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The Efficacy of the Augmented Video-based Portable System as a Useful Clinical Tool to Complement Rehabilitation [Version 1, 1 Approved]

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Abstract

Most clinics and clinical research facilities have embraced 2D motion analysis technology primarily because they are reliable, accurate, inexpensive, portable and less complex to operate when compared to 3D motion systems. The purpose of this study was to evaluate the effectiveness of a rehabilitation regime using a low-cost augmented video-based portable system (AVPS). The study was a rehabilitation assessment study performed within a clinical motion analysis laboratory. Two case studies were evaluated based on two rehabilitation regimes designed for a mild cerebral palsy (CP) adult patient and a patient recovering from an Achilles Tendon Rupture (ATR) respectively. The AVPS was used as a clinical tool to assess the level of recovery during a walking task performed while the patients underwent routine rehabilitation regimes. Gait assessments were performed at specific time points to monitor recovery in both case studies. Ultrasound was used to complement the AVPS outcome measures for the ATR assessment. The AVPS produced gait outcome measures that provided useful clinical data at different time points. These gait outcome measures – walking speed, temporo-spatial parameters, and gait symmetry data were sensitive to detecting changes to the lower limb rehabilitation regimes administered to the CP and ATR patients.

Keywords

2D Motion Capture; Gait Analysis; Low-Cost; Optical Motion capture

Introduction

Motion analysis is routinely used in clinical practice and biomechanical research to aid in rehabilitation and the assessment of limb function in healthy participants and patients respectively. However, the cost of such equipment can be prohibitive, and as a result many start up clinics and research laboratories (particularly those in low and middle income countries), are unable to utilise high quality three dimensional motion analysis systems. Consequently, many of these centres will settle for low budget, optical three dimensional motion analysis equipment [1] and/or cost effective two dimensional motion analysis equipment. The need for a low cost, yet effective method of motion capture and analysis was initially developed by Wall and associates [2] and more recently, our group have developed an augmented video based portable system (AVPS) [3]. The AVPS is a two dimensional, user friendly system with minimal set up costs. Furthermore, we have also previously demonstrated that the system is a valid and reliable method of data acquisition, both in healthy participants and patients with neurological disorders (i.e. Stroke patients) [3-5].

Physiotherapists led rehabilitation regimes are typically designed to support and assess the improvements or decrements in patients gait in response to a variety of conditions, including cerebral palsy patients, and patients recovering from lower limb orthopaedic fractures, ligament ruptures and tendon ruptures. Cerebral Palsy (CP) is a perinatal disorder that is idiopathic in nature and leads to progressive deficits, such as bony deformities, muscle contractures, and gait abnormalities. Furthermore, while the majority of the research in CP has focused on children [6-10], adults also frequently present with altered or impaired gait, and reductions in their ability to engage in activities of daily living. It seems feasible therefore, that the AVPS may be a valuable tool in gait assessment of patients with CP.

In addition, the AVPS has been proposed as a valuable rehabilitation assessment tool within orthopaedic clinics / rehabilitation centres [11]. Yet, despite the fact the AVPS has been concurrently validated against a gold standard three dimensional motion analysis system [3], it has not been used within the field of orthopaedics. The Achilles Tendon Rupture (ATR) is common with an incidence of rate of 18-37 per 100,000 [12]. Typically an ATR occurs in middle-aged males who partake in activity on an irregular basis [13]. Patients present with severe pain in the tendon, a palpable gap at the rupture site, and marked weakness of ankle plantar-flexion. Treatment options include non-surgical interventions (plaster of Paris, bracing or splinting) or surgical repair of the tendon.

It seems clear therefore that, although the AVPS is a valid and reliable method of motion capture and gait analysis, before undertaking larger trials there is a need for some evaluation of the AVPS as part of clinical rehabilitative practice. Consequently, the aim of this study was to determine the usefulness and feasibility of the AVPS system in a clinical rehabilitation environment. To accomplish this we undertook two case studies of patients undergoing treatment; one case regarded a patient with gait abnormalities due to CP, and one case of a patient recovering from orthopaedic treatment after suffering a complete ATR.

Methods

Two case studies were independently run after obtaining ethical approval from the University of the West of Scotland. Both case studies were performed using the same experimental setup (Figure 1).

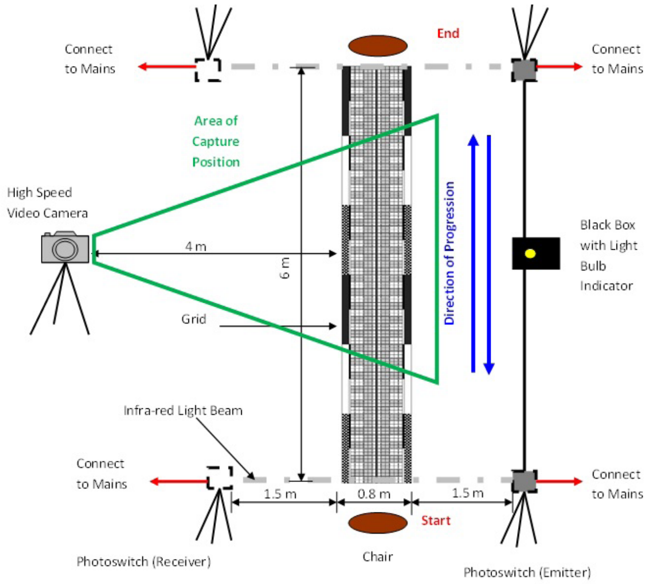

Figure 1: Gait assessment experimental setup.

The following are details of the methodologies:

Case Study 1: Study Design and Protocol using Cerebral Palsy Patient

This case study was of a female adult (age = 38 years, height = 1.65m, body mass = 75kg) with mild CP. The study monitored the patient throughout a rehabilitation process of prescribed exercise administered by a qualified physiotherapy practitioner. The physiotherapy session involved an initial assessment that took into account the patient's personal preferences, values, rights and characteristics [14]. The exercise regime comprised conventional functional training, range of motion and flexibility exercises for the lower limb and a home based exercise programme designed to improve joint mobility. The study commenced from the onset of the rehabilitation process right through to the follow up session ten weeks after the baseline measurement.

The AVPS analysis was performed at the biomechanics laboratory located at The University of The West of Scotland. For this case study, testing was carried out on two time points

(TP). TP1 was prior to starting physiotherapy, with TP2 occurring ten weeks after starting physiotherapy treatment. The protocol required the participant to walk across a 6m long, high-contrast-grid vinyl mat while being video-filmed in the sagittal plane. Temporo-spatial gait analysis and the production of sagittal plane estimates of joint kinematics were measured. In the sagittal plane, strategically placed bulls-eye markers were placed on the participant's hip joint (greater trochanter), knee joint (lateral epicondyle), ankle joint (lateral malleolus), toe (first and fifth metatarsals) and the heel (medial and lateral sides) covering both the ipsilateral and contralateral sides (Figure 2). Anthropometric measurements were obtained before three walking conditions were performed; barefoot, wearing comfortable shoes with a prescribed splint support and wearing comfortable shoes without a splint for support with the order chosen at random. Data acquisition required, the participant to perform three gait cycles up and down the walkway grid mat, barefoot, and at a self-selected, comfortable walking speed. Following a three minute rest the participant performed a further three gait cycles wearing comfortable shoes again at a self-selected speed. Following a final three minute rest the participant performed another round of three gait cycles, this time wearing comfortable shoes (with splint) at a self-generated walking speed. High speed video (EX-FH20 EXILIM Casio, USA) data was processed using the ProTrainer system (Sports Motion Inc®, Cardiff, CA) software and descriptive statistics were derived. Step length variability was determined using the coefficient of variation (CV), where CV = (standard deviation / mean) x 100. The CV for the temporo-spatial measurement parameters were calculated using the mean of both legs averaged over all evaluated gait cycles.

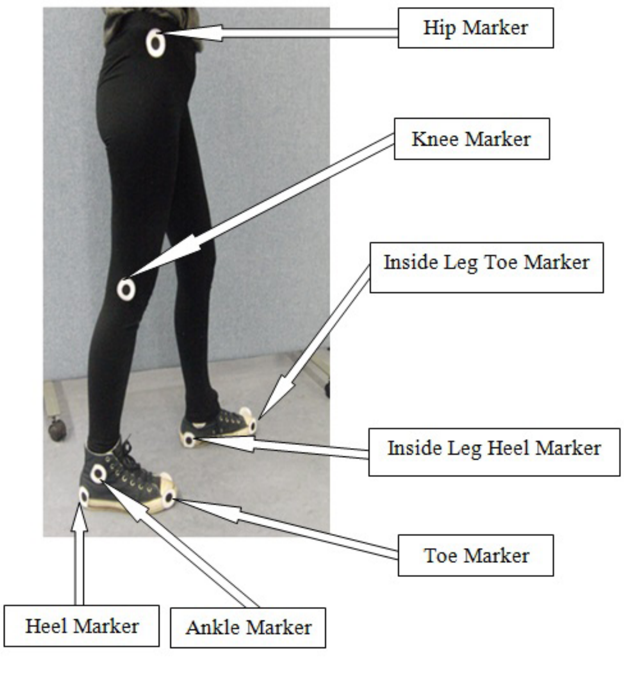

Figure 2: Volunteer marked with black-and-white bull's eye markers.

Case Study 2: Study Design and Protocol using Achilles Tendon Rupture Patient

This case study was of an adult male patient (age =25 years, height = 1.83m, body mass = 86kg). In this case, the investigation was to use the AVPS to evaluate a prescribed physiotherapy program on a non-surgical complete ATR rehabilitation patient using temporo-spatial parameters as the outcome measure. The patient underwent conservative treatment to repair an ATR on his left ankle by a qualified physiotherapy practitioner. The study took place at the Biomechanics Laboratory located at the University of The West of Scotland. Data was collected from the onset of the rehabilitation process right through to the discharge from care. The prescribed physiotherapy intervention was based on the conventional physiotherapy routinely administered to ATR patients within the National Health Service in Scotland, UK. The gait assessment required the patient to walk wearing comfortable shoes across a 6m long, high-contrast-grid vinyl mat while being video-filmed in the sagittal plane. Temporo-spatial gait analysis and the production of sagittal plane estimates of joint kinematics were measured using the Silicon Coach Software (Dunedin, New Zealand). Bull's eye markers were placed on the hip joint, knee joint, ankle joint, heel and toe.

The gait analysis protocol used at each time point was identical to that described in the first case study. However, in this case assessments occurred at four time points, TP1 was the baseline measurement which was performed after the cast removal but prior to starting physiotherapy. TP2 was performed during the first week of physiotherapy and three weeks from baseline. TP3 and TP4 were carried out at nine weeks and seventeen weeks from baseline respectively. Following gait analysis and motion capture, descriptive statistics were derived and paired t-tests were carried out to compare TP1 with each subsequent time point i.e.TP2, TP3 and TP4. In addition, the left limb temporo-spatial gait parameters were compared with the undamaged right limb as a means to biomechanically evaluate the level of recovery. Gait symmetry was also measured for walking speed, step time and step length and expressed as a ratio of the affected limb to the healthy limb. Ultrasound measurements were also obtained to evaluate the rate of recovery at the different time points.

Results

Case Study 1

Walking with comfortable shoes, walking with splints and comfortable shoes, and walking barefeet scenarios showed an increase in walking speed at TP2 for the left limb (Table 1). Apart from walking with comfortable shoes all other walking scenarios showed an increase in walking speed at TP2 for the right limb. At TP2, for the walking with comfortable shoes task and walking with splints and comfortable shoes task, the percentage stance time reduced by 2.87% and 0.73% but increased by no more than 5.68% during swing time. Conversely, the barefoot task showed a percentage stance time increment of 1.97% and a 3.76% swing time reduction at TP2. During the walking with comfortable shoes task the CV for the left and right limb step length at TP1 (TP2) were 2.69% (5.08%) and 0.47% (1.83%) respectively. For the walking with splints and comfortable shoes task the CV for the left and right limb step length at TP1 (TP2) were 4.69% (2.13%) and 2.60% (4.53%) respectively. The CV for the left and right limb step length at TP1 (TP2) were 0.47% (4.97%) and 0.93% (10.39%) respectively for the barefoot task. The spatial symmetry at TP1 (TP2) for the walking with comfortable shoes, walking with splints and comfortable shoes, and walking barefeet scenarios were 0.99 (0.89), 0.99 (1.05) and 1.03 (1.21) respectively. The temporal symmetry at TP1 (TP2) for the walking with comfortable shoes, walking with splints and comfortable shoes, and walking barefeet scenarios were 1.09 (1.03), 1.00 (1.06) and 1.10 (1.06) respectively.

Table 1: Measurement outcome parameters for adult CP pilot study at different time points.

Parameters for TP1 and TP2	Walking with Comfortable Shoes	Walking with Splint and Comfortable Shoes	Walking Barefoot
Walking Speed (m/s) for Left Limb (Mean (SD))	TP1: 0.892 (0.003) TP2: 1.011 (0.004)	TP1: 0.921 (0.003) TP2: 0.968 (0.001)	TP1: 0.843 (0.003) TP2: 0.868 (0.001)
Walking Speed (m/s) for Right Limb (Mean (SD))	TP1: 0.962 (0.001) TP2: 0.950 (0.002)	TP1: 0.952 (0.001) TP2: 0.977 (0.001)	TP1: 0.821 (0.001) TP2: 0.881 (0.001)
Percentage (%) Stance Time	TP1: 66.54 (4.52) TP2: 64.63 (0.62)	TP1: 67.18 (2.23) TP2: 66.69 (1.44)	TP1: 65.39 (4.11) TP2: 66.68 (1.53)
Percentage (%) Swing Time	TP1: 33.47 (4.52) TP2: 35.37 (0.62)	TP1: 32.82 (2.23) TP2: 32.82 (0.73)	TP1: 34.62 (4.11) TP2: 33.32 (1.53)
Left Limb Step Length (cm)	TP1: 62.72 (1.69) TP2: 64.91 (3.30)	TP1: 58.37 (2.74) TP2: 57.71 (1.25)	TP1: 52.60 (0.25) TP2: 50.30 (2.50)
Right Limb Step Length (cm)	TP1: 59.29 (0.28) TP2: 61.28 (1.12)	TP1: 58.15 (1.50) TP2: 60.48 (2.74)	TP1: 53.49 (0.50) TP2: 55.43 (5.76)

Case Study 2

The gait speed, temporal and spatial parameters produced symmetries closer to 1 at TP4 when compared to TP1 (Table 2). Both the left and right limb knee joint angles at initial contact showed no significant differences between TP1 and the other time points ($p > 0.067$). However, there were significant differences in the knee joint angles between time points TP2 and TP3 for the left limb ($p = 0.038$), and TP3 and TP4 for the right limb ($p = 0.008$). For the left limb, at terminal contact, there were significant differences between the knee joint angle baseline measurement and TP2 and TP3 ($p < 0.010$) respectively. No significant differences were observed between TP1 and TP4 ($p = 0.067$). Both the left and right walking speeds showed significant differences between TP1 and all other time points ($p < 0.009$). The step length ($p < 0.02$) and step time ($p < 0.015$) showed significant differences between TP1 and all other time points. Throughout the gait assessment at the four different time points both limbs showed significant differences in their step lengths ($p < 0.006$). Also, apart from TP1 knee joint angle at terminal contact ($p = 0.04$), TP1 walking speed ($p = 0.001$) and TP1 step time ($p = 0.017$), all other measurement parameters TP2, TP3 and TP4 showed insignificant differences between the left and right limbs ($p > 0.109$).

Table 2: Gait outcome measures at four different time points.

Measurement Parameters	Gait Assessment Session Time Points (Mean (SD))			
	TP1	TP2	TP3	TP4
Left Limb Knee Joint Angle at IC (˚)	180.00 (2.65)	183.70 (2.08)	181.33 (1.53)	177.33 (2.89)
Left Limb Knee Joint Angle at TC (˚)	146.33 (2.08)	124.30 (2.52)	134.33 (2.31)	135.67 (3.21)
Right Limb Knee Joint Angle at IC (˚)	180.67 (3.79)	187.00 (0.00)	177.00 (1.00)	178.67 (2.08)
Right Limb Knee Joint Angle at TC (˚)	129.33 (4.16)	137.70 (3.06)	129.33 (2.52)	142.33 (3.79)
Left Limb Walking Speed (m/s)	0.73 (0.01)	1.20 (0.09)	1.15 (0.07)	1.38 (0.02)
Right Limb Walking Speed (m/s)	0.77 (0.03)	1.22 (0.03)	1.18 (0.07)	1.36 (0.01)
Gait Speed Symmetry	0.95 (0.03)	1.00 (0.05)	0.97 (0.03)	1.01 (0.02)
Left Limb Step Time (s)	0.70 (0.01)	0.60 (0.03)	0.57 (0.04)	0.51 (0.01)
Right Limb Step Time (s)	0.60 (0.03)	0.50 (0.00)	0.58 (0.01)	0.53 (0.01)
Temporal Symmetry	1.17 (0.05)	1.06 (0.05)	0.98 (0.08)	0.97 (0.03)
Left Limb Step Length (m)	0.60 (0.01)	0.80 (0.03)	0.73 (0.05)	0.79 (0.01)
Right Limb Step Length (m)	0.40 (0.02)	0.50 (0.05)	0.61 (0.03)	0.69 (0.01)
Spatial Symmetry	1.56 (0.09)	1.40 (0.08)	1.19 (0.02)	1.15 (0.01)

IC – Initial Contact; TC – Terminal Content

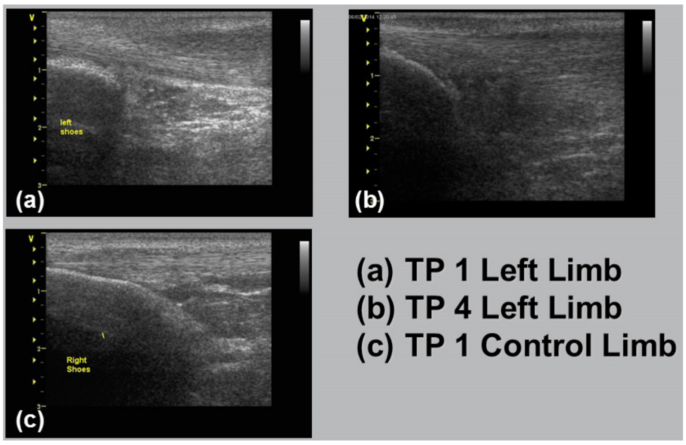

Figure 3: Image of the Achilles Tendon captured from the back of the heel (a) At TP1 the left Achilles Tendon shows the oedema pushing down the fibre alignment of the tendon. Oedema is indicated by the dark region on the top right side of the image, (b) At TP4, at the top right side of the image, the left Achilles Tendon shows a very mild build up of oedema present and indicated by the darkness of the fibre alignment of the tendon, (c) This is the control limb at TP1. Notice the Achilles Tendon without any oedema.

The ultrasound images obtained at TP1 for left limb, TP4 for the left limb and TP1 for the control limb are shown in Figure 3. The images reflect the rate of recovery which complement the AVPS outcome measures.

Discussion

The main findings of the present study indicate that clinical gait outcome measures obtained from a cost effective AVPS unit is a quick and feasible method of gait evaluation. In addition, the AVPS provided valuable information to support clinical practice regarding a patient's rate of recovery, and their response to a rehabilitation regime in both neurophysiological disorders and musculoskeletal related injuries. In particular, in both cases, the AVPS was able to provide detailed and robust data regarding the degree of improvement to physiotherapy.

Gait is a well-established functional activity of daily living. Over the years gait outcome measures have been used to evaluate gait in healthy participants, and patients with neuromuscular abnormalities. Various measurement parameters based on kinematics, kinetics, temporo-spatial measurements as well as indices have been used to provide useful information regarding the functional abilities of the patients with gait difficulties. [15-19] Three dimensional motion analysis systems currently are used for the purpose of obtaining these measurement parameters, however, they can be expensive and in most cases beyond the budgets of many clinical research facilities. Equinus, excessive knee and hip flexion, early heel-rise, foot-drop and excessive limb function during swing are common gait deviations. Depending on the level of severity weaker patients can reveal attributes such as excessive pronation, excessive dorsiflexion, knee and hip flexion (crouch gait) and toe drag [20]. Variability is evident in walking and occurs between repetitions of movement strides or gait. As a consequence of gait variability, deteriorated gait patterns [9, 10] and temporo-spatial variability are also common features associated with CP and ATR. As part of the a prescribed treatment modality to improve biomechanical alignment and functional capabilities in patients with ambulatory difficulties and neuromuscular disabilities, rehabilitation regimes based on conventional physiotherapy techniques are incorporated as standard treatment plans designed to improve gait abnormalities and physical mobility [21]. Finally the AVPS continues to undergo development and efforts are being channelled towards using mobile phones to record patient video and using inherent Apps to perform the gait analyses.

Earlier studies have evaluated walking speed in stroke using the AVPS in response to gait rehabilitation [22, 23] and to assess walking recovery using a prescribed therapist-made ankle foot orthosis (SWIFT Cast) [24, 25]. The results from these studies all showed marked improvements in the patients' walking speed towards the end of their rehabilitation period when compared to baseline measurements. Consequently, the AVPS system appears well suited to tracking improvements in patients gait during routine clinical practice. The AVPS hardware set up time is approximately 10 minutes. This includes laying the walkway grid mat, setting up the tripod stands right through to data collection. Data processing and analysis are similarly quick, although may depend on the number of motion trials captured. The financial cost of the AVPS is low (approximate cost £700) compared to the gold standard Vicon Motion Analysis System (approximate cost £250,000). The AVPS is user friendly with limited expertise required to operate it. Furthermore, it is compatible with various add-on two dimensional software such as Pro-Trainer motion analysis software (Sports Motion, Inc. Cardiff, CA), Siliconcoach video analysis software (Siliconcoach Ltd., Dunedin, New Zealand), Kinovea video analysis software (Kinovea, France), Coach's Eye video analysis software (Techsmith Corporation, USA) and Hudl video analysis software (Agile Sports Technology, Inc. USA) which have shown excellent agreement with the gold standard Vicon Motion Analysis System.

In Case study 1, the spatial parameters showed low levels of CV. The percentage stance and swing time temporal parameters showed variable results at TP1 and TP2 when both tasks were performed. In terms of consistency between tasks and TPs, walking speed appears to be a variable outcome measure useful for evaluating the efficacy of the administered standard rehabilitation regime. In Case study 2, the results of the temporo-spatial parameters at TP4 are in agreement with previously published work on healthy participants [26]. Although the temporo-spatial parameters seem to have provided useful outcome measures, the level of sensitivity of the measurement parameters in response to the patient's rate of recovery appeared consistently more pronounced in the walking speed, step length and gait symmetry measurements.

These data indicate that the AVPS can be both feasible and valuable within clinics, clinical rehabilitation centres and clinical research facilities where clinicians, allied health professionals and clinical researchers can benefit from shared clinical data that could lead to improvements in evaluating rehabilitation interventions at affordable costs. Furthermore in terms of rehabilitation, the AVPS could be used as a clinical training aid and teaching tool among nurses and allied health professionals to bridge the gap between clinical research and clinical practice. Since the goal is to monitor and improve functional ambulation and joint mobility within the National Health Services, assessing conventional physiotherapy programs designed to improve lower limb function can also come at a high cost when complex three dimensional motion analysis systems are involved. For that reason the AVPS has a place within neuromuscular related rehabilitation clinics and research facilities where limited budgets dictate the roadmap to rehabilitation assessments.

Conclusion

The case studies have shown that from a clinical perspective clinical gait assessment plays a vital role in physical medicine and the rehabilitation process. The outcome of the study also suggests that the AVPS can be considered as a measurement and rehabilitation tool designed to aid treatment and monitor the progress as well as assess the effectiveness of prescribed rehabilitation regimes for patients with neuromuscular and musculoskeletal related gait deficits.

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