Chapter 7
A Colour-Coded Analysis of Movement Dynamics Associated to Potentials of Motion-Based Commercial Games to Supplement Training of Patients Diagnosed with Fibromyalgia Syndrome

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Introduction

Fibromyalgia syndrome (FMS) is considered a condition that impacts one's sensing of their body that results in a long-term experience often reflected upon as a holistic wide-bodily form of pain that to an extent is as unexplainable as it is unspecific. Additionally, this condition, as a result of the pain, commonly affects patients' well-being by them also experiencing fatigue, limb stiffness, headaches, sleep deprivation, numbness, mood swings, impairment to cognitive performance, irritable bowel movements and other life-impacting states related to anxiety and depression. Both male and female can be affected; however, statistically, increased diagnosed reports are of the condition impacting females (Boissevain & McCain, 1991; Clauw, 1995; Henriksson et al., 1992; Olsen et al., 2013; Sørensen et al., 2019; Waylonis & Heck, 1992; Wolfe et al., 2010).

The research studies originated as a result of discussions between a specialist rheumatologist (who was also an adjunct professor at Aalborg University Esbjerg campus) and the authors who are both senior researchers exploring technologies for inclusive wellbeing and empowering behavioural approaches relating to play and creativity. A typical general advice from the specialist rheumatologist to his patients was for them to 'stay as physically active as possible'. This is in line with related literature stating that exercise therapy is an established treatment for fibromyalgia,

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E. Brooks, D. J. Brown (eds.), *Virtual Reality Games for Rehabilitation*, Virtual Reality Technologies for Health and Clinical Applications,
https://doi.org/10.1007/978-1-0716-3371-7_7

with efficacy studies in adults documenting significant improvements in patient's physical fitness, pain threshold and intensity and sleep (McCain et al., 1988; Busch et al., 2008a; Gowans et al., 1999, 2001; McCain, 1986).

In these two studies, as reported previously in this thread (Brooks & Petersson-Brooks, 2012; Mortensen et al., 2015), participants were patients diagnosed by their various doctors as having fibromyalgia syndrome (FMS). These patients had been subsequently assessed by the specialist rheumatologist at his local private treatment clinic who confirmed their condition and offered participation in the studies. As well as FMS, the clinic treated conditions such as rheumatoid arthritis and related other associated connective tissue diseases.

A posited initial hypothesis was on the potentials of such patients' self-training to exercise towards alleviating their movement pain(s) associated with FMS through gameplay. Inclusion conditions were women of age 18 or above diagnosed with FMS according to the commonly used American College of Rheumatology (ACR) criteria (1). Exclusion criteria were patients diagnosed with other diagnosed rheumatic diseases or conditions as determined by the specialist rheumatologist.

Both research studies were conducted in a large room with space for free and dynamic gameplay movements at the SensoramaLab – a human-centred behavioural laboratory complex exploring primarily virtual reality, interactivity, games, motivation and empowerment via adaptable interfaces and systems, alongside creative expression through motion performance. The SensoramaLab was situated at Aalborg University Esbjerg city campus on the west coast of Denmark.

The first intervention acted as a primary proof-of-concept and feasibility prestudy where three patients participated. Fifteen patients participated in the second study with seven completing sessions. The first study was where a single commercial game platform was used with interactive content responding to physical motion activities to substantiate a hypothesis on the potentials of patients' self-training to exercise.

Three game platforms were used in the second study. An outcome reflection relates to the history of the field whereby typical has been where a solitary game experience is used. This can lead to boredom and posited is how a narrative that consists of tasks/challenges along a journey or adventure may more fully engage a patient over a treatment period.

In both studies where the focus was on fibromyalgia, senior students conducted sessions with supervision led by the authors as senior researchers. A focus was on studying interactive gameplay content that responded to physical motion activities. The students who conducted the tests were considered competent at using the game controllers and the selected game platforms. They were also native Danish speakers, which enabled easier communication when interfacing with the participants.

In the established scenarios, the participants could select a preferred game aligned to how they believed it could best help their situation whilst stimulating motivation to play. The gameplay motion data was generated using selected devices that used either handheld or camera-based controllers. A primary goal was to motivate patients' compliance in their home-based exercise regime as a part of their activities in daily living (ADL). Results indicated positive potentials from the gameplaying, however, a negative was the high dropout/noncompliance from the original batch of proposed participants/patients.

Methodology

In the second study, a qualitative description approach was used supported by quantitative observation measures in the description of the primary outcome: participants' experience with the selected MCVGs. Quantitative measures were used in description of the secondary outcome consisting of indicators of pain and fatigue symptom severity and performance of ADL. All data were treated confidentially, and to assure anonymity, pseudonyms were used in all cases. As reported in (Mortensen et al., 2015), Test of Playfulness (ToP) was used as an observational tool for assessment of play experience. This tool considers aspects of (1) intrinsic motivation, (2) internal control, (3) suspensions of reality and (4) framing, with each aspect consisting of a number of items, e.g. actively engaged and acts self-direct, which separately have three subcategories: extent, intensity and skilfulness. The ToP tool is considered as reliable and valid in observation of both children and adults.

The Importance of Game Knowledge and Competence by Instructors

It was clear from the baseline that the participants had little or no experience of gameplay with such game platforms. Thus, the importance of the students' knowledge and capacity to instruct was of great importance to support and assist the experience towards a positive reflection.

In these studies the students' profiles were of (study 1) a single male Medialogy Msc student (Medialogy is an education based upon creativity and technology where typically projects are game-based with a focus upon human performance and gameplay) and (study 2) two Msc occupational therapy students.

Theoretical Method of Analysis Posited from Prior Research

In the authors' 2005 publication titled 'Play Therapy Utilizing the Sony EyeToy®' (Brooks & Petersson, 2005), two hospitals, one in Denmark and one in Sweden, collaborated where rehabilitation medical staff, doctors and play therapists supervised children patients playing the affordable, popular and commercially available Sony Playstation 2 EyeToy®. This was to investigate potentials of games utilising mirrored user embodiment in therapy.

The published work from this investigation is the first part of our resourced prior work that is built upon for this reflection on fibromyalgia method of analysis. In this prior work it states how aesthetic resonance (AR) was targeted in the study. Aesthetic resonance (AR) is when the response to intent is so immediate and aesthetically pleasing as to make one forget the physical movement (and often effort) involved in the conveying of the intention. This mind-body relation is posited as relating to the authors' approach to fibromyalgia alongside and integral to how an immersed 'play' mindset rather than a 'therapy' mindset is targeted which our prior research has shown as optimal. The set-up in this study utilised the same data used as control data to the interactive feedback content (gameplay) parallel to that used for monitoring simultaneous performance progress by the player/patient.

System set-up tailoring to each individual's preferences was adaptable towards optimising gameplay performance. In this prior paper (Brooks & Petersson, 2005), the often-used all-encompassing term of presence was challenged with a positing of aesthetic resonant state of the user being beyond 'a feeling of being there' as is typically interpreted in defining presence (Brooks, 2003).

In this prior work, systems such as the EyeToy®, that focus on the body as the interface, was posited as being an under resourced opportunity for therapists to include into training as, unlike traditional biofeedback systems, specific licensing is not required as there are no attachments to the patient. In the paper this was related to Flow (Csikszentmihalyi & Csikzentmihaly, 1990). We hypothesised in that study on how tools such as the EyeToy® have potentials to decrease the physical and cognitive load in a daily physical training regime, and this we stated as being central to our concept.

This thread continues by the first author's most recent research presentations on 'cognitive decoupling' associated to his SoundScapes concept as presented in five keynotes around the world in the fall/winter of 2021 (Brooks, 2021a, b, c, d, e). Herein, by bringing together the prior and recent research, we posit how cognitive decoupling can be achieved via digital gameplaying where body tracking interacting with the game content control may assist fibromyalgia patients in distancing (decoupling) from the pain associated with the disease: related can be the use of VR in pain decoupling in line with Hoffman's work as an example – see, e.g. https://depts.washington.edu/hplab/research/virtual-reality/. This directly associates to our statement in the prior paper (Brooks & Petersson, 2005) where we state how gameplaying actions do not need to be conscious, as at a certain level they can be unconscious skills, which, supported by playful aspects of the game, proactively push the participant's limits towards new levels of movements (p. 304). This claim substantiated from prior field research interventions.

We further stated in the prior paper (Brooks & Petersson, 2005) how we attempted to understand movements according to a semiotic interplay between participants' inner and outer world via elaborating with our theoretical framing citing related literature.

In the prior studies with the two hospitals, the planned method incorporated triangulated methodologies of video observations, interviews, questionnaires and diaries/field notes.

The video recordings underwent numerous temporospatial analyses by two independent coders where the units of analysis were the qualitatively different expressions of movement.

This methodology is detailed in the publication (Brooks & Petersson, 2005) with text and figures illustrating technique, approach and outcomes. Included in the analysis/coding was observed expressive gesture, action and pause periodic segmentations and performances. Alongside was compared temporal specific aspects concerning rhythm as a periodic repetition, dynamic kinetic changes and structural patterns of gameplay.

Detailed spatial analysis was also correlated with foci on specifics of range and intentionality of movements alongside facial expressions and utterances of participants.

Cumulatively, we referred to this as our manual multimodal analysis method. Alongside this manual method we conducted an automated computer analysis using the software EyesWeb by the University of Genoa and specifically from the 'EyesWeb Gesture Processing Library' (see Figs. 2 and 3 herein associating to Figs. 4 and 5 in (Brooks & Petersson, 2005)). These figures correspond to the appendixes in (Brooks & Petersson, 2005) where generated graphs and tables from these analyses are exemplified as well as detailing the created algorithms. For example, Fig. 4 in the paper details the quantity and segmentation of movement with threshold/buffer/motion phase indicators – buffer image, pause and motion phase durations. Further, Fig. 5 in (Brooks & Petersson, 2005) (Fig. 3 herein) illustrates the Contraction Index (CI) analysis via silhouette bounding rectangle initially set on buffer image. Finally, Table 3 in (Brooks & Petersson, 2005) informed on temporospatial analysis of one annotated session video file from the archive. This is not replicated herein as our focus is on colour coding of motion but may be of interest for readers to cross-reference our temporospatial analysis approach. A Silhouette Motion Image (SMI) algorithm was used that is capable of detection of overall quantity, velocity and force of movement.

The extracted measures related to the 'temporal dynamics of movement' were computed, and an adjustable threshold value slider was changed according to each participants' functional ability so that he or she was considered to be moving if the area of the motion image was greater than the related (threshold) percentage of the total area (Figs. 7.1, 7.2 and 7.3).

Building on (1) above, we similarly resource from our previous work where a focus was on empowering a participant to be able to digitally paint based upon dynamics of motion. This we determine as (2) where a focused selection is from the research in Portugal that led to a paper titled *Ao Alcance de Todos*. *Ao Alcance de Todos* is Portuguese for 'Within Everyone's Reach' in English and was realised as a 2-week workshop festival that was hosted at Casa da Música, Porto, Portugal in April 2008 (Brooks, 2008). This included a collection of the first author's works combined as an interactive installation in a space 14 m by 18 m, built as the national orchestra rehearsal room with a suspended/sprung wooden floor.

Extracted from this body of work are the algorithms used in the body painting section of the installation. This was where participants could move in front of a

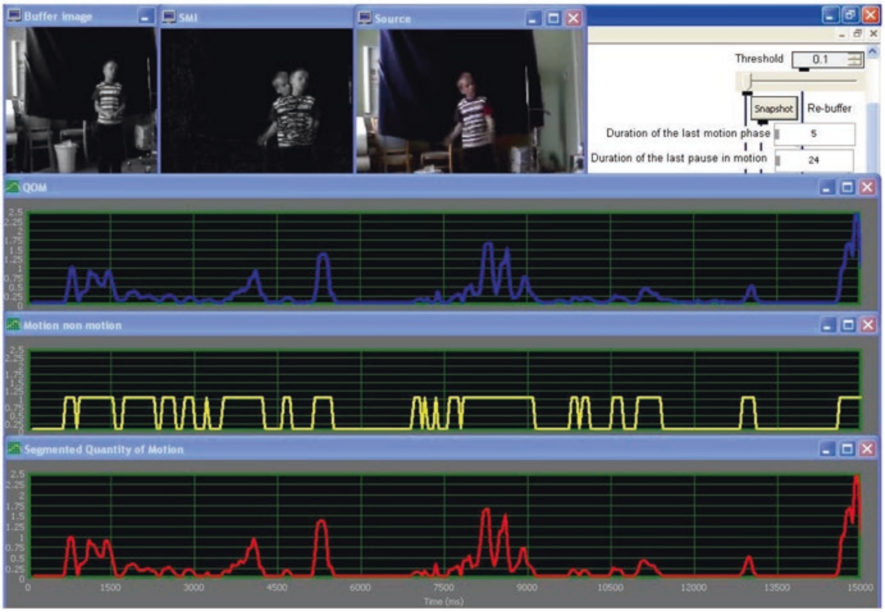

Fig. 7.1 Quantity and segmentation of movement. Threshold/buffer/motion phase indicators (upper right). Buffer image, Silhouette Motion Image (SMI) and source windows (upper left) – see also Fig. 4 in (Brooks & Petersson, 2005)

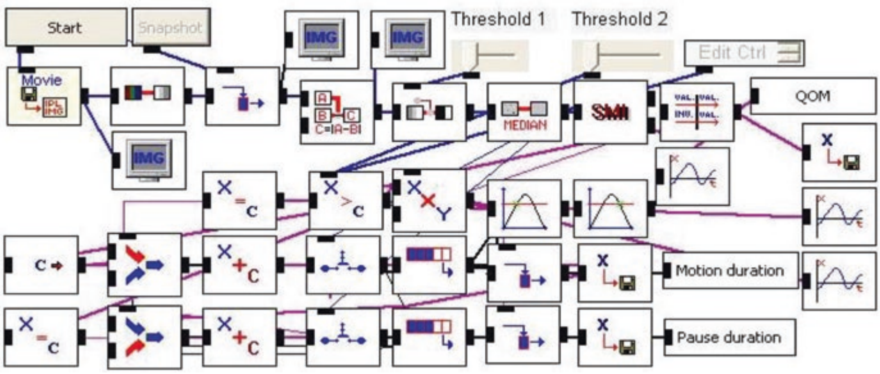

Fig. 7.2 EyesWeb algorithm for processes illustrated in Fig. 7.1 above: see also Fig. 4 (Brooks & Petersson, 2005)

camera and play music and simultaneously digitally paint and generate A3 size paintings of their creations. The algorithms originated from the first author's role in leading a European project based upon his research within the field of handicapped, elderly and (re)habilitation (Brooks & Hasselblad, 2004). Figure 9 in the original paper illustrates the exhibition of paintings and a group of attendees with special

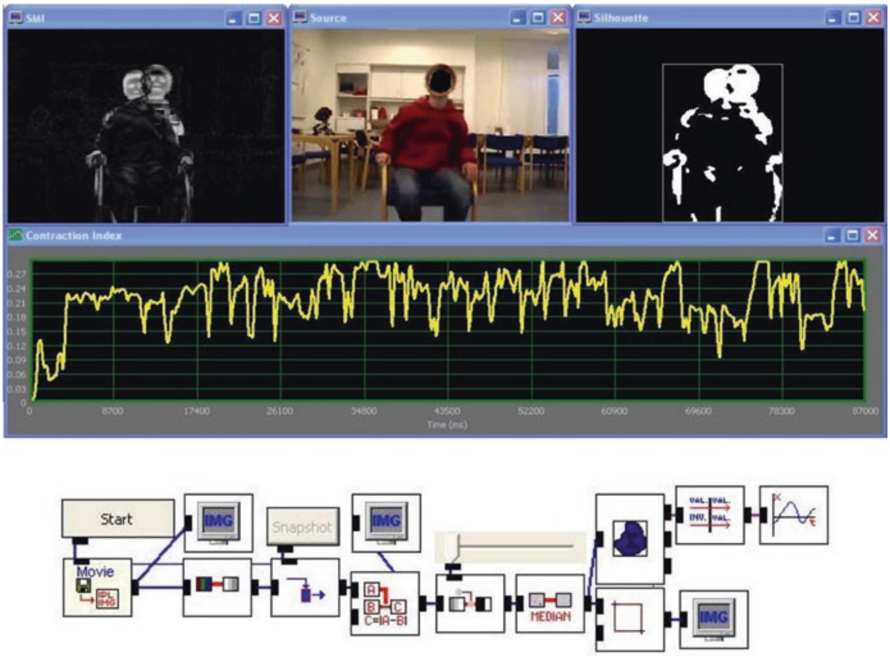

Fig. 7.3 Upper = Contraction Index (CI) analysis of motion. Upper right shows silhouette bounding rectangle initially set on buffer image. Lower = EyesWeb algorithm for CI analysis process as illustrated (Fig. 5 in (Brooks & Petersson, 2005))

needs who were painting (details of the participants is in the original paper). The second author was involved in interviewing and questioning on the participants' experiences in the workshops.

The EyesWeb algorithm for body painting was programmable to match individual nuances of control – across dysfunctionality – via a threshold control. Input motions are qualified and input to a threshold value to enable control of the process of stepping through a colour selector. As a participant's motion diminishes below the threshold, the algorithm stops painting, and when the dynamics of motion are once again above the threshold, the painting restarts but at the next step of the selector processing, i.e. the next designated colour in the selected paint chart (according to participant function versus threshold sensitivity control).

By combining from studies (1) and (2), it is posited how a manual annotation of fibromyalgia participants, such as conducted in our works, can be supplemented by an automated process that determines a colour coding schematic to identify dynamics of motion. Albeit a low-level indication of motion dynamics, this is speculated as being a significant addition to real-time analysis of such motion performance.

The feedback painting and/or gameplay is hypothesised as approaching a 'cognitive decoupling' such that the pain for the fibromyalgia patients is more bearable due to the motivation and enjoyment of playing the game alongside (simultaneously or independent) the fun of painting and playing music through body motion. Slight adjustments are foreseen as required in order to fine-tune the analysis method posited, but if achievable, then a colour-coded swift analysis of motions above a certain threshold for each individual with associated pains that typically prevent reaching such dynamics would be a contribution to this field for others to also explore and improve and is thus speculated to contribute to advance the study of fibromyalgia.

A further and earlier study (Brooks et al., 2002) by the authors includes a different form of colour-coding that rather than dynamics of quantity and quality of movement, it focused upon range and area of motions where the colouring of shapes alongside generated sounds was the multimedia feedback for participants. A focus was on achieving closure of the afferent/efferent loop to empower the participants who were from a school for children and adolescents with special and profound needs in Sweden. This was achieved using three (or more) specific data sourcing sensors set up according to participants' functional abilities – see Fig. 7.4. The sensors used were based upon infrared technology and have an invisible volumetric sensing profile. Linear sensor profiles and planar sensor profiles were also used – see appendix Fig. 7.11.

Data from movement within the sensing areas were mapped to the software (typically Cycling74 Max (Brooks, 2021a)) that could scale and route the big- and thick-data streams to selected multimedia (Fig. 7.4).

Fig. 7.4 A three-sensor set-up using infrared sensing with volumetric profiles with participant on vibroacoustic chamber generating motion data that results in sounds and coloured images on a large projection screen in front of her

The selection of the multimedia (visuals, sounds, robotics, games, etc.) could be according to each participant's preferences, but herein the focus is on the interactive visuals in the form of colour that result from the set-up (Figs. 7.4, 7.5 and 7.6). This earlier study gives a more digital representation of the motion as the generated data in each invisible sensing zone is representational of a proportional addition of colour. In other words, in each sensing zone (of three in this case) where motion is detected, a proportional saturation of the selected hue relates to the distance/range of motion and is not dependent on the dynamic of the motion.

In the case of the later research (Brooks & Petersson, 2005), the dynamic motion is represented by a duration of colouring, whilst the dynamic data is above a programmed threshold of motion according to the programming of the selected colour (Figs. 7.7, 7.8 and 7.9).

The colours are not mixed and projected in the later studies as one sensor is used (camera with planar profile) versus in the early research where three sensors were used, such that three colours could be mixed. The different colouring in the figures are time-based projections of each threshold change stepping through the selected colour chart in the algorithm.

Fig. 7.5 A three-sensor set-up using infrared sensing with volumetric profiles with two different participants illustrating how different selected images are coloured versus the cited later studies where colouring was determined by the actual body movement silhouette

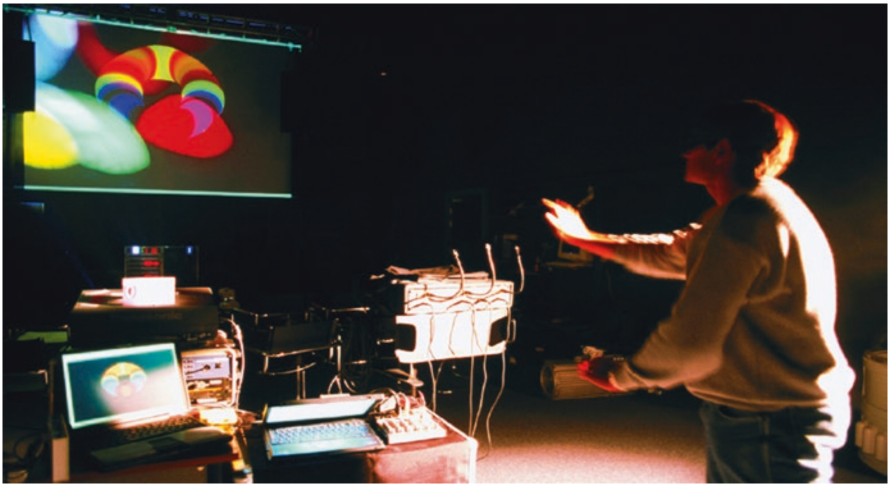

Fig. 7.6 The author's three-sensor set-up using infrared sensing with volumetric profiles mapped to red, green and blue colouring, with a participant illustrating how a selected image (doughnut shape on screen) is coloured as well as control of corresponding robotic moving head lighting colouring (in the figure the coloured lighting circles over and to left of the multicoloured doughnut shape – the computer screen lower left shows without lighting overlay)

Fig. 7.7 A single camera sensor set-up where colouring was determined by the actual whole body movement silhouette (black areas in figure = head, two hands and two upper thighs) according to a programmable threshold of activity that steps through a selected colour chart

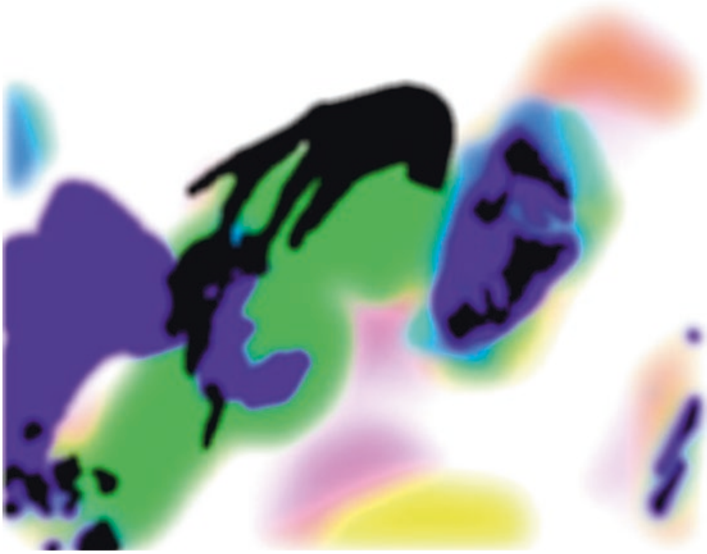

Fig. 7.8 A single camera sensor set-up where colouring was determined by the actual hands and head of a participant's movement silhouette (black-filled shapes) according to a programmable threshold of motion activity that steps through a predetermined colour chart

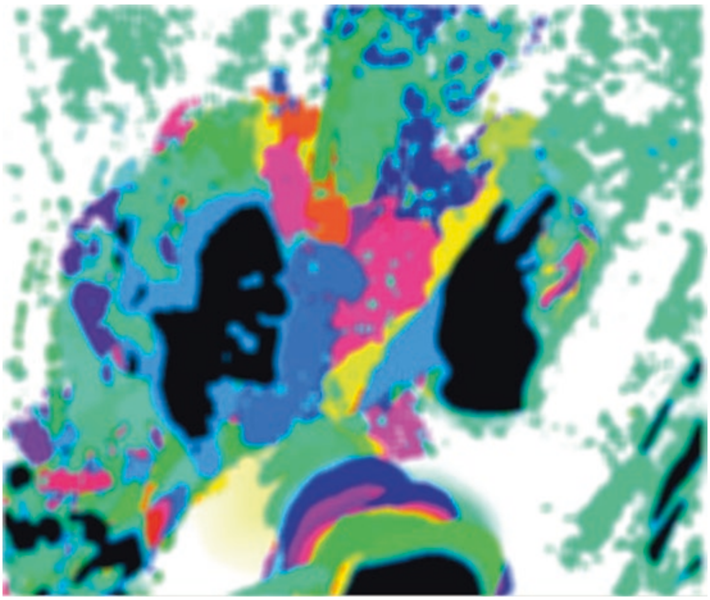

Fig. 7.9 A single camera sensor set-up as Figs. 7.7 and 7.8, where colouring was determined by the participant's and therapist's head movement silhouette (black-filled shapes)

Discussion

Motion-controlled video games (MCVGs) were found in our studies with fibromyalgia patients as having positive potentials. As previously reported in this thread (Brooks & Petersson-Brooks, 2012; Mortensen et al., 2015), two explorations were undertaken to learn and study the experiences of women with FMS in exploring through motivated play commercially available MCVGs. The studies included investigating indicators of symptom severity and performance of activities of daily living (ADL).

The first study involved three patients and the Nintendo Wii gaming platform using a single hand-held Wiimote controller. Two participants completed ten sessions, each playing a preferred game that was selected in the initial instruction session.

The second study involved 15 female participants diagnosed with FMS. Seven participants completed a programme of five sessions with Nintendo Wii using a single hand-held Wiimote controller, five sessions with PlayStation Move (PS3 Move) using two hand-held controllers and five sessions with Microsoft Xbox Kinect – a hands-free camera-based interface.

The sessions in the second study were planned to be conducted over a period of around 7 weeks, which, on reflection, may have influenced adherence as (Mortensen et al., 2015) shows the actual period was 9–17 weeks duration. Of the 15 originally selected participants, 8 did not complete the programme. This dropout percentile bears resemblance to related work (Busch et al., 2008b).

Interviews were conducted at baseline and post-intervention and were supported by data from observation and self-reported assessment.

Related literature reports on studies with larger numbers of subjects with positive outcomes from exploring ‘exergaming’ as an effective tool in therapeutic intervention for women with fibromyalgia, e.g (Collado-Mateo et al., 2017)., and beyond (e.g. in acquired brain injury) where gameplay was considered as motivational and an enjoyable alternative form of rehabilitation (Burke et al., 2009).

Participants reported their experiences of MCVGs as a way to get distraction from pain symptoms whilst doing fun and manageable exercise. They enjoyed the slow pace and familiarity of Wii, whilst some considered PS3 Move to be too fast-paced. Xbox Kinect was reported as the best console for exercise; however, overall in the studies there was no indication of general improvement in symptom severity or performance of ADL. Results are reported in (Mortensen et al., 2015) on Visual Analogue Scale (VAS), Brief Fatigue Inventory (BFI) and ADL Questionnaire (ADL-Q) and are not repeated herein. Additionally, data and interview analyses were conducted and again reported in (Mortensen et al., 2015).

Manual analysis only was conducted in these reported studies (Brooks & Petersson-Brooks, 2012; Mortensen et al., 2015). Herein, based upon the authors’ prior researches and ongoing work in progress, a means to automate low-level analysis of body motions that can be associated to fibromyalgia pain-restricted movement via colour-coding is posited. The data that achieves the colour-coding can also be analysed in line with the authors' 2005 methodology where quantity and quality of movement was determined. These approaches offer opportunities for next-generation researchers to explore such analysis of the big and thick data at different levels according to desired outcomes. Our subsequent hypothesis from this work related to how artificial intelligence (explainable AI and/or deep learning) can add to this analysis set-up to inform (e.g. Brooks, 2021e).

In this body of work, it has been demonstrated how MCVG can act as an effective healthcare intervention for persons with FMS associated to temporary pain relief (to be discussed further relating to cognitive decoupling) and enjoyable low-impact exercise such as resulting from gameplay and or digitally creating music and/or painting. The literature indicates how rehabilitation exercise is recommended in the management of fibromyalgia syndrome (FMS). People with FMS often find it counterintuitive to exercise because of pain exacerbation, which may influence adherence to an exercise programme. In general it would seem that motion-controlled video games may offer temporary pain relief and fun as a low-impact exercise for women with FMS.

An illustration of the overview of the first author's SoundScapes concept (a 'Communication method and apparatus' – see patent number US6893407B1) of invisible sensing of dynamic movement mapped to multimedia feedback in (re) habilitation (Fig. 7.10) and the three sensing technology and differing profiles typically used in SoundScapes (Fig. 7.11) are illustrated in the Appendix. The term 'Communication' in this context and with upper case refers to the SoundScapes' modular and flexible feed-forward and feedback loop that affects achieving of afferent-efferent neural feedback loop closure that is reflected as motivational for participants whilst communicating causality of their own sensed motion dynamics. Correspondingly, the set-up 'Communicates' data to the system that is informing, logged and archivable for post-session analysis. It also 'Communicates' to the facilitator or therapist if the system is optimally matched to the patient/participant.

In this paper a colour-coding of motion dynamics is posited that gives a real-time opportunity for analysis and thus corresponding system parameter change in order to fine-tune the system to each individual patient/participant. Thus, a reflection on the methodology was that a previously used motion-based body-painting algorithm could be tested to determine dynamic changes of body movements during gameplay. This would generate a colour-coded result to indicate (as in further 'Communicate') within or between adjacent or initial and final sessions any potential benefits that were otherwise unseen. Whilst this could potentially advance the field of evaluating in a quantitative manner, it is only speculated at this time without testing.

Summary of Related Studies on Fibromyalgia/Pain and Digital Technologies

Summarising related studies on fibromyalgia/pain and digital media technologies (here we focus on sensors, virtual reality environments and games) that associate to the approach taken by the reported studies herein notable is an article by (Wiederhold et al., 2014) that approximately a decade ago stated how:

> Recent studies indicate that computer-generated graphic environments—virtual reality (VR)—can offer effective cognitive distractions for individuals suffering from pain arising from a variety of physical and psychological illnesses. Studies also indicate the effectiveness of VR for both chronic and acute pain conditions. Future possibilities for VR to address pain-related concerns include such diverse groups as military personnel, space exploration teams, the general labor force, and our ever increasing elderly population. VR also shows promise to help in such areas as drug abuse, at-home treatments, and athletic injuries.

More recently, aligned with technological advances and gaming industry pervasiveness, VR is commonly associated to gaming whereby head-mounted displays (HMDs) have become affordable alongside stand-alone platforms or personal computers with online access to VR games (and other) content. Educations have been initiated around the world on gaming due to market size and potentials across disciplines, and the authors were founder leaders of such an education from 2002 in Denmark titled 'Medialogy' (Medialogy, 2002).

Previous to those studies reflected in this text, the authors were awarded with a best paper award at the International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2012), Laval, France, with their contribution titled 'Perceptual Game Controllers and Fibromyalgia studies' (Brooks & Petersson, 2012). This 2010–2011 investigation was of gesture-based control of video games to promote and motivate self-driven home-based aerobic exercise (AE) training regimes to improve pain threshold associated to fibromyalgia. Forty-nine patients with fibromyalgia in total participated within two studies where control was other registered patients with the involved Norwegian medical doctor (expert in fibromyalgia) who had a local practice conducting assessments. Pre- and post-interviews, tests and VAS registrations of pain, disturbed sleep, lack of energy and depression were supplemented by patient-reported global subjective improvement or otherwise – conducted by the patients' doctors. Multiple angle (3) video cameras synchronised to the gameplay for correlation analysis. Outcome measures were at baseline and completion. Three game platforms were studied: the MS Kinect, Sony MOVE and Nintendo Wii, with the first study with 10 sessions of 1 h each per patient and second study with 5 game sessions of 1 h being played by each patient on each platform (15 sessions in total each). Positive outcomes with completion involved patients reporting purchasing their own game platform for self-driven home training.

Building on the positive finding from our initial studies that ongoingly involved expert fibromyalgia medical professionals, subsequent investigations involved therapist students alongside the experts, as reported online (Mortensen et al., 2015)

(Epub 2013 Sep 12) in the *Journal for Disability Rehabilitation Assistive Technology*, which fed into another study as reported in 2014 under the title '*Engagement in Game-Based Rehabilitation for Women with Fibromyalgia Syndrome*' (Brooks & Brooks, 2014).

Around the same time, (Botella et al., 2013) reported on the effectiveness of VR as an adjunct to cognitive behavioural therapy (CBT) in the treatment of fibromyalgia (FM) with a small sample of six patients. Reported results '*showed the long-term benefits of significantly reduced pain and depression and an increased positive affect and use of healthy coping strategies*.'

In (Villafaina et al., 2019) a single-blinded randomised controlled trial was conducted with fifty-five women with fibromyalgia in a university setting investigating '*the effects of a 24-week exergame-based intervention on health-related quality of life (HRQoL) and pain in patients with fibromyalgia as well as to analyze the effectiveness of the intervention in subgroups of patients with different pain intensity levels*.' Conclusions indicate how the results point to how exergames '*could be a useful tool to improve perceived health status and pain intensity level in women with fibromyalgia with a reduced health-related quality of life*.'

More directly associated to the reported studies conducted by our team, (De Carvalho et al., 2020) reported on a randomised control study where thirty-five women, divided into two groups (control group where $n = 19$, performing stretching exercises; and a Wii exergame group, $n = 16$) where assessments were using the fibromyalgia impact questionnaire (FIQ), algometry, step tests, cardiopulmonary parameters, and fatigue in the lower limbs. Treatments lasted for 7 weeks with 3 1-h sessions weekly with re-evaluations after the tenth and the 20th sessions. Results indicated how (De Carvalho et al., 2020):

> The exergames group showed significant reduction of their fibromyalgia symptoms, as demonstrated by lower FIQ scores in the key domains on questions regarding missed work, pain, fatigue, problems resting, stiffness, anxiety, and depression. Significant improvements were observed in mean algometric values in the cervical region, the second chondrocostal junction, the lateral epicondyle, left medial knee border, left occipital region, trapezius, supraspinatus, gluteal muscles, and the greater trochanter. Improved cardiovascular adaptation was reflected by decreased systolic blood pressure, reduction in fatigue of the lower limbs assessed by the CR10 Borg scale, and improved exercise capacity assessed by a step test.

Conclusions being that '*Exergames have the potential to increase exercise capacity, decrease the impact of fibromyalgia, promote cardiovascular adaptation, reduce fatigue of lower limbs, and improve the pain threshold in women with fibromyalgia*.' (De Carvalho et al., 2020).

In a subsequent report (de Carvalho et al., 2021) is more specific on analysing the effect of exergaming on muscular activity at rest and on maximum voluntary isometric contraction which was conducted by the same team with the same participants/groupings/sessions/design. This time evaluations involved EMG, dynamometry by load cell, baropodometry and algometry before interventions with reassessments after the tenth and 20th sessions. Again reported results were positive with conclusions that the exergaming showed potentials to increase the peak torque for dorsiflexion and plantar flexion movement for the participants by also producing a decrease in tender point count equal to that with flexibility exercises and does not produce changes in the static balance.

In the same year, (Polat et al., 2021) investigated motion-controlled video games and their effect on women ($n = 40$, split into control [VR] and conventional training groups) with fibromyalgia on their pain, functionality, cardiopulmonary capacity and quality of life. MS XBox Kinect was used with the VR group lab, and home exercising was scheduled with all patients evaluated at baseline and 4th and 8th weeks. '*Primary outcome measure was Fibromyalgia Impact Questionnaire. Visual Analogue Scale (VAS), Hospital Anxiety and Depression Scale, Fatigue Severity Scale (FSS), Symptom Severity Scale, EuroQol-Five Dimensions Index Scale/Visual Analogue Scale (EQ-5D-index/VAS) and Six Minute Walk Test (6MWT) were used as secondary outcome measures*'. Outcomes indicated how VR '*game exercises along with aerobic exercise increased cardiopulmonary capacity and quality of life in fibromyalgia syndrome. In addition, they increase patient satisfaction and may improve patient compliance to exercise*'.

More recently, (Gava et al., 2022) reviewed the effects of gaming on pain-related fear, pain catastrophising, anxiety and depression in patients with chronic musculoskeletal pain. Findings were based on very low- or low-quality evidence. In a conclusion, the review showed how gaming modalities may have positive effects on some mental health outcomes, but there were conflicting results with low-quality evidence, which indicates that more high-quality randomised controlled trials are needed.

Conclusive Comments

From our individual and combined positions, we have explored interactive sensor-based activities including virtual reality environments/virtual interactive space (VIS)/human performance/entertainment, etc. for many years since the early 1990s. The first author's investigations of sensor interfaces mapped to different multimedia interactive digital content in the form of auditory/musical, visual/effect and robotic content as direct feedback to a participant; and the second author's mature body of research investigating play associated to formal/informal and non-formal learning. The combination of the two bodies of research gave credence to the researchers' concept on how games (exergaming) could be used in therapeutic environments where entertainment, enjoyment and simple fun led to new advancements in wellbeing and (re)habilitation. Different participants with different profile of age/condition have volunteered over the years, and many of the corresponding studies were undertaken with healthcare experts externally (hospitals, treatment clinics, etc.) or located at the SensoramaLab that was founded by the researchers in 2004 at Aalborg University Esbjerg campus in Denmark. Games and virtual reality related to human behaviour were the core foci at the lab complex.

Following their initial studies in the field, their findings align with others who have reported that the effects of exergaming on fibromyalgia can result in additional benefits for patients such as improvements in lower-body strength, cardiorespiratory fitness autonomic control, exercise capacity, cardiovascular adaptation and pain threshold and also decreases the impact of fibromyalgia reducing fatigue – especially of the lower limbs.

Positive results in favour of aerobic exercises, flexibility exercises, strength training, stretching and body awareness therapies for fibromyalgia treatment have also been reported. The conclusions (Botella et al., 2013; Brooks & Brooks, 2014; Brooks & Petersson, 2012; De Carvalho et al., 2020, 2021; Gava et al., 2022; Herrero et al., 2014; Medialogy, 2002; Mortensen et al., 2015; Polat et al., 2021; Villafaina et al., 2019; Wiederhold et al., 2014) as reported in this text of expert teams in their respective field reflect our findings (as non-experts in pain/fibromyalgia conditions but who research with such experts). Further, (Brooks, 1999) reported on a system along with data regarding the acceptability, satisfaction and preliminary efficacy of a virtual reality (VR) environment for the promotion of positive emotions where results showed significant increases in general mood state, positive emotions, motivation and self-efficacy. These preliminary findings show the potential of VR as an adjunct to the psychological treatment of such an important health problem as chronic pain and align with such applications of technology in healthcare (Brooks, 1999, 2011).

These related findings support our addendum in recommending that further studies should be undertaken investigating additional games and interfaces that, through adaptability to achieve optimisation and personalisation, may advance coping with fibromyalgia as well as increasing compliance through their adaptability to a given physical condition and (thus) limitation. Aligned from this text and our posit of means to support interventions and treatment design, we also believe the investigation of means for subject/participant and intervention therapist to (in real time) identify through colour-coding (or other) feedback methodology is fruitful as a support for the therapists and individuals in their self-driven home sessions to improve their own life quality. To end, however, it must be stated that from the concluded studies it is unclear from those volunteers who completed the research sessions and continued to play such games at their home. This has no follow-up re-testing to conclude from in this work as following 2015 that which was scheduled was cancelled due to management closure of the SensoramaLab where the studies took place in Aalborg University Esbjerg, Denmark, soon after the fibromyalgia investigations that were located therein. However, the authors are positive to their contribution to this field and welcome correspondences as appropriate.

Acknowledgements The authors wish to thank all of the participants for their time and efforts across all cited studies. Special thanks in the cited (1) and (2) studies go to the senior Medialogy student and Occupational Therapy students, rheumatologist Hans-Jacob Haga for recruiting participants and gathering data on pain and fatigue and also Eva Ejlersen Wæhrens for allowing use of the ADL-Q. The other cited works acknowledge the patients/participants, doctors, play therapists from the research partner hospitals and staff at the special school in Landskrona, Sweden.

Appendix

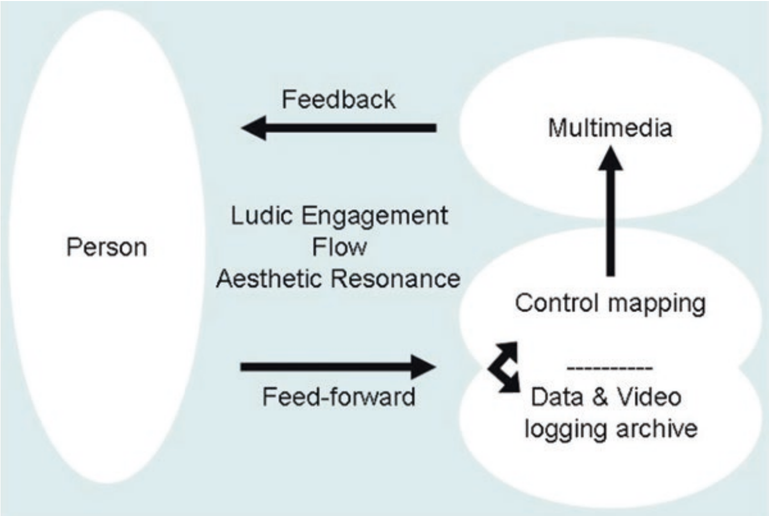

Fig. 7.10 Overview of the signal flow where movements result in data generation (feed-forward) that is processed and routed in software to affect multimedia software (or, e.g. robotic lighting hardware) that generated multimedia content that is sensed by the participant. The thick data is archived with video recording for post-session correlation analysis. The generated multimedia content is representational of the movement dynamics and/or range of motion whereby the quality and quantity of the movement is within the thick data

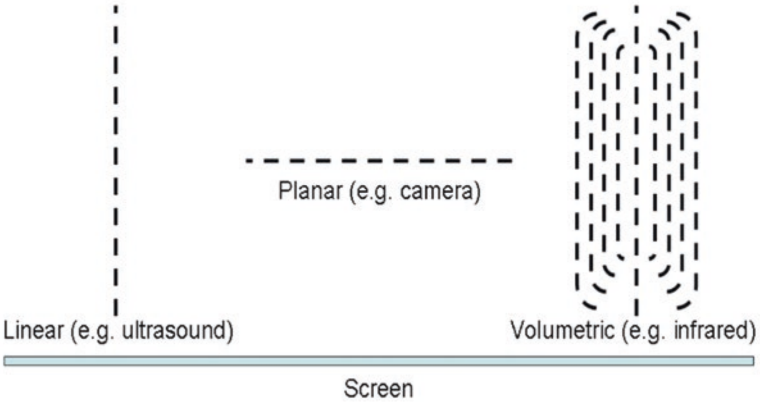

Fig. 7.11 The three sensing profiles and technology typically used in this research being linear (ultrasound), planar (camera) and volumetric (infrared) relational to a screen where the colouring of the image is viewed by participants. Dotted lines indicate data profile regions

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