Towards a Visual Representation of the Effects of Reduced Muscle Strength in Older Adults: New Insights and Applications for Design and Healthcare

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Abstract. This paper details the evaluation of human modelling software, which provides visual access to dynamic biomechanical data on older adult mobility to a new audience of professionals and lay people without training in biomechanics. An overview of the process of creating the visualisation software is provided, including a discussion of the benefits over existing approaches. The qualitative evaluation method, which included a series of interviews and focus groups held with older adults, and healthcare and design professionals, is discussed together with key findings. The findings are illustrated with examples of new dialogues about specific mobility issues impacting on healthcare and design planning which were facilitated by the data visualisations.

Keywords: Virtual human software, data visualization, older adult mobility.

1 Introduction

Biomechanics is the scientific study of the human in motion, examining the causes and consequences of different movements. It fuses an understanding of the mechanics of motion with the structural and functional anatomy of the musculoskeletal and neurological systems of the body, enabling a scientific analysis of the causes of movement problems to be undertaken and solutions for these problems proposed and tested for efficacy. However, the scientific data produced is complex and the biomechanics community have to date been unable to effectively communicate the results of biomechanical analysis to non-biomechanists, i.e. clinicians, practitioners and lay people.

For many older adults certain routine tasks associated with activities of daily living (ADL) are difficult or painful to perform. Whereas biomechanists may have good insight into the causes of mobility problems (e.g. by studying the stresses on older people's joints and muscles and how these change during tasks), the biomechanical data and analysis on which this knowledge depends is difficult to comprehend by the range of other disciplines involved in the care and rehabilitation of older people, such as physiotherapists, OTs, and orthopaedists, and also by designers of the built environment. Consequently, this may limit optimum rehabilitation, healthcare planning or design for older people.

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2 Background

2.1 Data Capture and Difficulties in Communication

New dynamic biomechanical data were captured from 84 older adults in the 60+, 70+ and 80+ year-old categories undertaking ADL, using a motion capture camera system, maximum strength measurements, and reaction force data measured using floor mounted measurement platforms [1]. The focus of the study was on collecting lower limb data, as risk of falls was identified as a major risk in everyday mobility tasks.

A biomechanist would typically present the results of analysis by plotting 2D graphs of e.g. changes in the joint moments over time (Fig. 1). The comparison between different joints or different rotation directions in a limb would be achieved by overlaying of graphs or viewing them side by side. Analysis and interpretation of this form of data requires skill and training in biomechanics, making it unsuitable for communication to other professional disciplines or lay persons.

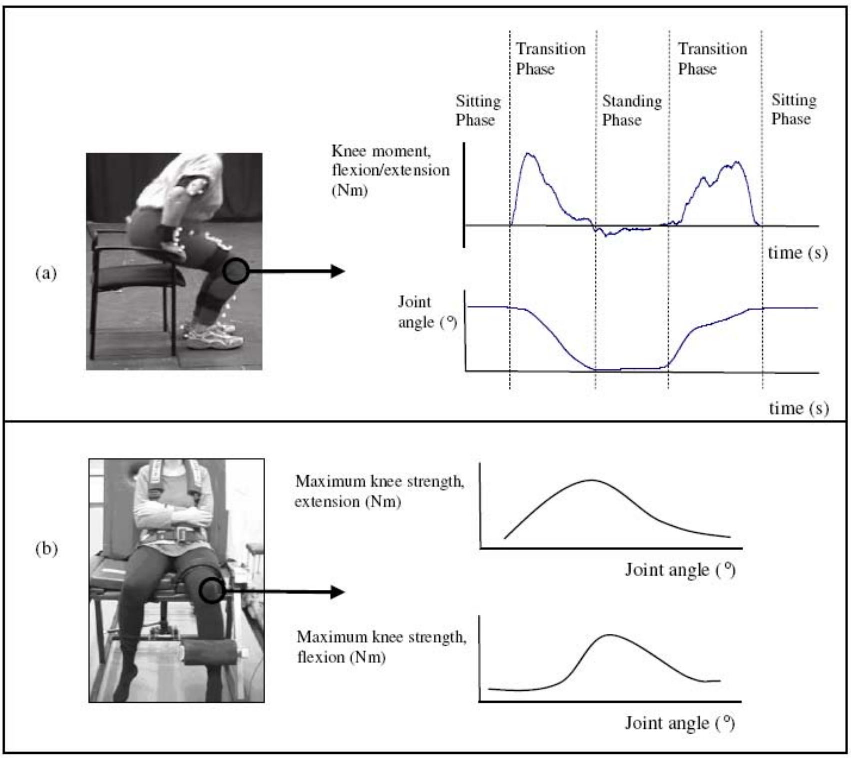

Fig. 1. 2D plots of selected biomechanical data for the sit-stand activity for a single joint in only one rotation direction. (a) Changes in the left knee joint moment[i] in flexion/extension[ii] during the sit-stand activity. (b) Variation in maximum strength for the left knee joint compared with the angle of the joint. Two graphs are needed as different muscle groups are in use in flexion and in extension, producing different maximum values.

In addition, this format of analysis makes it difficult to accurately assess how demanding the tasks were for the older adult participants. This is particularly significant for older adults as peak values of the moments are more likely to be close to their maximum capability, creating instability at the joint. The maximum strength which can be provided at a joint is not constant but rather varies with factors such as joint angle and angular velocity. In order to truly assess the percentage of their maximum capacity which the older person is using would require the cross-referencing of several graphs (Fig. 1). This manner of presentation of data is static and is not viewed in its dynamic or relative context. This makes the sequencing of the movement in e.g. both hips and knees particularly difficult, or impossible, to fully comprehend, even by biomechanists. It is here that a dynamic and contextual mode of presentation, and the knowledge and expertise of the other disciplines would be invaluable.

2.2 Visualisation Method

A software tool was developed, which generates a 3D animated human 'stick figure', on which the biomechanical demands of the ADLs are represented visually at the joints (represented as a percentage of maximum capability, using a continuous colour gradient from green at 0%, amber at 50%, through to red at 100%).

The approach taken to visualising data was to minimise the viewer's exposure to the complexity of the original data and the underlying calculations. Although the generation of the visualisation required the knowledge of the biomechanical moments, direction of forces and joint angles to calculate, the end result was expressed as a percentage value. The meaning of 'functional demand' i.e. how hard the muscles are working relative to their maximum capability, was therefore not conceptually difficult to understand. The hypothesis was that this mode of visualisation could enable complex data to be simplified without losing the validity of the original dataset.

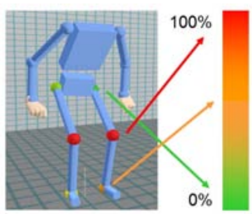

Fig. 2. Colour coding of the biomechanical demands of activities

The advantages of this form of visualisation are immediately apparent in the animation stills (Fig. 3) where one can see the relationship between the motion and the dynamically changing 'stress' on the joints. With this mode of presentation of data one can easily compare different joints simultaneously (in contrast to Fig. 1), in context, and make immediate visual comparisons e.g. between different individuals doing the same activity or between an individual doing the same activity in different ways. This is not achievable using current modes of presentation of biomechanics data.

(a)

(b)

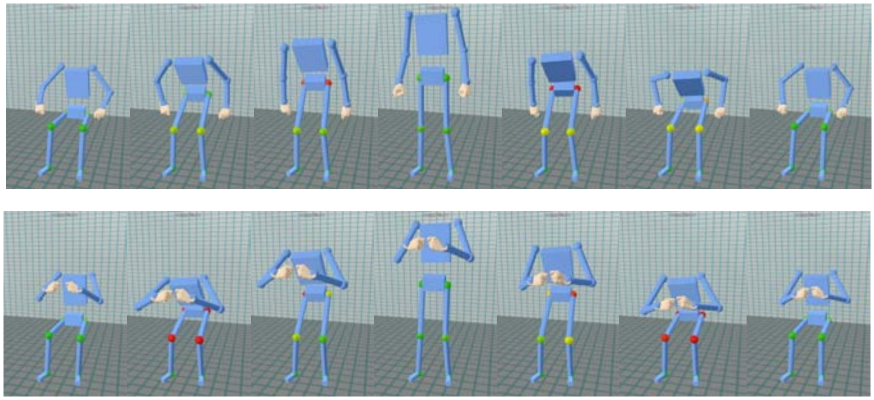

Fig. 3. Stills from animations: comparison of a 67 year old male with a history of back problems and of fractures rising from a chair in two different ways (a) using arm rests (b) without using arm rests

In Fig. 3 it can be seen that the arm rests provide the individual with a significant mechanical advantage, sharing the loading between the arms and the legs. When the participant was asked to perform the activity without using the arm rests the demands on the lower limb joints are close to their maximum capacity (indicated by 'red' in the second still from the left, Fig. 3b). It can also be seen that even with the use of the arm rests, close to the end of rising from the chair and on the beginning of the sitting movement the demands are high at the hip joints (indicated by 'red' third frame from the left, Fig. 3a). This indicates that any further deterioration in strength at the hip joints may cause problems for this individual, and may cause risk of falls on rising from chairs.

An additional advantage of this visualisation technique is an ability to view animations from any angle or distance (Fig. 4) providing the opportunity to examine specific details of the data in contrast to the fixed viewpoint of existing video camera techniques.

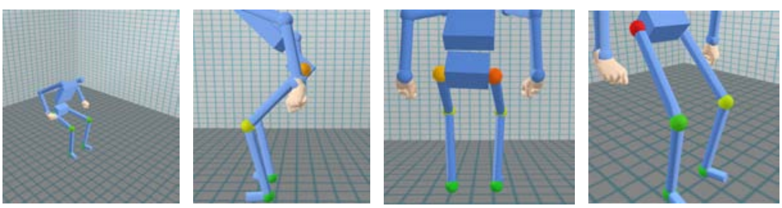

Fig. 4. Changing the point of view of the visualisation

3 Evaluation Methodology

The tool was evaluated through a qualitative methodology using interviews and focus groups. Interviews were held individually with older adults (N=18), and healthcare and design professionals (N=15). The older adult participants were recruited to match as closely as possible the cohort of individuals from whom the original data for the visualisations were obtained (i.e. both genders, distributed across the 60+, 70+ and 80+ year old age groups, with corresponding reported health-related conditions). The selected range of professions comprised clinical medicine, physiotherapy, occupational therapy, bioengineering, disability consultancy, engineering design, and interior design. The key themes explored in the interviews were: i) issues and concerns regarding the effect of ageing on mobility; and ii) any communication problems encountered between professionals and older people when discussing mobility. These informed and provided the context for the focus groups.

(a)

(b)

(c)

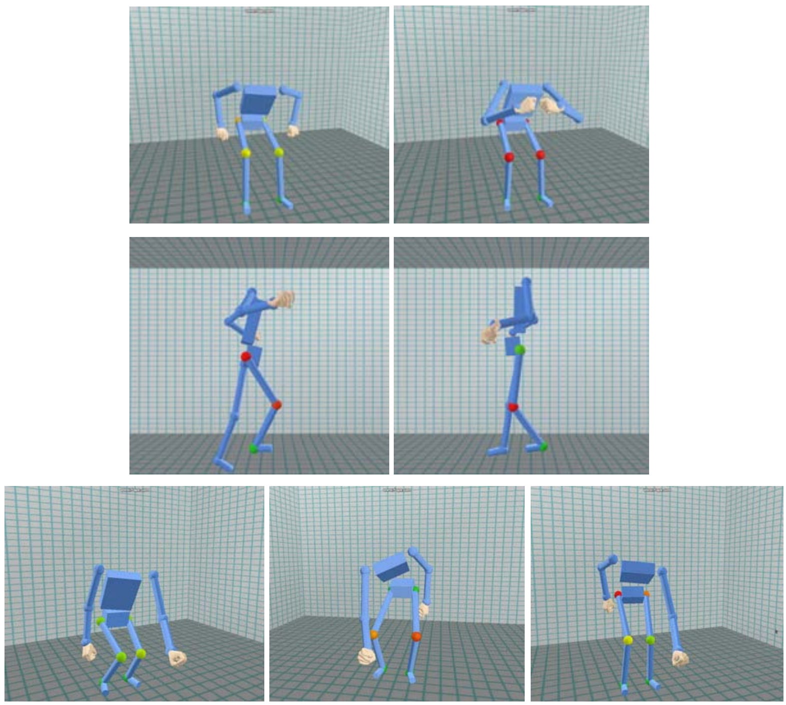

Fig. 5. Videos shown in focus groups: (a) comparison of an individual performing sit-stand activity with (left) and without (right) use of armrests; (b) comparison of an individual going up (left) and down (right) stairs; (c) comparison of three different individuals lifting an object from a high to a low shelf: (left) 74 year old female with no apparent problems – note knees and hips are shown green; (middle) 81 year old male, osteoarthritis of knees – note red and orange indicated at the knees; and (right) 67 year old male, history of back problems and history of fractures – note red and orange at hips.

Three focus groups (FG) were held to evaluate responses to the dynamic visualisations: FG1 comprising older adults; FG2 with a range of healthcare and design professionals; and FG3 with a mixture of older adults and professionals. The participants for the FGs were drawn from the group of individuals interviewed in the previous stage, and consisted of older adults (N=8) and a mix of healthcare and design professionals (N=8). In FG1 and FG2, the participants were shown a sequence of animations, without explanation prior to a facilitated semi-structured discussion to explore in detail: i) their initial responses, understanding and interpretation of the visualisations; ii) the insights they provided; iii) potential applications; and iv) how the prototype might be improved. In FG3, the mixed group discussed the outcomes from FG1 and FG2 in more depth, and compared the professionals' responses with those of the older adults. Each FG was videoed for later analysis, and participants asked to complete questionnaires to capture additional responses.

It was clearly not desirable to present too large a range of animations within the short time limits of the FGs (over 900 animations were available: 84 individuals each with 11 different activities). The researchers decided therefore to limit the animations to a selection of those most effective at showing the variation of joint colour in relation to lower limb movements. The animations were selected to i) show an individual doing the same activity in two different ways (Fig 5 (a), Fig 5 (b)) and ii) the comparison of different individuals doing the same activity (Fig 5 (c)). To ensure consistency between the animations shown at FG1 and FG2, videos of the visualisations were taken using screen capture software.

4 Enabling New Dialogues

From analysis of the discussions in the three focus groups, it is clear that new kinds of dialogues about biomechanical issues have emerged, facilitated by the tool. The most obvious and significant outcome is that these dialogues involved non-biomechanists, including those who would normally be regarded solely as the subjects in this area of research, i.e. older adults. The method of visualising and presenting the data clearly enabled people without training in biomechanics, both professionals and lay older people, to access and interpret the information. Each of the participants could interpret different details in - or offer different perspectives on - the visualisations, based on their background, experience or field of knowledge. Further, the common visual medium enabled the sharing of these different insights, without recourse to specialist terminology or knowledge.

In this section, three examples of dialogues are provided to illustrate the nature of the discussions and the issues and insights they developed. In the extracts, the following coding is used: (P=physiotherapist; PS=physiotherapy student; B=bioengineer; Dr=doctor; Des=designer; DE=design engineer; DC=disability consultant; and OP=older participant).

4.1 Dialogues 1a and 1b: Detailed Analysis Generating New Insights

The visualisations of three different individuals lifting an object from a high to a low shelf (Figure 5) provoked discussion about the causes of 'stress' on joints and how the problems might be alleviated. The following two dialogues from FG2 provide examples of detailed analysis between professionals from disparate disciplines e.g. designers and physiotherapists - a dialogue about real data which would not have been possible with conventional presentation formats of biomechanical data.

1a *(analysis)* DE: One's moving a lot quicker than the other one. Me as a boy, me as I am now. Des: The person on the right looks less agile. DE: They're bending in a very different motion. P: The left one's going down much further. The actual

height drop is considerably more on the left, and the leg pattern's symmetrical on the left and asymmetrical on the right. B: The left figure appears to be better balanced in comparison to the right. P: I think the person on the right has to use a lot more trunk rotation in order to achieve what they're trying to achieve.
(insight) DE: He's having to turn in a different way. I guess the assumption is that he's got an imbalance somewhere in his joints, so he's got to do things differently if he's reaching with his left hand from the way he'd do them if he were reaching with his right hand. Which means one size doesn't fit all…one solution's not going to work for everybody. Or maybe not for the same person in two different positions.

1b *(analysis)* DC: High stress levels appear to be at the hips and the right knee. DE: Interestingly it's in the right knee as he stands up, as he straightens up again. B: It seems to fluctuate as well. P: In the right figure, there's almost no movement at the ankle at all. They're totally unable to use their ankles. They're having to compensate everywhere else.
(insights) Dr: You get the impression they're saving their ankles and knees, but causing more pain at their hips. P: Trunk rotation as well to be able to achieve a reach. Dr: So there might be pre-existing problems in the knees and the ankles that are now causing new problems in the hip.

4.2 Dialogues 2a and 2b: Same Situation, Different Perspectives

Returning to the discussion of the differences in the sit-stand activity with and without the use of arm rests (section 2.2, Fig. 3), the following two extracts illustrate the dialogues that emerged a) amongst older people in FG1 and b) between design and healthcare professionals in FG2. Although the same visualisations were shown, there were clear differences in emphasis and knowledge, yet all were equally valuable.

2a OP1: I've got two hip replacements and a knee replacement. So I was quite familiar with their movements. Right away I say, 'that's like me'. OP2: That's my knee… I see myself getting up and down from the chair. OP3: That is one of the exercises we do at the cardiac rehab, sit to stand, and it's just square stools you sit on. You can press on your knees like that [indicates the movement], and rock forward and up and down.

2b Des: I think it's just really evident immediately why you would…give someone arms on chairs, without having to have some person try it, and see for themselves that this doesn't work. P: It's a very clear indication of what's a normal movement pattern, and what's an abnormal movement pattern. And the compensations that you make when you have a problem, say a knee or a hip, and how you have to compensate, both in the speed of the movement and quality of the movement. And how you have to compensate elsewhere in the body to still achieve the same goal.
DC: I think the figure on the left hints at the cruciality of the height of the arms of the chair. DE: Thinking of the person on the right trying to stand up from a bus seat...with no arm rests by the way... is challenging, but I can't actually do anything about that because of the legal requirements.

4.3 Dialogues 3a and 3b: Older People Empowered to Share Experiences

Those usually regarded as the ‘clients’, in this case older people, made a significant contribution to the understanding of the issues provoked by the data being presented more clearly and visually, dynamically and contextually. The following examples demonstrate the quality of discussion generated from the older adults regarding the visualisations of an older adult going up and down stairs (Fig. 5b). This provoked a discussion about how important handrails on stairs are to the everyday experience of older people:

3a OP1: In one, it's his knee and his hip turned red, but in the other figure, there was only one, the knee turned red. Could it be … that it only affects them going up-stairs instead of down-stairs? OP2: Going up stairs it's essential to have a balustrade. You could not walk up stairs...well you can but with difficulty. OP3:…you don't always get a staircase with two banisters. Coming up from the train station today, the steps were wide, so you only had the one banister. OP4: I can also get down airplane steps backwards, which is much easier, provided there's a banister. In fact it's the only way I can do it, I can't do it any other way.

In FG3, the older adults were able to raise this issue with the professionals present, using the visualisations to back up their experience. The comments from the older participants had equal prominence in the discussion, and they were able to engage with professionals in examining the issues.

3b OP1: I think the important thing to get across is, just like this, how valuable the handrail is…and it gives people confidence to go up stairs. Without a handrail you say ‘oh god, am I going to get up here’. The handrail's very important. OP2: We spoke about going upstairs holding on to both [hand-rails]...but that's not possible if you're using a walking stick, you know, you've got to hold the walking stick in one hand, and just use one hand to go up.

5 Conclusions

Analysis of the discussions in the focus groups revealed new kinds of dialogues between older people and professionals about their experiences, based on real understanding of where the mobility problems are occurring. New dialogues also emerged between professionals from a range of different disciplines, crucial for different aspects of the care, wellbeing or design of the built environment for older people. Neither of these would have been possible using current conventions of presenting biomechanical data. The physiotherapist commented: “Many professionals find it difficult to talk in lay terms, and simple software like this would allow them to do that, and actually be understood.” and it was felt that the tool “clearly articulates for the health professional and the older person what is going on in the joints” and that it could provide a means to explain and encourage normal movement patterns “to limit, mitigate or overcome pain”.

Both clinical and design professionals indicated that the objectivity of the visualisation method would complement or improve on the current and prevalent use of subjective judgment, intuitive skill, and trial and error, thereby allowing more accurate diagnosis in a clinical setting on the one hand, and presenting a sound rationale for design approaches on the other.

All the perspectives represented in the focus groups, both lay and professional, are valuable, indeed essential to fully understand the mobility issues in older people with chronic enduring conditions brought about by age and/or illness. Up to this point in time there has not been the means for the key knowledge and insights of biomechanists to be shared in an understandable and meaningful way outside of their own profession. This mode of visualising and presenting biomechanical data has the potential to provide a significant new tool for: i) biomechanists, to easily communicate the concepts and principles of motion, and the physics and forces involved; ii) the wide range of other professionals whose decisions have profound consequences for healthcare planning, and design of e.g. furniture and the built environment; and last but not least, iii) for older people themselves, to enable them to enter a discussion about their everyday experiences and to be able to show exactly when and where something becomes painful, difficult, or affects their confidence in carrying out a particular ADL.

This research has verified the hypothesis that using this form of human modeling software to represent the complex data in this particular visual format communicates essential biomechanical information across traditional disciplinary boundaries, and provides a common basis for the discussion of what the data might mean to both the older adult and the healthcare or design professional. Freeing the discussion from the conventional presentation of biomechanical data, its numerical form and scientific language, provides the opportunity to open a new dialogue between stakeholders in older adult mobility, generate new insights, and offer improved healthcare and design planning.

Beyond this, the method has potential to be applied to a range of mobility conditions and rehabilitation challenges where the same generic issues pertain e.g. stroke, knee joint replacement, ankle foot orthoses, and falls prevention. Firstly, by providing a common platform for the full spectrum of knowledge specialisms to engage in the articulation and communication of biomechanical issues – knowledge which is currently disconnected and underexploited because of the lack of a common, accessible and understandable medium. Secondly, by empowering clients, whose personal experiences and insights remain largely unarticulated and isolated from specialists' discussions: if their own understanding about the impact of biomechanical issues on their recovery and rehabilitation could be enhanced, this could potentially improve their motivation and adherence to therapeutic interventions.

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Glossary

i biomechanical moments are the rotational forces at a joint generated by the action of external linear forces

ii flexion/extension refers to the straightening/bending of a limb around the joint.

Reference

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