanding of motor behaviour in a rather limited number of distinct activities, such as generic reaching and gazing, and in specific activities such as reaching for a seatbelt and car ingress and egress. Despite all the effort this work is neither complete nor comprehensive. But what if we want to go beyond local activities into wider spaces and beyond individual activities into team operations? This could involve simulating processes such as maintenance, safety operations, and manufacturing - all with their own special task and environmental characteristics. Are we able to use agents for that, bearing in mind the amount of research to be done and the resources available? I don't think so. So why not use real humans in simulations? Simply bring in all intelligence at once by putting a "human-in-the-loop"! Virtual Reality (VR) is the term commonly used for immersing humans in a digital world by presenting a virtual environment on a head-mounted display (HMD) or on a flat or panoramic projection wall. For representing the human bodies moving in VR, avatars are used (figure 8). An avatar is a digital human model driven by an instrumented human who is immersed in a virtual environment.

As a member of the NATO HFM RTO Task Group "Virtual Environments for Intuitive Human-System Interaction" in recent years, I was in a position to explore the possibilities and potential

Figure 8. Instrumented human and his avatar displayed on the screen in the background (courtesy: US Naval Postgraduate School / The Moves Institute, Dr. Eric Bachmann).



of VR techniques. The use of VR for simulation, training, rehearsal, and after-action-review of military operations in urban terrain particularly drew my attention, not in the last place because the techniques could also be used for design evaluations. It will not surprise you that VR has its own research questions. I will present a number of studies that address the issue of how well humans are able to manoeuvre in a virtual world as compared to a real world. Before going to the first study, one should know that numerous techniques have been developed and tried in the past to move virtually into wider spaces while actually staying on the same spot. A clear advantage of such techniques would be that simulations could be done in existing laboratories of limited size. Unguder (2001) distinguished mechanical locomotion devices and sensor-based controls. He described three generations of locomotion devices, all developed for the United States Army Dismounted Infantry Training Program. These devices will now be presented briefly, together with their problems in terms of human factor issues according to a usability study by Unguder's thesis supervisor Dr. Rudolph Darken (US Naval Postgraduate School / The Moves Institute).

- *Uniport*, one of the first devices built for lower body locomotion. The user is sitting on a stabilised unicycle. The user moves forward and backward by pedalling. The direction of motion, controlled by the seat, is uncomfortable and awkward to control. Small motions and manoeuvrings, such as sidestepping, are almost impossible to perform.
- *Treadport*, a standard treadmill with a mechanical attachment

to the user's waist. The attachment gives feedback to the system and provides force-feedback to the user. It allows users to walk instead of pedalling. However, it does not solve all of the problems associated with the Uniport. The users turn their waists to specify the direction of movement. Physical movement is constrained to one direction and fine movements are awkward if they are not in the direction of the treadmill.

- *Omni-directional treadmill,* consisting of two perpendicular belts, one inside the other. A harness prevents the user from falling. A tracking arm is used to locate the user's position and orientation relative to the platform. When the user moves off the centre, servomotors attempt to drive the user back. Although this treadmill seems the most elegant solution to the problem as far as mechanical locomotion devices are concerned, a number of problems remain. The biggest problems are the manoeuvring and small movement tasks. Whenever users try to manoeuvre, such as turning in place or sidestepping, the treadmill drives them to the centre. Even if there is no motion with a manoeuvring task, the treadmill responds to the user as if there is a motion, consequently causing the users to stumble or lose their balance. Another problem is latency: when the user tries to accelerate and change direction rapidly, there is very little time for the treadmill to respond. If the treadmill cannot keep up with the pace of the user's movements, a misalignment occurs and the users loose their balance. For more detailed information, refer to Darken et al. (1997).

Unguder (2001) concludes that the mechanical locomotion devices are not good enough to provide realistic movements and manoeuvring capabilities for their users. The other techniques mentioned for moving in virtual environments either use hand-held controls or sensors attached to the user's body at, for example, their head, hands, or feet. These are used to steer and set the speed of motion through a virtual environment (VE). Cohn et al. (2004) of the US Naval Research Laboratory and the University of North Carolina, tested two techniques: a joystick (VE-JS) and walking-in-place (VE-WIP), both while wearing a stereo 47° horizontal FOV HMD. In the latter technique, the subject "walks" while staying on the same spot. A 6-dof accelerometer on top of the subject's head was used to move through the virtual environment - a modified version Templeman et al.'s (1999) walking-in-place, using various sensors on the lower extremities. Besides the two controls, three other conditions were tested: real walking in the virtual environment, wearing a stereo 47° horizontal FOV HMD (VE-WALK), walking in a real environment with natural vision (REAL-WALK) and walking in a real environment with restricted, 47° horizontal, field of vision (REAL-WALK-RESTR.FOV). Subjects were asked to walk through various rooms, stopping as close as possible to various objects placed on the wall (first subtask) or when they perceived themselves to have broken the plane of a doorway (second subtask) (figure 9). The real world condition was mapped one-to-one to the virtual one. A degraded performance, i.e. reduced accuracy, was found in both subtasks for the joystick and walking-in-place controls when compared to walking in a virtual environment (figure 10). Accuracy while walking in a virtual environment compared to walking in a real environment is particularly affected when having to stop in doorways.

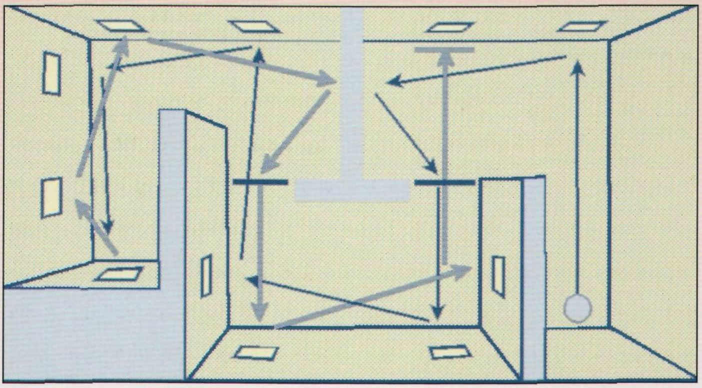
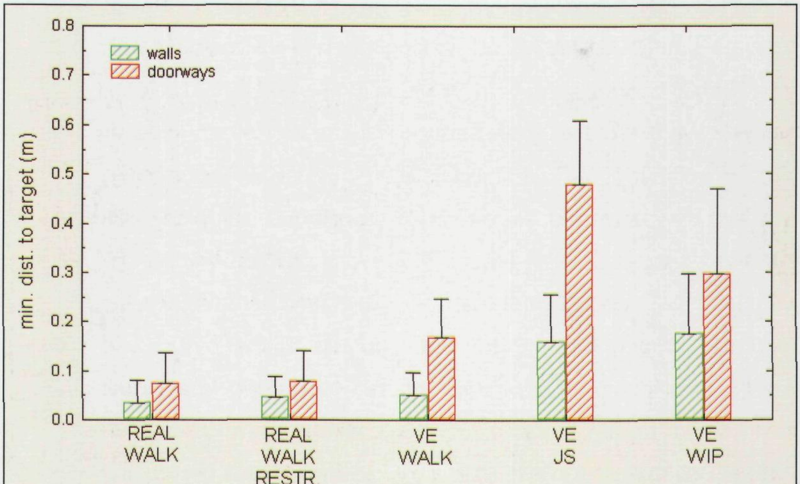


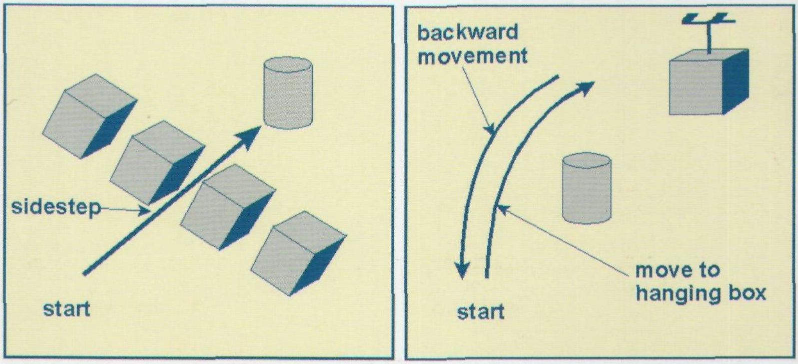
Figure 9. Experimental set-up and walking path used by Cohn et al. (2004).

Figure 10. Minimum distance to target at walls and doorways for the five conditions tested by Cohn et al. (2004). Average group scores with 1 standard deviation are shown.



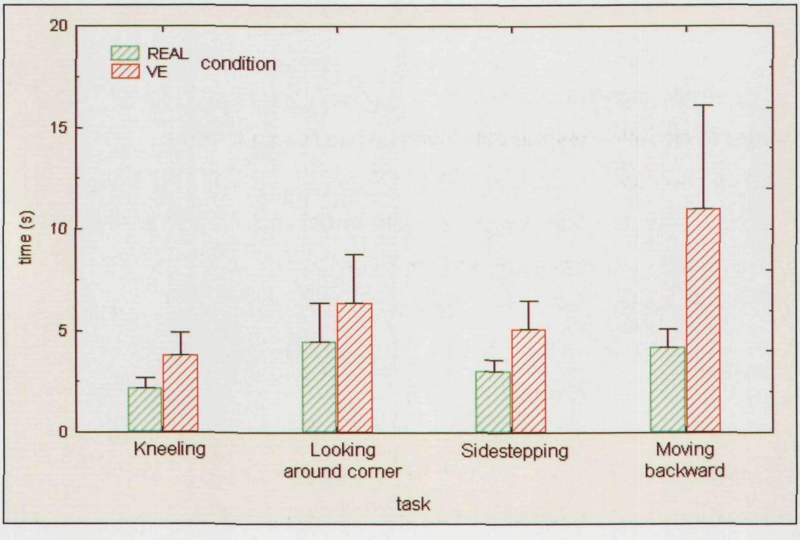
Unguder (2001) tested the other key task performance characteristic, which is speed. The time to complete each of four different tasks was measured from a starting point in a room. These were, first, a "kneeling" task, where test subjects were asked to read letters written on the bottom faces of cube-shaped objects hanging elsewhere in the room; second, a "looking around a corner" task, where the subjects were asked to identify letters on boxes while minimising their visual exposure to others at the other side of a wall; third, a "sidestepping" task where the subjects were asked to move through a narrow path between cube-shaped objects on the floor (figure 11, left) and, finally, a "moving backward" task where the subjects were asked to move to a box hanging in the room and back again while keeping their eyes on the box while having to go around an object (chair) on their path (figure 11, right). The tasks were performed in a real environment (REAL) as well as in a one-to-one copy virtual environment while wearing a

Figure 11. Two of the tasks tested by Unguder (2001): sidestepping (left) and moving backward (right).



non-stereo 45° horizontal FOV HMD (VE). Generally, the subjects moved more slowly and more carefully in the virtual environment (smaller steps, paying more attention) (figure 12). The way subjects manoeuvred in this condition was also different (moving closer to the cube-shaped objects when kneeling, higher visual exposure to others when looking around the corner), especially in the sidestepping and moving backward tasks, where there were many collisions with the virtual objects. This can be explained by the limited field of view of the HMD and the lack of an avatar. Also, the weight of the HMD and cables and the lack of stereoscopy hindered manoeuvring ability.

Figure 12. Time needed for completing each of four tasks tested by Unguder (2001). Average group scores with 1 standard deviation are shown. Two conditions are distinguished: real environment (REAL) and virtual environment (VE).



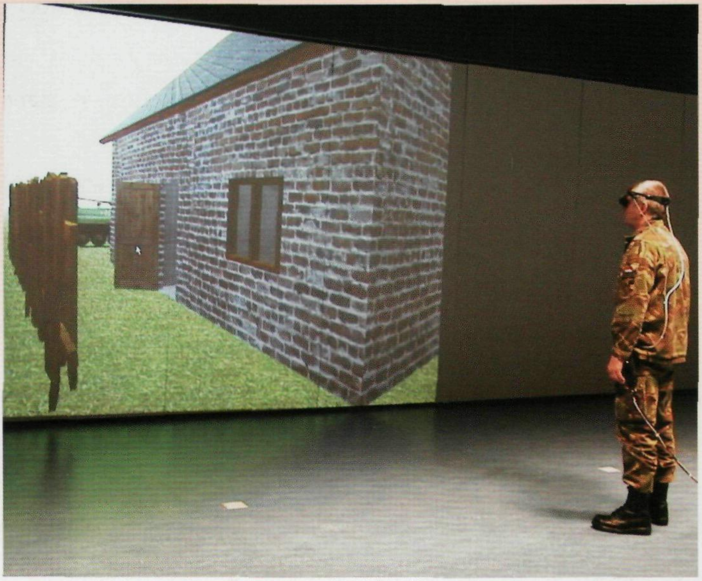


Figure 13. Virtual environment for studying military team operations and manoeuvring in urban terrain.

At TNO Human Factors, full body avatar technology was introduced for the study of military team operations and manoeuvring in urban terrain (figure 13). To get a feel of the matter, in a first experiment by Erik den Dekker and Koen Tan the test subjects had to walk between the ends of two parallel walls on their left, while avoiding the end of another wall on their right. They then had to retrace their steps, walking backwards (figure 14). The edges of the three walls were positioned on a straight line, with mutual distances of 0.6 m, 0.8 m or 1.0 m. Four conditions were compared: a real environment (REAL), a real environment with a 30° horizontal field of view (REAL-FOV30), a virtual environment with

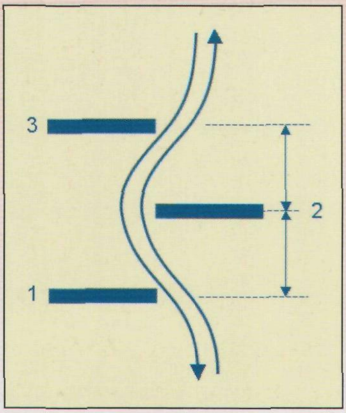
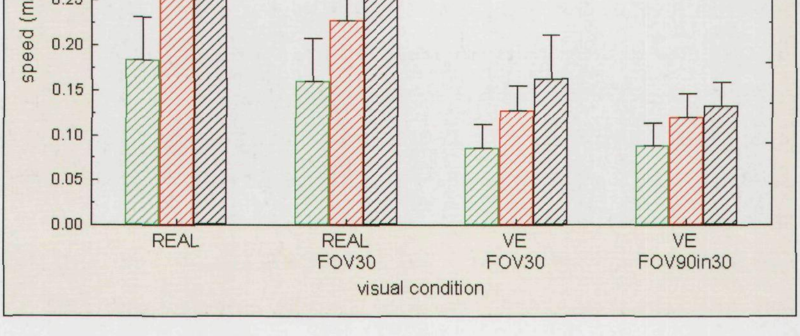


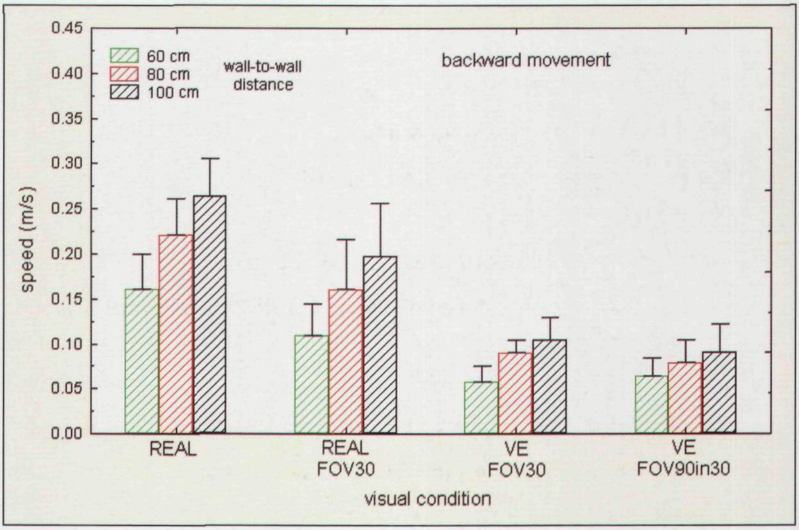
Figure 14. Top view of the experimental set-up for testing the speed and accuracy of passing by three parallel walls, forwards and backwards.

Figure 15. Speed between the first wall and the third wall, while moving forwards (below) and backwards (next page). Average group scores with 1 standard deviation are shown. Three wall-to-wall distances are distinguished: 0.6 m, 0.8 m and 1.0 m. REAL = real environment; VE = virtual environment; FOV30 = 30° horizontal field of view; FOV90in30 = 90° view compressed into 30° FOV HMD.



a non-stereo 30° horizontal FOV HMD (VE-FOV30) and a virtual environment with a 90° view compressed into the 30° FOV HMD (VE-FOV90in30). Speed between the first wall and the third wall was calculated (either 1.2, 1.6, or 2.0 m divided by the time between these two walls measured), as well as accuracy (i.e., the distance of a lower spine sensor to the edge of the second wall, when passing by this wall). Performance was lower in VE-FOV30 than in REAL (figures 15 and 16). Speed when moving forwards and backwards was about equally affected. Accuracy was more affected when moving backwards than when moving forwards. A considerable part of the performance degradation seems to be caused by the limited field of view, as can be seen when comparing REAL-FOV30 with REAL. Clearly, compressing a 90° view into the 30° FOV HMD (VE-FOV90in30) did not improve the average

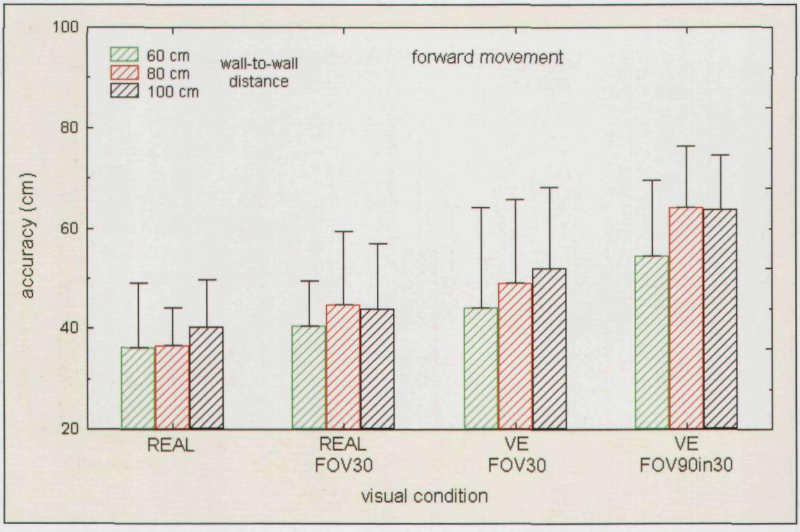
Figure 15. (Continued; see previous page).



group performance with respect to VE-FOV30. However, some subjects benefited from the enlarged field of view as it made it easier for them to see where they were putting their feet.

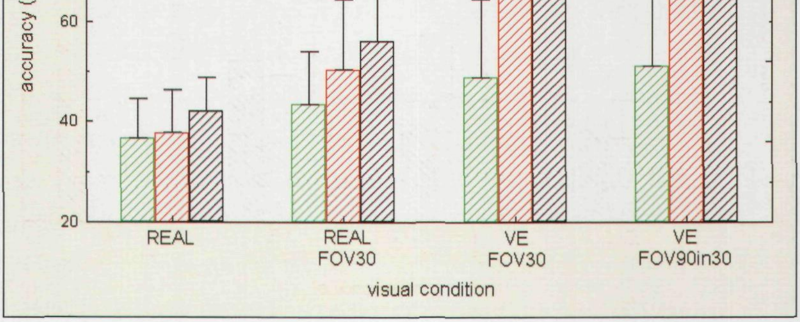
The three studies described give us some insight into what to expect from immersive VR. Further studies will have to look at ways of getting task performance closer to reality. HMD field of view and depth information will have to be dealt with, as well as the risk of motion sickness (Bles and Wertheim 2001). Exactly how close performance in a virtual environment should come to per-

Figure 16. Accuracy, defined as the distance of a lower spine sensor to the edge of the second wall when passing by this wall forward (below) and backward (next page). Average group scores with 1 standard deviation are shown. Three wall-to-wall distances are distinguished: 0.6 m, 0.8 m and 1.0 m. REAL = real environment; VE = virtual environment; FOV30 = 30° horizontal field of view; FOV90in30 = 90° view compressed into 30° FOV HMD.



formance in reality with respect to speed and accuracy depends on the application. For testing operational procedures, for instance, a qualitative evaluation may very well be done with current VR techniques. Whether and when more demanding applications can be dealt with will depend on enabling technology becoming available. An interesting development is real-time tracking of 3D body segment posture and movement through inertial sensors, also known as "sourceless" sensors (acceleration, rate-of-turn/gyro and earth magnetic field data). This dispenses with the need for a "link" between the body and fixed stations in the surroundings, thereby eliminating interference, noise and occlusion, enlarging the area of operation and possibly improving update rate and accuracy. Your own avatar and the virtual environment could be visualized on your HMD by a processor carried in a ruck-

Figure 15. (Continued; see previous page).



sack. Position data for a single reference point on the body is needed to place the avatar correctly within the virtual environment. For that, a relatively simple tracking system (optical, RF, etc.) seems sufficient. Various organizations around the world are working on sourceless sensors, including the Naval Postgraduate School / The Moves Institute, Monterrey CA, USA, CEA Laboratoire d'Electronique de Technologie de l'Information, Grenoble, France and Xsens Motion Technologies, Enschede, the Netherlands.

Research program

The special chair of Simulation-Based Design Ergonomics includes teaching and research tasks. Here I will discuss the research program, divided into three topics:

1. Digital human modelling

Laboratoire d'Anthropologie Appliquée (Laboratory of Applied Anthropology, LAA) has a long tradition in digital human modelling for design purposes, mainly in the area of traffic and transport (vehicles, control rooms, workstations), supervised by Professor emeritus Alex Coblentz and Professor Régis Mollard. The model ERGOMAN and the database ERGODATA have been used successfully for simulations on design options in many applications. The focus of the research program will be on studying dynamic motor behaviour; that is, describing and explaining the observed strategies. Judging from the need for this insight from practical and scientific viewpoints, the greatest need is for research involving confined spaces. I will come back to this in the next topic. With regard to wider space and team operations (two or more people interacting), the focus will be on avatar-related research and development, aiming to bring simulations in virtual environments closer to reality, particularly where these concern task performance. A first joint activity of LAA and TNO Human Factors will take place in a European project aimed at implementing VR-techniques for safety operations in industry - risk assessment, training and incident/accident investigation - to be applied in all phases of the lifecycle of plants, from design to dismantling. Hopefully, the use of avatars instead of agents will serve to bring people other than designers - particularly future users - into the design process. It resembles replacing traffic lights by a roundabout in that it involves changing from a pre-programmed process to less orchestrated co-operation. As a final point on this topic of the research program, I intend to encourage the relatively small VR and digital human modelling societies to make presentations in the larger community of the International Ergonomics Association (IEA).

2. Confined spaces

Looking at the confined spaces in military vehicles (refer to the example given early in this presentation), there no doubt that research is needed to optimise task performance (speed, accuracy) and physical fitness/comfort through design (space dimensions, seat characteristics, position and orientation of visual targets and controls) and/or through work organisation (durations, breaks, etc.). Insight into motor behaviour is important if we are to understand the effect of design on task performance and physical fitness/comfort. In future cars, an increase in space might be expected if the so-called AUTOnomy by General Motors, presented at the Paris 2002 motor show, is anything to go by. The six inch thick "skateboard" chassis accommodates the (fuel cell) propulsion and control systems. This allows the driver and passengers more space as there is no engine, transmission, driveshaft, pedals or steering column. The body of the car can be virtually anything from a sports coupe to a pickup truck. A central docking port on the top surface of the chassis connects all the controls by wire. The driver merely has a steering guide that is easily set to a left, right or even centre driving position. Will all cars be like this? It does not seem that way, to judge from confined space cars like the well known SMART and Toyota's PM (Personal Mobility) - a car of the future presented at the Tokyo 2003 motor show. Confined spaces are found elsewhere as well, notably in industry (maintenance, manufacturing) and in other modes of transport such as aircraft. In the latter, the importance of research and solutions is increasing, especially for comfort- and health-related issues on ultra-long-haul flights (four months ago Singapore Airlines flew with an Airbus A340-500 non-stop in 18 hours and 18 minutes from Singapore to New York), and performance issues such as reduction of ingress/egress times. In the research program, generic human motor behaviour will be studied by means of an experimental workstation such as the one shown before (figure 6). It will be interesting to see whether the control parameters determined in the research I have already mentioned (refer to the section 'Agents'), will hold in confined spaces. Possibly others, such as task performance parameters (speed, accuracy), will appear. For studying the effect of space dimensions and duration aspects on task performance and physical fitness/comfort, an experimental workstation will be used that allows for closing in a test subject to a certain extent by means of metal plates in front of the knees and at both sides of the upper body at hip/upper leg and shoulder heights (figure 17). The amount of confinement directly affects the opportunity for posture variation. I expect that experimentally-determined effects of possibilities for posture variation, expressed in terms of dimensions, will be easy for designers to use. Recently, Paris 5 DESS (Diplôme d'Etudes Supérieures Spécialisées) Ergonomics students Véronique Colaciuri and Emeric Wiederkehr finished their study on the effects of various levels of confinement of the lower extremities.

3. Body-mounted equipment

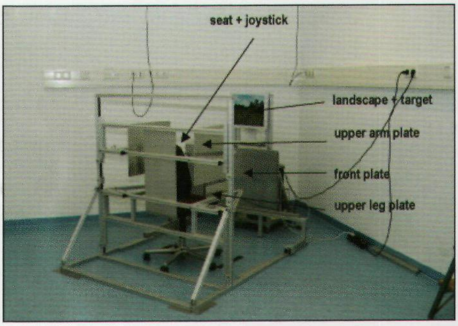
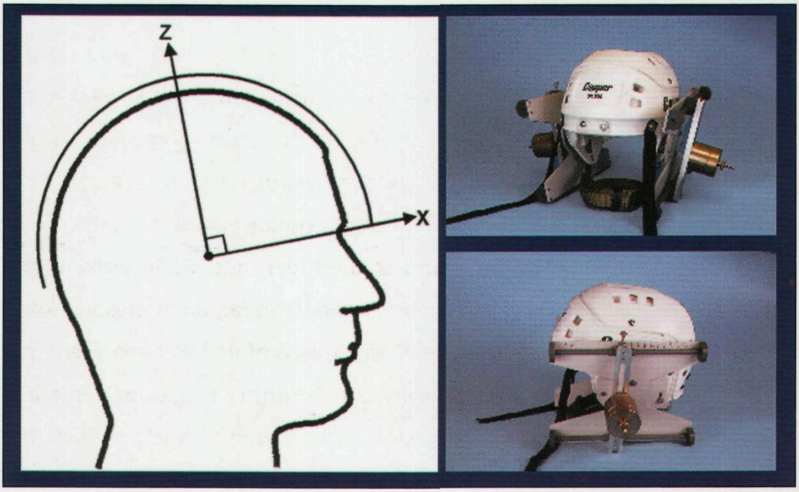


Figure 17. Experimental workstation for studying the effects of space dimensions and duration aspects on task performance and physical fitness/comfort.

LAA, in co-operation with Professor Pierre-Yves Hennion (Université Pierre et Marie Curie – Paris 6), has focused on studies involving head-mounted equipment, such as optimisation of respiratory masks to face shapes and addressing biomechanical research questions related to neck load and body balance. The focus of the research program will be on studying the most comfortable position for the headgear's centre of mass. The positions are described in relevant design terms, i.e., in a head-fixed co-ordinate system based on skull geometry (between glabella and inion) and eye position. This is based on the fact that these are essential to all headgear and anticipates the growing use of 3D scan data in headgear design (figure 18, left). Paris 5 DESS Ergonomics students Bénédicte Carrel Billiard and Hélène Billet studied the effects of various masses on the most comfortable position and applied the results, together with Claudy Koerhuis, M.Sc. (TNO Human Factors) to a helicopter pilot helmet with night vision goggles (Delleman et al. 2004). For studying the effect of mass on the most comfortable position, an ice hockey helmet with discs at each side was used (figure 18, right). The discs could be moved up and down as well as forwards and backwards. The test subjects were asked to find the most comfortable position while standing upright looking straight ahead and at their feet, and while walking and going around an obstacle on the floor. So far, an interesting interplay of mass and balance effects on comfort has been seen. The experimental helmet will be used for further studies with the aim of eventually building a mathematical model which predicts the most comfortable position of headgear centre of mass, based on factors such as head circumference, mass, head posture and movement and exposure duration. The neck load sensations as determined with this psychophysical research approach and the load predictions by a biomechanical neck model (for instance MADYMO) will be used for simulations on the effects of design options, as well as for studying the relationship between neck load and neck disorders. A transfer of the research approach to trunk-mounted equipment and the study of task performance issues are foreseen.

Research is a joint effort of various academic and company groups operating in the field of simulation-based design ergonomics. Besides the research groups and researchers already mentioned, I would like to acknowledge the work done at the University of

Figure 18. Head-fixed co-ordinate system based on skull geometry (between glabella and inion) and eye position (left) and experimental equipment for studying the most comfortable position of headgear centre of mass (right).



Michigan (Professor Don Chaffin, Dr. Matt Reed), the Technical University of Munich (Professor Heiner Bubb), the Chalmers University of Technology (Professor Roland Örtengren), the University of Iowa (Professor Karim Abdel-Malek) and the National Tsing Hua University (Professor Mao-Jiun Wang). Within TNO the research on seating (figure 1, physical interfacing / vibrations) by Aernout Oudenhuijzen, M.Sc. (TNO Human Factors), and Dr. Murielle Verver (TNO Automotive) is acknowledged. In the research program to be carried out co-operation with the research groups and researchers mentioned will be continued. Furthermore, the aim is to work in a closer co-operation with the Delft University of Technology and the Vrije Universiteit Amsterdam.

Acknowledgements and a concluding remark

Coming towards the end of this presentation, I would like to thank several people in particular.

First of all, the president of René Descartes – Paris 5 University and the director of TNO Human Factors for making a co-operation framework agreement, thereby laying a good foundation for the special chair of Simulation-Based Design Ergonomics established by the university. I will do my best to live up to the trust you have placed in me.

Professor Régis Mollard, director of UPRES Ergonomie and LAA, and Professor Daniel Jore, director of UFR Biomédicale des Saints-Pères, for their efforts to create the special chair and for the warm reception I received. I am very much looking forward to working with you and my new French colleagues.

Dr. Wouter Lotens, for asking me to work at TNO Human Factors, giving me the opportunity to build on simulation-based design ergonomics and for contributing to bringing about the co-operation framework agreement.

Professor emeritus Rients Rozendal, Vrije Universiteit Amsterdam, for supporting me during my first steps in the field of ergonomics and for supervising my Ph.D. thesis. Professor emeritus Toon Huson, Leiden University, for giving me my first job. Professor emeritus Hans Dirken, Delft University of Technology, for supervising my Ph.D. thesis. Professor Jan Dul, Erasmus University Rotterdam, formerly at TNO, for his continuous support during my professional career and for his inspiring views. One needs to stand on the shoulders of others to be able to see further ahead.

My colleagues in the first ten years at TNO, who now work at TNO Work and Employment in the teams of Professor Peter Vink and Professor Paulien Bongers, as well my colleagues at TNO Human Factors, where I work today; in particular the Department of Performance & Comfort, headed by Professor Hein Daanen. Nothing happens without colleagues.

My parents, my brother and sisters and my in-laws. I know that you are proud, which is a great support.

Annebep, Thomas, and Lauren. You are wonderful and deserve much more of my time.

Thank you all for coming. Many came a long way. I am sure you will enjoy this magnificent city as well.

My concluding remark can be put very simply: simulation-based design ergonomics has a short past and a great future as a means for reducing time-to-market, time-to-operation and costs for proper design.

J'ai exposé.

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